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AN INTEGRATED METHODOLOGY FOR ATM LOCATION STRATEGY

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AN INTEGRATED METHODOLOGY FOR ATM LOCATION STRATEGY

(ATM YERLEŞİM YERİ STRATEJİSİ İÇİN BÜTÜNSEL BİR YAKLAŞIM)

by

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LIST OF SYMBOLS

AHP	: Analytic Hierarchy Process
ANP	: Analytic Network Process
ATM	: Automated (Automatic) Teller Machine
DEA	: Data Envelopment Analysis
DM	: Decision maker
ELECTRE	: The ELimination Et Choix Traduisant la REalit´e
FAHP	: Fuzzy Analytic Hierarchy Process
FANP	: Fuzzy Analytic Network Process
FCLAM	: Flow capturing location-allocation model
FCLP	: Fixed charge location problem
FST	: Fuzzy Set Theory
GCM	: Global Criterion Method
HLP	: Hub location problem
LARP	: Location-arc routing problem
LF	: Location Factor
LRP	: Location-routing problem
MADM	: Multi-attribute Decision Making
MAUT	: Multi-attribute Utility Theory
MAVT	: Multi-attribute Value Theory
MCDA	: Multiple Criteria (Multi-criteria) Decision Analysis
MCDM	: Multiple Criteria (Multi-criteria) Decision Making
MODM	: Multiobjective Decision Making
MOO	: Multiobjective optimization
MOP	: Multiobjective programming
NAICS	: North American Industry Classification System
PROMETHEE	: Preference Ranking Organization METHods for Enrichment Evaluations
QAP	: Quadratic assignment problem
TFN	: Triangular Fuzzy Number
TOPSIS	: Technique for Order Preference by Similarity to an Ideal Solution
VIKOR	: The VlseKriterijumska Optimizacija I Kompromisno Resenje
VRP	: Vehicle Routing Problem
WTS	: Weighted Total Score

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ABSTRACT

Reducing capital and operational costs became a main course of action to improve business performance and to be competitive for every company in today's challenging economy. On the other hand, companies also aim to improve their service delivery and customer satisfaction accordingly. Location management is widely regarded as one of the critical issues for its cost reduction and profit increase potential in every line of business. Therefore, companies need to develop location strategies for their business units such as factories, distribution centers and stores in accordance with the overall business strategy.

Automatic Teller Machines (ATMs) are one of the most important key touch-points to reach the customers in the banking industry. Furthermore, ATM location problem is a vital decision for banks to make service available to their customers when they need it and due to the opportunity of cost optimization.

ATM location management is a complex problem as there are many components that have influence on the decision. Some of these components can be measured whilst some of them can be expressed by subjective evaluations. Additionally, there are inherent factors which conflict with each other and affect the judgment positively or negatively. Moreover, the number of criteria that needs to be taken into account while deciding ATM locations increases the problem complexity in addition to problem size. Nonetheless, from the bank perspective; ATMs are expected to sustain their operability and profitability for an extended period of time after they start to operate. As a result of wrong decisions, moving or redeploying the machines may be perceived by customers as indicating financial problems with the bank, and this may cause a loss of reputation. The additional incurred costs due to moving and redeploying ATMs make the problem more considerable. Therefore, location selection is also a strategic decision for the banks

that requires a scientific approach which includes in-depth analyses by incorporating the personal opinions and experience of the experts while considering the resource limitations of the problem.

In this study, we propose a novel integrated methodology to solve ATM location problem that combines Fuzzy Analytic Network Process (FANP) and Global Criterion Method (GCM). The proposed methodology is used to evaluate the existing ATM locations of a Turkish bank while also deciding the new location alternatives. However, the approach is applicable to the cases where a bank is at the initial stage of its ATM deployment process.

Initially, the decision criteria for deployment problem are determined based on the literature. Then, these criteria are modified as a result of series of interviews with the experts who work on ATM management in order to build a general framework. The relative importance of criteria are assessed by the same experts in consensus. FANP is utilized to identify the location factors which affect location decision and decide the importance of these factors since it takes into account the interdependence between the criteria and handles the imprecise nature of human comparison judgments by using natural language in the perception of experts. Chang's extent analysis is employed for eliminating the vagueness of the decisions from the evaluation process. The decision-makers are asked to express their opinions on the comparative importance of various factors in linguistic terms. These linguistic variable scales are then converted into fuzzy numbers, since it becomes more meaningful to quantify a subjective measurement into a range rather than an exact value. Finally, the relative importance of the criteria is obtained. The decision process includes the identification of 17 criteria grouped into 5 clusters which are named financial, commercial, traffic, demographic and strategic. Number of Bank's ATMs, Expected Level of Commission Income and Expected Level of Transaction Income were found as the three most significant criteria that should be analyzed deeply by the decision makers in ATM location selection decision.

Afterwards, the following steps of the case study is performed in a Turkish bank which is among the top ten private banks in Turkey in order to demonstrate the applicability and validity of the model. A decision group is formed in the bank and Beşiktaş municipality is selected as the application region and the subregions of the considered region are decided. It is intended to use the weight of each criterion to compute the scores of subregions. Then, these scores are used as an input for the multiobjective model that decides the satisfactory number and locations for ATM installation.

Three objectives are idefined to take into account the multiobjective nature of ATM location problem. These objectives are maximizing the weighted total score of locations, minimizing the total number of ATMs, and minimizing the total weighted distance that customers travel to reach the ATMs. GCM is used to transform the multiobjective model into a single objective model. The model is solved by Lingo solver in order to find optimal solution which decides the number and locations of ATMs and assignment of customers to the deployed ATMs. GCM is preferred due to its simplicity and the amount of information that is required to run the model. Moreover, its ability to find Pareto optimal solution is another reason to use this method. Scenario analyses are conducted to suggest alternative solutions to the bank where they can choose the most appropriate solution. The results of the scenario analyses are then compared to the existing situation for each objective function to evaluate the performance of the proposed methodology.

The results of the proposed method are considered applicable and valid by the experts who included in the decision processes and the bank found the methodology practicable.

Keywords: Automatic teller machines, Location problem, Location strategy, Multiple criteria decision making, Fuzzy analytic network process, Global criterion method.

ÖZET

Günümüz zorlu ekonomisinde, yatırım ve operasyonel maliyetlerin azaltılması, iş performansını iyileştirmek ve rekabet edebilmek için tüm şirketlerin en önemli eylemleri haline gelmiştir. Öte yandan şirketler hizmet sağlama şekillerini ve dolayısıyla müşteri tatminini artırmayı amaçlamaktadırlar. Yerleşim yeri yönetimi maliyetlerin azaltılması ve karın artırılması potensiyeli nedeniyle her iş kolu için en kritik konulardan biri olarak kabul edilmektedir. Bu nedenle, şirketlerin fabrikalar, dağıtım merkezleri ve mağazalar gibi iş birimleri için şirket stratejisinin bütünü ile uyumlu yerleşim yeri stratejisi geliştirmeleri gerekmektedir.

Otomatik Vezne Makineleri (ATM'ler), bankacılık sektöründe müşteriye ulaşmak için kullanılan en önemli temas noktalarından biridir. Bununla birlikte, müşterilere ihtiyaç duydukları zaman hizmet sunabilmek için ve maliyet optimizasyon fırsatları nedeniyle yerleşim problemi bankalar için hayati önem taşımaktadır.

Otomatik Vezne Makineleri yerleşim yeri yönetimi, yerleşim kararını etkileyen pek çok bileşeni içermesi nedeniyle karmaşık bir problemdir. Bu bileşenlerden bazıları ölçümlenebilirken bazıları ise subjektif değerlendirmeler ile ifade edilebilmektedir. Ek olarak, birbiriyle çelişen ve doğası gereği kararı olumlu veya olumsuz yönde etkileyen faktörler de bulunmaktadır. Ayrıca, ATM yerleşim yeri kararını verirken dikkate alınması gereken kriter sayısı problemin büyüklüğünün yanı sıra problemin karmaşıklığını da artırmaktadır. Bununla beraber, banka açısından; ATM'lerin hizmete alındıktan sonra uzun bir süre işlerliğini ve karlılığını sürdürmesi beklenir. Yanlış kararlar sonucunda makinelerin taşınması veya yeniden yerleştirilmesi müşteriler tarafından bankanın finansal problem yaşadığı şeklinde algılabilir ki bu da itibar kaybına neden olabilir. ATM'lerin taşınması ve yeniden yerleştirilmesi nedeniyle ortaya çıkacak ek maliyetler ise problemi daha mühim hale getirmektedir. Bu nedenle, bankalar için

ATM yer seçimi aynı zamanda, uzmanların kişisel düşünce ve tecrübeleri ile problemin kaynak kısıtlarını dikkate alarak yapılan detaylı analizleri içeren bilimsel bir yaklaşımla ele alınmayı gerektiren stratejik bir karardır.

Bu çalışmada, ATM yerleşim probleminin çözümü için Bulanık Analitik Ağ Süreci ve Global Kriter Yöntemi'ni entegre eden yeni bir metodoloji önerilmektedir. Önerilen metoloji, bir Türk bankasının mevcut ATM konumlarını değerlendirirken yeni konum alternatiflerini de belirlemek için kullanılmaktadır. Bununla birlikte, yaklaşım bir bankanın ATM kurulum sürecinin ilk aşamasında olduğu durumlarda da uygulanabilir.

İlk olarak, yerleşim problemi için kriterler literatüre dayalı olarak belirlenmiştir. Ardından, genel bir çerçeve oluşturmak üzere ATM yönetimi konusunda çalışan uzmanlarla gerçekleştirilen bir dizi görüşme neticesinde bu kriterler nihai haline getirilmiştir. Kriterlerin göreceli önem değerleri bu uzmanlar tarafından fikir birliği ile belirlenmiştir. Kriterler arasındaki karşılıklı bağımlılıkları dikkate alması ve uzman görüşünde doğal dili kullanarak insanların karşılaştırma kararlarının kesin olmayan doğası ile başa çıkma yetenekleri nedeniyle yerleşim yeri kararını etkileyen kriterlerin belirlenmesi ve bu kriterlerin önem değerlerinin bulunması için Bulanık Analitik Ağ Süreci kullanılmıştır. Chang'ın mertebe analizi, değerlendirme sürecinde kararlardaki belirsizlikleri gidermek için kullanılmıştır. Karar vericilerden, kriterlerin karşılaştırmalı önem derecelerine ilişkin fikirlerini dilsel ifadelerle bildirmeleri istenmiştir. Öznel bir ölçümü kesin bir değer yerine bir aralıkta nicelendirmenin daha anlamlı olması sebebiyle, bu dilsel ifadeler daha sonra bulanık sayılara dönüştürülmüştür. Son olarak, kriterlerin göreli önem dereceleri belirlenmiştir. Karar süreci, finansal, ticari, trafik, demografik ve stratejik olarak adlandırılan beş kümeye gruplandırılmış on yedi kriterin tanımlanmasını içermektedir. Banka ATM Sayısı, Beklenen Komisyon Geliri ve Beklenen İşlem Geliri ATM yer seçimi kararında karar vericiler tarafından derinlemesine analiz edilmesi gereken en önemli üç kriter olarak bulunmuştur.

Daha sonra, örnek vaka analizinin takip eden adımları, modelin uygulanabilirliğini ve geçerliliğini göstermek için Türkiye'de ilk on özel banka arasında yer alan bir Türk bankasında gerçekleştirilmektedir. Bankada bir karar grubu oluşturulmuş, İstanbul ili Beşiktaş ilçesi uygulama bölgesi olarak seçilmiş ve hangi alt bölgelerin dikkate alınacağına karar verilmiştir. Alt bölgelerin puanlarını hesaplamak için her bir kriterin ağırlığının kullanması amaçlanmıştır. Daha sonra, bu puanlar, ATM kurulumu için tatmin edici sayı ve yerleri belirleyen çok amaçlı model için girdi olarak kullanılmıştır.

ATM yerleşim probleminin çok amaçlı doğasını hesaba katmak için üç hedef belirlenmiştir. Bu hedefler, ağırlıklı toplam puan skorunu en üst düzeye çıkarmak, toplam ATM sayısını en aza indirmek ve müşterilerin ATM'lere ulaşması için seyahat ettikleri toplam ağırlıklı mesafeyi en aza indirmektir. Global Kriter Yöntemi, çok amaçlı modelin tek amaçlı modele dönüştürülmesi için kullanılmıştır. Model, ATM'lerin sayısını ve yerini belirleyen ve bu ATM'lere müşterilerin atanmasını sağlayan en uygun çözümü bulmak için Lingo çözücüsü tarafından çözülmüştür. Basitliği ve modeli çalıştırmak için gereken bilgi miktarı nedeniyle Global Kriter Yöntemi tercih edilmiştir. Ayrıca, Pareto optimal çözümleri bulma kabiliyeti de bu yöntemi kullanılmasındaki diğer bir nedendir. Bankaya en uygun çözümü seçebilecekleri alternatif çözüm önerilerinde bulunmak için senaryo analizleri gerçekleştirilmiştir. Daha sonra önerilen metodolojinin performansını değerlendirmek için senaryo analizlerinin sonuçları her bir amaç fonksiyonu için mevcut durum ile karşılaştırılmıştır.

Önerilen yöntemin sonuçları, karar süreçlerine dahil olan uzmanlar tarafından geçerli kabul edilmiş olup, banka metodolojiyi uygulanabilir bulmuştur.

Anahtar Kelimeler: Otomatik vezne makineleri, Yerleşim yeri problemi, Yerleşim yeri stratejisi, Çok kriterli karar verme, Bulanık analitik ağ süreci, Global kriter yöntemi.

1. INTRODUCTION

Nowadays, companies compete with each other more than ever before for maximizing customer satisfaction while minimizing their overall costs. Therefore, making service ready when customer needs it is the critical key factor for customer satisfaction and achieving this with the minimum cost becomes more important for survival in these harsh economic conditions. Banks also have been attempting to maximize their profit by keeping the costs at minimum level while enhancing customer experience and satisfaction with the provided service.

50 years ago, banks started to invest in the development of non-branch distribution channels to attract new customers and sources of revenue. Automated teller machines (ATMs), which emerged at 1960s, were first attempt of alternative service channels. After the diffusion of ATMs in 1970s, call centers arouse in 1990s and after 2000, it was the era of Internet. Recently, wireless technologies have been playing an important role even in the banking industry (Barrué et al., 2010). Declined revenues, increased costs, and falling margins led up to the remodeling of service delivery strategies in the last decade. Additionally, rapidly changing customer behaviors and expectations inclined banks to begin constant improvement efforts of these alternative channels (Lund et al., 2002).

Branches and ATMs, which constitute physical distribution channels, still play crucial role in the success of retail bank. Furthermore, with the emerging digitalization in the banking industry, banks became focused on optimization and transformation of their branch network since it is the most expensive channel to run. The big share of sales achieved, decreasing traffic and the importance of relationship management are also other reasons that banks focused on branch network. On the other hand, ATMs are not really concentrated on compared to digital channel which attracted more attention and investment due to the market pressure and transformational nature of the digital channel (Janjua, 2017).

ATMs can be considered as one of the most important service facilities in the banking industry since they can be utilized as sales and service channels. The investment in ATMs and the impact on the banking industry is growing steadily in every part of the world. Therefore, optimizing ATM network plays a significant role in the distribution channel improvement.

Designing the optimum ATM network with right locations, right number and right services that are provided to the customers can enable considerable amount of reduction in cost and increase in revenue, thus increase in profit margins. Hence in this thesis, we intended to propose an integrated methodology which evaluates the existing ATM network of a bank and suggests new alternative locations.

1.1 Automated Teller Machines: Past, Today and Future

Both banks and customers have gained benefits by diffusion of alternative service channels. Banks decreased their costs especially those arising from setup and employee cost compared to bank branches. They have also reached more customers that could not have been reached by a branch network. Moreover, the automated services that have been provided by the alternative distribution channels also reduced mistakes due to human error, increased the operational efficiency and quality. Customers are satisfied by paying less transaction fee, getting a 24-hour service without queuing for a long period of time, and being served in a larger area not just in the neighborhoods where the bank branches are situated. Besides the advantages of alternative distribution channels, ATMs differ from others as they are the only way to provide cash related services. On the other hand, the delivered services by ATMs are not limited to those that are cash related.

Automated Teller Machine is: “a computerized telecommunications device that provides the customers of a financial institution with access to financial transactions in a public space without the need for a human clerk or bank teller" (Adepoju & Alhassan, 2010). In the literature ATMs are also referred as "Automatic Teller Machines" or "Automated Banking Machines".

Barclays launched the first ATM in 1967 at a bank branch in Enfield, London, by having contract with John Shepherd-Barron who invented a machine that could enable instant access to banknotes at any time of the day. The unveiling of ATM machines were considered groundbreaking as people had been accessing cash only during branch opening hours until then (Dunkley, 2017). As there was not any bank card in those days, instead of bank cards customers were using vouchers which were provided by a teller at their bank branch to withdraw money. These vouchers were only valid for six months, and it would be signed and placed in the ATM's drawer. After then, a six-digit customer code entered to the machine in order to get the cash from a separate drawer (Smith, 2017). On the other hand today, customer is usually identified by inserting a plastic card with a magnetic stripe or a chip that contains a unique card number and security information, such as a personal identification number (PIN) (Adepoju & Alhassan, 2010).

ATMs were first introduced to the market as cash dispensing machines which only enabled customers to withdraw money (Bátiz-Lazo & Reid, 2008). With the evolution of the technology, ATMs became multitask machines that provide more than a hundred types of transactions. Just a few of them are - depositing money; money transfer; fund transactions; repo / bond transactions; checking balance and viewing account movements; bill; loan and credit card payment; mobile phone top up; money exchange and even purchase and sale of gold.

ATMs are one of the most important service facilities in today's omni-channel banking industry (Aldajani & Alfares, 2009). The ATM channel is still preserving its key role since 1960s as a core banking touch point for customers by providing access to funds and banking experience. Importance of its role has not been diminished even in the evolvement of new electronic payment systems. Furthermore, branch network optimization causes a decrease in the number of branches and this reduction strengthens the ATMs prominence as customers sustain their need for physical contact with banks.

According to the Consultative Group to Assist the Poor's analysis, ATM transaction costs in high-traffic locations can be advantageous by as much as 90% percent compared to branch transaction costs. Moreover, as the cost of establishing wide branch networks rises, particularly in rural locations, ATMs can act as a "mini branch" where customers conduct various transactions which they could in bank branches (Proverbio et al., 2016). ATM habits of customers have also changed over time due to increasing ATM fees and usage of debit and credit cards. Some customers began to limit their usage with their own financial institutions' ATMs where they wouldn't be charged. Others started to use ATMs less often by withdrawing more money each time ("Location, Location, Location," 2008).

Different regions indicate different rates of growth in terms of number of ATMs, with a common growth trend that exceeds gross domestic product growth. This shows that financial institutions continue to invest in ATMs, but also that retail consumers and consumers of small and medium sized enterprises continue to use this important channel to access their funds. Furthermore, ATMs also keep playing a vital role for the reduction of the cost of cash through re-circulation. This re-circulation does not only provide benefits for the financial services institutions that adopt them, but also for the economy and society by reducing the amount of cash in circulation (Burelli et al., 2014). The World Bank data shows that in the world in 2009, there were 40.75 ATMs per hundred thousand adults on average while in 2014 it had risen to 50.92 ("The World Bank Data: Automated teller machines (ATMs) (per 100,000 adults)," 2015). Additionally, Figure 1.1 depicts the number of installed ATM machines in the world, which was 2.0 million in 2010 and 3.2 million in 2014, was projected to be 4.0 million by the end of 2018. The number of ATM units, the volume and value of transactions indicates the continuous growth of the channel which also proves its importance (Proverbio et al., 2016).

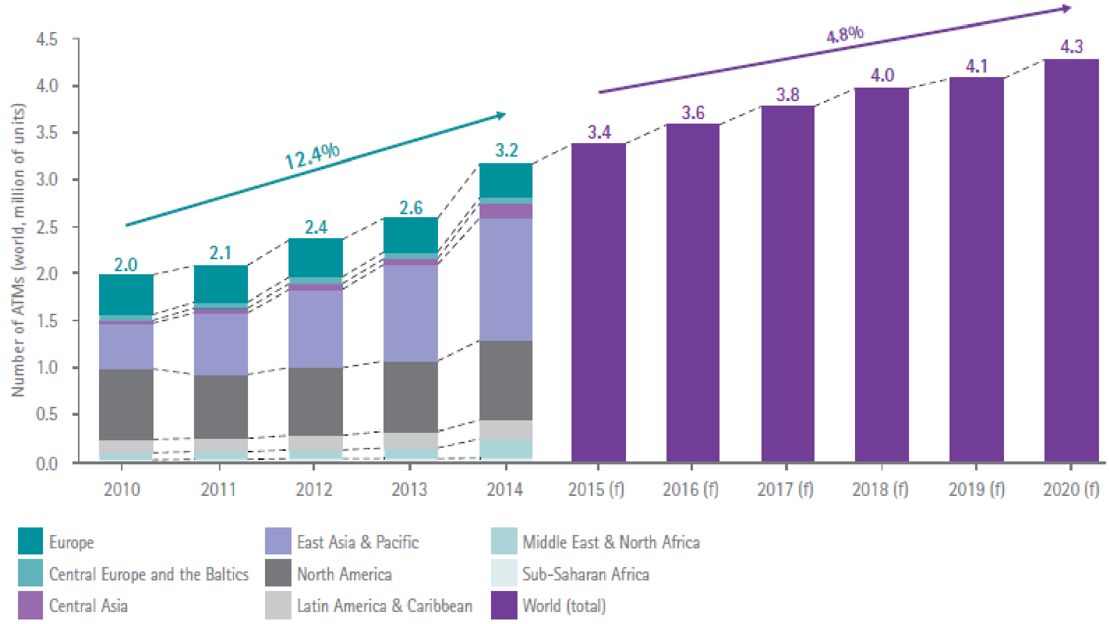

Figure 1.1: Number of ATM (world, millions of units) (Proverbio et al., 2016).

ATM industry has been following the technological developments closely and adapting ATMs to the digital transformation successfully. For instance, contactless ATMs where transactions can be made with contactless cards have started to be deployed. The customer taps her / his contactless card against the ATM and enters the pin to perform the transaction. Moreover, smart phones and mobile applications are utilized to login and preselect the transaction that will be made, and the customer completes the transaction by tapping the phone against the ATM. Australia and New Zealand Banking Group (ANZ) deployed tap-and-pin functionality in 2015, whilst Barclays unveiled contactless mobile cash access in the U.K. in November 2016. Biometric technology is another significant promise for the ATM channel. DCB Bank of India introduced biometric authentication for cardless transactions in their ATMs. In the US, Citibank is also piloting a new concept in which ATMs are with no screen and eye retina-scanner. Other developments are voice-activated ATMs which were rolled out by Abu Dhabi Islamic Bank in the United Arab Emirates for visually impaired users and interactive ATMs that were deployed by several banks such as Royal Bank of Canada which recently enabled video conferencing for small-business banking. Considering all of the aforementioned issues, it appears that financial institutions continue to invest in ATMs with the development of the technology. Nevertheless, all these advances are also outcomes of seeking more secure, reliable, convenient access to cash and reduction in transaction times (Cluckey & Warren, 2017; Smith, 2017).

The cash has reached its final days and the future of the world is cashless. The cost of physical paper and coin cash -handling it, securing it, insuring it- is troublesome and causes the society to move to the cashless world (Andrews, 2017). The usage of cash is decreasing and accessing the cash was the primary purpose ATMs. However, today ATMs offer a variety of services beyond cash related transactions and they are considered machines that automate and perform mundane tasks quickly, efficiently and seamlessly. Additionally, they are also regarded as tools that are capable of data gathering and analytics by the financial institutions. Therefore, it is apparent that the ATMs will keep evolving and conserve its position or even make it more powerful in the coming days (Cluckey & Warren, 2017). According to the ATM Future Trends 2017 Report (Cluckey & Warren, 2017) which includes results from a survey of more than 300 ATM industry members at all corporate levels in the United Kingdom and the United States, industry members who take the view that the ATM has passed its peak constitute one quarter of members who believe the ATM is at or still approaching its prime. This important finding of the survey can be also regarded as an indication of the ATM's future.

1.2 ATM Management

Management of ATMs is a very complex issue for the banks as the process is related to a great number of agents and variables. Different departments of the headquarters, branches, outsource companies and customers are all involved in the ATM Management process. Additionally, the process comprises of several sub-processes such as deployment, cash management, security management, remote monitoring and maintenance.

Furthermore, ATM operators have been facing many challenges which makes ATM management harder (Cluckey & Warren, 2017):

- the cost of competitive upgrades,
- expenses related to compliance with government regulations and network rules,
- pressure from governments and groups to reduce or eliminate fees and surcharges,
- physical attacks that can destroy an ATM and cause catastrophic damage to the structures around it;
- sophisticated malware attacks that can result in multimillion-dollar losses within hours,
- skimming and other scams that shake public trust in the safety and security of ATMs,
- enhancing payment technologies that reduce consumer demand for cash,
- rising government interest in (and international card brand promotion of) the concept of a “cashless society.”
- continued global economic uncertainty.

All these issues indicate that more attention should be paid to ATMs and ATM management by the banks.

1.3 Aim and Scope of the Study

ATM location management is one of the most important sub-processes of ATM management and should be performed as a result of strategic and operational decisions since it directly affects customer satisfaction and accordingly profitability of the bank. Moreover, deciding the optimum number and locations of ATMs is a long-term decision for the banks.

From the banks perspective; ATMs are required to sustain their profitability and operability for a long time after they start to operate. As a result of wrong decisions, moving or redeploying the machines because of bad performance may be perceived by the customers as there are problems with the bank and this may cause loss of reputation (Adams, 1991). Furthermore, the additional incurred costs due to moving and redeploying ATMs makes the problem more considerable. The number of criteria that should be taken into account while deciding locations of ATMs increases the problem complexity in addition to problem size.

Therefore, this thesis proposes a novel integrated approach that combines Fuzzy Analytic Network Process (FANP) and Global Criterion Method (GCM) to determine the optimal locations for ATM deployment problem. The process of the proposed methodology can be considered in two main stages: FANP and GCM. Nevertheless, we detailed the process in five main phases, which is presented in the "4. Proposed Methodology" chapter.

FANP stage was conducted based on the literature review and interviews with the experts who work on ATM management in order to establish a general framework for determining the criteria that are considered in the deployment problem.

On the other hand, the foundation of the CGM stage was built on a case where a Turkish bank evaluates its existing ATM locations and searches for the new locations. However, the model can also be applied to the problem where the bank is at the initial stage of locating its ATMs.

The main objective of the proposed methodology is aiding researchers as well as decision makers such as bank managers, consultants and banking software developers who work on ATM location management to make sound location decisions.

1.4 Contribution to the Literature

Despite the variety of studies on service facility location problems as presented in the "2.4 Review of the Service Facility Location Problems" part in Chapter 2, there were a limited number of publications focused on ATM location problems. These publications address deployment problems by applying mathematical models or geographical analysis; however they do not examine the related criteria thoroughly before solving the models and incorporate the subjectivity as a preliminary stage for making the right location decision. To the best of our knowledge, this study is the first research that analyzes the ATM deployment decision criteria and integrates it with a mathematical model. There is no indication in the literature that any of the previous studies apply to ATM location problem within this scope.

Moreover, when Turkey banking industry case is considered; it is seen that banks have been giving attention to deployment management only for the last few years. Most of the financial institutions still work with primitive methods which do not involve any scientific techniques whilst a few of them endure astronomic costs for the related software. Therefore, under all these considerations it is explicit that there is a need for this kind of research in which the subjectivity is included as a part of the scientific decision process to achieve the most satisfied results. This is the motivation of the thesis.

Our proposed methodology differentiates from the previous ATM location studies in three perspectives which make the methodology more applicable to real-life problems:

- Initially, unlike the previous researches the new approach considers multi-criteria nature of the problem and also discerns the resource limitations of the problem.
- Second, it takes account of the locations' attractiveness as location scores from decision makers' point of view.
- Lastly, the methodology uses two operations research techniques to obtain complete solutions in a simpler and more efficient way.

1.5 Organization of the Thesis

The thesis is organized as follows: In Chapter 2, a comparative literature survey is presented in detail which reviews researches that deal with service facility location problems.

Multi-criteria decision making approach and its most common methods are summarized in Chapter 3.

In Chapter 4, the proposed methodology with the application for ATM location management problem is introduced. The produced results and findings are also discussed in this chapter.

Finally, Chapter 5 draws a conclusion and addresses the limitation of the study and future research.

ATM deployment problem is a banking location problem that belongs to service facility location problems which are various and sundry. Therefore, we concentrated on service facility location problems. In the next chapter, service facility location problems are investigated in detail based on different characteristics of the location problems. The main objectives of writing the second chapter are to comprehend the nature of location problems with fundamental location models by considering different features and examine the dimensions relating to the solution and application of these problems. In this way, we could define our location problem, build the model and choose the right methods to solve the problem.

Furthermore, we recognized that field of location is lack a survey of service facility location problems on a broader canvas. The scarcity of the review papers on service facility location problems is also the evidence of the need for a survey in this context. Hence this is another motivation of the second chapter in which we presented a thorough review on service facility location problems. Our researches on service sector also led us to conduct this survey, as we noticed that there is a considerable gap in location science with respect to review of service facility location problems. Therefore, we intend to submit this chapter as a paper whose scope is designated as service facility location problems. Additionally, our intention is also to contribute to the improvement on location science in terms of service facilities by doing so.

The 2nd Chapter is organized as follows. In the 1st Section, scope of the survey is addressed and a classification framework to investigate service facility location problems is proposed. In Section 2 and Section 3, in order to understand the location problems deeply, we introduce and define the key features of facility location problems and the dimensions related with solution and application phase respectively. The 4th Section reviews the service facility location problems based on the proposed classification framework and application fields of the problems where we intend to address the related researches without giving all the details of them. Finally, in Section 5, we present the discussion for Chapter 2.

2. SERVICE FACILITY LOCATION PROBLEMS

Facility location problems (FLPs) have strategic and long-term essence, as the facilities are required to maintain their profitability and operability for an extended period of time even the conditions of the market, environment and population change. The high costs of locating and relocating the facilities make these decisions more critical for the organizations (Owen & Daskin, 1998; Arabani & Farahani, 2012). Moreover, the ability of a company to produce and sell its products effectively or delivering high quality services is partially dependent on the locations of company's facilities in relation to other facilities and to its customers (Daskin, 2013). Therefore, location theory, which was founded on Alfred Weber's single warehouse problem in 1909, has received much attention from scientific community since then. Afterwards, many researchers began to be interested in the subject and have conducted numerous studies including wide variety of location problems both in private (e.g., industrial plants, banks, retail facilities, etc.) and public sector (e.g., schools, hospitals, fire stations, etc.) (Farahani & Hekmatfar, 2009; Eiselt et al., 2015). Various techniques, which are based on operations research, statistics, economic analysis and systems science have been developed to handle these problems in recent decades (Chan, 2011).

The term of "location problem" refers to modeling, formulation, and solution of a class of problems which intends to determine the optimum locations for a set of facilities by minimizing or maximizing some objectives for satisfying the existing and / or projected demand with respect to a set of constraints in some given space (Farahani & Hekmatfar, 2009). The expressions; deployment, positioning, and siting are also used as synonyms of location (ReVelle & Eiselt, 2005).

The need of sound location decisions have inclined researchers to develop standard location models such as median, covering, center and so forth with generic formulations.

Moreover, a number of location problem classifications have been generated in the literature based on the characteristics of the problems, some of them are; features of decision space, time, market, competition and customer attraction function. All these concerted efforts have been made to understand the location problems thoroughly and eventually to achieve robust decisions. This also leads to conducted surveys on location problems or models apart from theoretical and practical researches on specific problems. The surveys are presented in Table 2.1 with the scope of the considered research.

Table 2.1: Review Papers

Reference	**The Scope of the Review**
Tansel et al. (1983)	P-center and p-median problems
Schilling et al. (1993)	Covering location problems
Plastria (1995)	Location theory in continuous space
Owen & Daskin (1998)	Strategic facility location considering dynamic or stochastic problem characteristics
Plastria (2001)	Static competitive facility location
Krarup et al. (2002)	Discrete location problems with push–pull objectives
Hale & Moberg (2003)	General review of the location science research
Klose & Drexl (2005)	Facility location models for distribution system design
ReVelle & Eiselt (2005)	Location analysis considering problem characteristics and problem structures
Boffey et al. (2007)	Congestion models in the location of facilities with immobile servers
Loiola et al. (2007)	Formulations of quadratic assignment problems
Mladenović et al. (2007)	Metaheuristic approaches for p-median problem
Nagy & Salhi (2007)	Models and methods for location-routing problems
Şahin & Süral (2007)	Hierarchical facility location models
Alumur & Kara (2008)	Network hub location models
Daskin (2008)	Taxonomy of location problems based on the space in which the problem is embedded with an emphasis on discrete location problems
ReVelle et al. (2008)	Discrete location theory and modeling
Farahani et al. (2010)	Multiple criteria facility location problems and their solution methods

Reference	The Scope of the Review
X. Li et al. (2011)	Covering models for emergency response facility location and planning
Arabani & Farahani (2012)	Location problems with an emphasis on dynamic facility location
Başar et al. (2012)	Taxonomy for emergency service station location problem
Farahani et al. (2012)	Models, solutions and applications of covering location problems
Lopes et al. (2013)	Taxonomy of current methods and objectives on location-routing problems
Farahani et al. (2014)	Modeling efforts and solution methods of hierarchical facility location problems
Prodhon & Prins (2014)	Types of location-routing problems and solution methods
Basu et al. (2015)	Metaheuristic applications on discrete facility location problems
Seyedhosseini et al. (2016)	Mathematical models and solution algorithms of dynamic location problems
Schneider & Drexl (2017)	Standard location-routing problems and solution methods
Ahmadi-Javid et al. (2017)	Classification of healthcare facility location problems

It is seen that from Table 2.1 for the most part, papers focused either on a particular model or problem type. However, Hale and Moberg (2003) is distinguished from other papers since they intended to provide a broad overview of location science topics by classifying previous researches based on their location models. Additionally, Başar et al. (2012) and Ahmadi-Javid et al. (2017) also differ from other surveys since they address specific facility types with their applications. These two papers present detailed reviews within their scope (emergency service stations and healthcare facilities respectively), as they investigate previous researches based on several problem characteristics. By considering the scope of the presented review papers, one can realize that each paper covers a specific facility type, problem or model even though all these reviews provide valuable insights.

In order to analyze the research trends in the service facility location problems over time, we searched SCOPUS which is the largest title, abstract, keyword and citation database of peer-reviewed literature. Different keywords were tested in the database and finally following phrase was selected as a suitable combination: TITLE-ABS-KEY (service AND facility) AND TITLE-ABS-KEY ("location selection" OR "location model" OR "location problem" OR "location decision").

775 cases were found as a result of the search. We did not limit the year of the search and exclude any document type to see the complete results. The articles span a range of areas including Computer Science, Engineering, Mathematics, Decision Sciences, and Social Sciences. European Journal of Operational Research (41), Computers and Operations Research (24), Lecture Notes in Computer Science (23), Annals of Operations Research (16), and Journal of the Operational Research Society (11) turned out to be the best sources (with the number of documents in parenthesis) in this area. 97.2% of the sources are journal papers and conference proceedings. In addition to this, only 1% of the publications are in the “Reviews” category of SCOPUS.

The distribution of the documents over the years is shown in Figure 2.1.

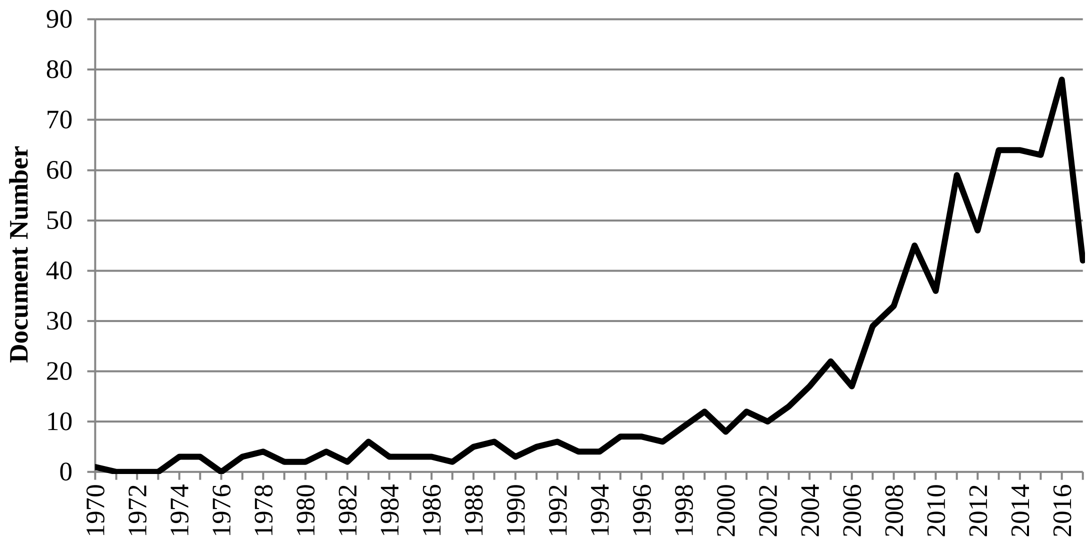

Figure 2.1: The number of documents on service facility location problems per year

It is seen that a steep increase in the number of publications began in the 2000s. Moreover, many advanced developed economies such as USA, European and developed Asian countries as well as emerging economies such as China and India have experienced rapid growth in service based economic activities since 2000s. The rapid growth in service activities result in many complex issues to the service systems. Among these, location selection is one of the most crucial issues (H. Y. Wu et al., 2009). Hence the transformation of economic activities also brought about the need of a new approach to location problems and one can conclude that this need also influenced the researches in the literature.

Modest decreases after the sharp increases should not mislead us since it reoccurs in every a few years. Therefore, we believe that the decrease in 2017 is also transient and the interest in service facility location problems will continue for a long while as this area has much to discover.

2.1 Scope of the Literature Survey

Journal articles and conference proceedings that have been published on service facility location problems since 2000 are focused in our review. Journal articles or conference proceedings that only contains a specific type of application field and facility were included, papers on generic application or service facility type have not covered in the review. Actually, there are researches which study service facilities with specific properties such as immobile and discretionary or more generic service facility location problems. However, we did not review these papers unless they present a case study on a specific application field or service facility since our intention was to investigate researches based on their characteristics that belong to the related application type. However, the generic service facility location problems also can be utilized, as their models can be potentially adapted to the working model depending on the underlying assumptions. Q. Wang et al. (2004), Aboolian et al. (2007), Beraldi & Bruni (2009), Albareda-Sambola et al. (2009), Drezner & Drezner (2011), Lee & Lee (2012), Panchumarthi & Singh (2012), Rahmati et al. (2013), Hajipour et al. (2014) and Tavakkoli-Moghaddam et al. (2016) can be mentioned as some of these problems.

Working papers, book chapters and dissertations were also omitted from the review in order to keep the study within reasonable length.

It is possible to divide services into two main categories such as facility based and field based services. In facility based services, customers travel to the facility to get the service, whilst in field based services it is the responsibility of company or organization to provide service to customers located at customer's site. In other words, the service provider has to be dispatched to the customer's site with the needed parts and tools in field based services. Delivery, emergency, and after-sales are examples of this kind of services (Zarnani et al., 2009). In the survey, we only considered facility based services as characteristics of the problems would change significantly with respect to the service type.

Nevertheless, the topography that is used (e.g., discrete versus planar location problems) in the problem, the nature of the inputs (e.g., static / dynamic or deterministic / probabilistic) and a variety of other criteria can be used to classify location problems. The characteristics that form the model and problem structure are named "Key Features of Location Problems". Furthermore, we also defined some characteristics which are related to application of the problem and solution phase and named them "Descriptive Dimensions of Location Problems". It is believed that these two types of characteristics assist with examining the location problems from different perspectives and enable the understanding and interpreting them in sufficient detail.

90 papers were identified within the scope of our intention for conducting this survey. We aimed to be as comprehensive as possible and strove to cover all related service facility location problems which decision makers generally come across. However, we apologize if we have inadvertently not covered any research. The problems are analyzed according to these two categories that are provided in Figure 2.2. Key features of location problems consist of 13 characteristics whilst descriptive dimension of location problems comprises 7 characteristics which are explained in the following section.

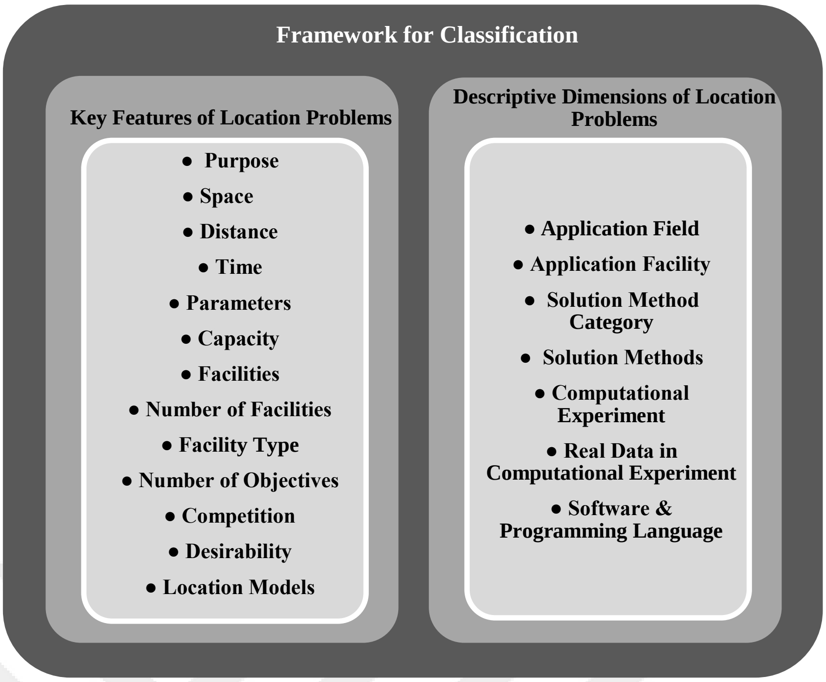

Figure 2.2: Framework for Classification of Location Problems

2.2 Key Features of Location Problems

The problems are divided into two groups, namely problems with mathematical optimization models (which are called mathematical optimization problems) and problems that do not include any mathematical optimization models. We investigated all the key features for the first group, while we only considered the key features such as purpose and number of facilities for the second group problems.

2.2.1 Purpose

We divide location problems into two broad classifications based on their purpose, namely “Location Analysis” and “Location Selection”.

Location Analysis problems aim to analyze the locations of facilities in specific area for the present time or for a period of time in order to assist in making location decisions. They provide statistical or spatial analyses to make deductions for location selection. On the other hand, Location Selection problems intend to find optimal locations in a given area or among the alternatives.

2.2.2 Space

Space in which the problems are modeled is one of the features and we divide location problems into two broad categories based on space characteristic namely, continuous and discrete.

Sometimes, it is assumed that in continuous models that there is a discrete set of demand points and facilities can be located anywhere in the service area (Klose & Drexl, 2005; ReVelle et al., 2008). However, in our taxonomy when demand continuously disperses over a region and occurs anywhere on a plane or facilities are located anywhere on the plane we assume that these models are continuous as in Daskin (2013). Continuous location models are also named "planar location models". These models can be utilized for locating video cameras or pollution censors to monitor certain environments (ReVelle et al., 2008).

Discrete location models presume that facilities can be located at discrete points and demand can also take place at discrete points. These problems are usually formulated as mixed integer programming models (ReVelle et al., 2008). The main difficulty of such models is amount of the data to be required (Plastria, 2001).

On the other hand, network location models assume that facilities can be located anywhere in the network which consists of nodes and links. Nodes are the points where the links meet. In these models, it is presumed that demand can also arise anywhere on the network (Plastria, 2001; Daskin, 2008). However, demand is often considered on the nodes. Demand for emergency highway services is a practical example where demand occurs both at the nodes and on the links (ReVelle et al., 2008). Distances are calculated by the shortest path distance in these models (Plastria, 2001).

Network location model is a special case of discrete location model. In other words, by removing the restriction that the distances between nodes are obtained from an underlying network, network model becomes a discrete model (Daskin, 2013).

While we were analyzing the papers, we categorized them into these three classes as mentioned above, i.e. discrete, network, and continuous.

2.2.3 Distance

The method of measuring distance between any two data points is another feature of location problems.

For network location models shortest distance between any pair of nodes using links in the network is considered (Daskin, 2013).

In discrete location models, distance between any pair of points may be arbitrary however, they generally follow a rule and use one of the distance metrics such as Euclidean, Manhattan, Chebyshev and Great Circle distance (Daskin, 2008).

Euclidean distance is the most widely used distance measure which is derived from the Euclidean norm and it is the shortest distance between two points in a line. The other mostly used metric is Manhattan which is derived from the Rectangular norm and also called Rectangular, Rectilinear, l_1 distance, City-block, Taxi, or Hamming distance (Plastria, 1995). This distance metric calculates the sum of the absolute differences of two data points' coordinates. The Chebyshev distance is defined as the maximum of the absolute differences between the features of two data points. This distance metric is also known as Tchebyschev distance and Chessboard distance (Kumar et al., 2014). These explained distance metrics are related to the plane, or at least a linear space. However, Great Circle distance is the most appropriate distance measure on sphere. Great Circle distance metric is used when the wide regions are considered in the problem and it is not possible to use planar models (Plastria, 1995).

Furthermore, in continuous space it is necessary to specify the type of used distance measure and the aforementioned distance metrics such as; Euclidean, Manhattan, Chebyshev can also be used in continuous models (Plastria, 2001).

In our location problems classification, discussed above metrics which are mostly used in the literature are considered. The distance metrics apart from these are regarded in the "Other" category.

2.2.4 Time

Location problems can generally be divided into two groups in terms of time feature: static and dynamic. We investigated location problems based on these features.

Static problems are also called single period location problems where there is just one period and problem parameters do not change over this period. However, in dynamic location problems which are also regarded as multi-period problem, there are discrete time planning horizons and problem parameters change over these planning horizons.

Static and dynamic location problems are considered as continuous time span and discrete time span respectively (Arabani & Farahani, 2012).

There are two types of dynamic facility location problems: in time-dependent problem, decision maker determines when to locate each facility over the defined planning horizon for the companies which face fluctuating demand (Owen & Daskin, 1998). On the other hand, in location-relocation problem, decision maker is allowed to relocate existing facilities and these problems mainly concerned with the time of relocation, number of relocation and cost of relocation (Arabani & Farahani, 2012).

Nonetheless, the papers were categorized as static and dynamic based on time feature since this level of detail perceived to be sufficient for our survey.

2.2.5 Parameters

Based on the type of the parameters used in the problems, location models may be deterministic or probabilistic (Daskin, 2013). Therefore, we divide location problems into these two categories.

In deterministic models, input of the model is (assumed to be) known with certainty and fixed whilst in probabilistic models, input is not known with certainty and subject to uncertainty (Klose & Drexl, 2005).

Owen and Daskin (1998) stated that uncertainty can be incurred in two different ways: either with planning uncertainty due to future conditions or absence of knowledge. All these problems, which consider uncertainty, are named stochastic location problems, as they address the stochastic nature of real world problems. There are two main approaches that deal with uncertainty in location problems, referred to as probabilistic approach and the scenario planning approach. In probabilistic approach, variables and parameters take probability distributions, where in scenario planning, parameters are uncertain and information of probabilities are unavailable, therefore a set of possible future values are considered for each variable / parameter (Arabani & Farahani, 2012). It can be seen that in probabilistic models some authors embed probability distributions into standard mathematical models whilst others use queuing models to incorporate these distributions (Owen & Daskin, 1998).

In the survey, papers were categorized as deterministic and probabilistic based on parameters feature, since this level of detail appears to be adequate for our research.

2.2.6 Capacity

A large number of location models (e.g., standard set covering, maximum covering, P-median, and center models) assume that facilities have unlimited capacity. These problems can be referred as “uncapacitated” problem. However, some facility location models treat facilities as having limited capacity by restricting demand allocation to the facilities (Klose & Drexl, 2005; Arabani & Farahani, 2012; Daskin, 2013).

2.2.7 Facilities

Location problems can also be differentiated based on the method for finding the number of facilities to be located. In some problems such as p-median and p-center problems, the number of facilities is predetermined and considered as an input to the problem. In these cases, the problems called exogenous. In other cases, in which the number of facilities is not preset and the solution of the problem is expected to provide this data as an output, the problems called endogenous (Daskin, 2013).

The number of facilities is restricted with a constraint in some location problems. However, these problems aim to find numbers of facilities as a result of the solution; accordingly these types of problem are also included in the endogenous category in our survey.

2.2.8 Number of Facilities

Location problems can also be classified based on the number of facilities to be located. In single facility problems, only one facility is located and all demand is served from this source. By contrast, in multiple facility problems, it is intended to locate more than one facility. Moreover, the number of facilities directly affects the model's difficulty (Plastria, 2001).

2.2.9 Facility Type

In some location problems, different facility types are considered whilst in other problems; all the facilities are regarded as identical. The facilities can be differentiated from each other in terms of the service types provided, price of the service, number of servers, service rate, and size of the facility. Moreover, we consider hierarchical facility location problems that they have different facility types.

2.2.10 Number of Objectives

Location problems may have single or multiple objectives. Many problems consider a single objective whilst others take multiobjective nature into account (Daskin, 2013). Single objective models aim to minimize or maximize a function such as maximizing total profit or minimizing total cost. However, multiple objective models intend to find compromise solutions by dealing with conflicting objectives (Hillier & Lieberman, 2001; X. Zhang et al., 2015).

2.2.11 Competition

Generally, location problems have the assumption of a spatial monopoly where the facility to be located is the single player in the market and offers a unique product or service. However, most situations do not fit these models and there is an explicit need to consider the competition with other players. Therefore, a location problem is regarded as competitive when it incorporates the fact that there is other facilities (or will be) in service in the market and the new facilities will have to compete with them for the market share (Karimifar et al., 2009). In this regard, other location problems which assume spatial monopoly are considered uncompetitive.

2.2.12 Desirability

Facilities can be broadly distinguished between desirable and undesirable where first group facilities are intended to be located as close as possible to the inhabitants such as hospitals, fire stations, shopping stores and educational centers. On the other hand, second group facilities are undesirable for the surrounding population who avoids these facilities including garbage dump sites, chemical plants, nuclear reactors, and prisons (S. Hosseini & Esfahani, 2009). These location models are also called “closer is better” and “farther is better” respectively (Daskin, 2013).

However, some of the researchers such as Erkut and Neuman (1989), Brimberg and Juel (1998), Daskin (2013) advocate that it is not sufficient to analyze location models in these two groups. Therefore, they differentiate between semi-desirable and undesirable location problems. There is a diversity of terms that are used for these two classes which also cause confusion. In some cases, obnoxious and noxious facilities are used for these terms. On the other hand, semi-obnoxious and obnoxious are also used instead of semi-desirable and undesirable.

Noxious facilities, which pose a risk to public health and safety, include hazardous waste disposal incinerator, chemical plants, and nuclear reactors, etc. On the other hand, obnoxious facilities, which generate negative effect in the surrounding environment and lifestyle but necessary for the population due to its essential services, involve garbage disposal sites, airports, and power plants etc. (Krarup et al., 2002; Tuzkaya et al., 2008; Tian & Liu, 2012).

Semi-desirable and undesirable facilities are not incorporated in the scope of this paper; hence all the researches included in the survey are conducted on desirable facility location problems.

2.2.13 Location Models

There are numerous location models that have been introduced to deal with location problems. Most of these models are derived from others, as it is possible to obtain another model by modifying the existing one or combining some of the characteristics of more than one model. Moreover, location science and operations research communities keep working on location models and all these attempts are for imitating real world problems which are really complex and easing the solution process of these problems. Therefore, the most used location models in the literature are here addressed which are examined in ten main categories as shown in Figure 2.3.

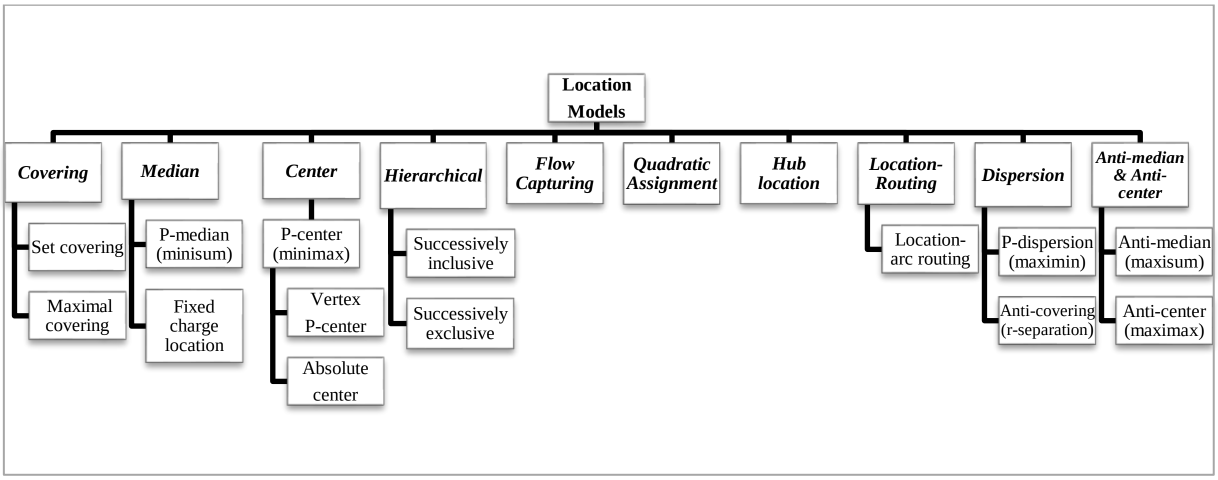

Figure 2.3: Location Models

Location-routing and hub models are excluded from the research, as they are comparatively different due to routing and designing network issues in the model. Hence these models can be regarded as advanced models. Nevertheless, dispersion, anti-median and anti-center models fall outside the scope of our survey since they are used for semi-desirable and undesirable facility location problems.

We only consider covering, median, center, hierarchical and flow capturing location models and their derivatives as the location model category in the survey. Moreover, mathematical optimization problems with multiple objectives are included in the related category according to the location model that is based on.

2.2.13.1 Covering Models

Covering problems aim to minimize the number of required facilities by locating these facilities in a specific distance (called the coverage distance or coverage radius) to the customers. In a covering problem, the demand is counted as covered by each facility if the travel distance or time between the customer and facility is equal or less than a predefined "acceptable" number (Fallah et al., 2009). Location problems for emergency service facilities, e.g. fire stations and ambulances can be regarded as covering problems because of the critical nature of demand (Owen & Daskin, 1998). For example, an ambulance should arrive in less than 10 min. at a person's house in order to deem the demand is covered. Moreover, covering models are also being used for private facilities where the coverage distance is accepted as the indicator of quality of service.

There are two types of covering problems; set covering and the maximal covering problem (Daskin, 2008). In set covering problem; the cost of locating facilities is tried to be minimized by locating minimum number of facilities where a level of coverage is specified. The set covering problem allows us to find out the required number of facilities to guarantee a certain level of coverage to all customers (Owen & Daskin, 1998). However, the resource restriction (in terms of the number of facilities we are able to locate) is not taken into account. Therefore, sometimes it is not possible to locate the required number of facilities due to budget limitations. Furthermore, set covering model treats all demand nodes in the same way without considering demand volume in each demand node. In order to obviate these two concerns, then the maximal (also called maximum) covering problem can be used (Daskin, 2013). The maximal covering problem aims to maximize the covered demands by restricting the number of facilities that can be located (Arabani & Farahani, 2012).

2.2.13.2 Median Models

In many cases, the benefits (costs) directly proportional to the distance between demand node and facility unlike the covering problems. Median models, which intend to find the median points among candidate facilities in order to minimize the sum of costs, can be utilized in these cases. Establishment of public services such as schools and hospitals can be counted in these kinds of problems (Jamshidi, 2009; Daskin, 2013). This class of problems decides both the facility location and the allocation; therefore they are also called as location-allocation problems.

P-median (which is also called minisum) and the fixed charge location problems (FCLPs) are types of median problems (Ahmadi-Javid et al., 2017). The objective of p-median problem minimizes the demand weighted total distance costs of locating the prespecified number of facilities. However, by adding the facility opening costs to the objective function of p-median problem, it becomes uncapacitated FCLP. Additionally, this problem removes the predetermined number of facilities constraint from p-median problem. Therefore, FCLP sites facilities to minimize the total cost (opening and travel) by determining the number of facilities endogenously (Owen & Daskin, 1998; Şahin & Süral, 2007). FCLP is also called plant location problem. In capacitated FCLP, a capacity constraint for each facility is added to the uncapacitated FCLP (Ahmadi-Javid et al., 2017).

2.2.13.3 Center Models

The center problem looks for the locations to meet all demand while the facilities have the minimum distance from the corresponding demand points. The most prominent types of center problems is the p-center problem (Arabani & Farahani, 2012).

P-center problem attempts to minimize the maximum distance between a demand point and its nearest facility by locating predetermined number of facilities, thus it is also known as minimax problem (Daskin, 2013). Vertex p-center problem is a special type of a center problem, in which locations are only allowed to be at the nodes of a network. However, in absolute center problems which is another special type of p-center problem, it is allowed to place facilities anywhere on the network, i.e. on the nodes and the links (Daskin, 2008).

Only p-center model is included in the categorization as the vertex p-center and absolute center models would be too much detail for our survey.

2.2.13.4 Hierarchical Models

A large number of facility systems are hierarchical (i.e. have different levels) as they include different facility types that are differentiated from each other in terms of service types and there are generally linkages between these facilities. Healthcare system consists of physicians' offices, local clinics, hospitals and medical centers; solid waste disposal system consists of transfer stations and landfill stations; production–distribution system consists of factories, warehouses and retail outlets; and education system consists of kindergartens, guidance schools and high schools, are some of the applications of hierarchical location problems (Bastani & Kazemzadeh, 2009; Daskin, 2013). For example, considering the case of healthcare system, a hospital can typically offer all the services provided in a local clinic. Furthermore, some health systems stipulate to obtain a referral from a general practitioner before a patient can ask for service at a hospital. Hierarchical systems generally classified as successively inclusive or successively exclusive. In the first class, a facility offers all the services that are provided by lower level facilities. On the contrary, in the second class facilities at each level provide service which is unique to that level (Güneş & Nickel, 2015).

2.2.13.5 Flow Capturing Models

Instead of assuming the demand arises at fixed points, in some location models facilities serve customers through point-to-point travel. In other words, facilities are located along customers' paths, i.e. preplanned trips such as daily commute to work (ReVelle & Eiselt, 2005). These models are called flow capturing location-allocation model (FCLAM). The main objective of FCLAM is to locate a given number of facilities in order to maximize the captured or intercepted demand which encounters at least one facility on its preplanned trip. The flow capturing approach fits several location problems such as automatic teller machines, advertising billboards, vehicle inspection stations and alternative-fuel stations (Tanaka & Furuta, 2012).

2.2.13.6 Quadratic Assignment Models

Quadratic assignment problem (QAP) aims to find the optimal assignment of facilities to locations so that it minimizes the total cost due to weighted sum of distances. The distances between locations, the demand flows among facilities and the facility versus location assignment costs are known in advance and the number of facilities and locations should be preset and equal in QAP (Loiola et al., 2007; Z. Drezner, 2015). This problem is regarded as one of the most difficult combinatorial optimization problems. Assigning the facilities to locations in an office can be considered a QAP problem (Bayat & Sedghi, 2009).

2.2.13.7 Hub Location Models

Deciding the location of hub facilities and designing the hub networks to connect a larger number of origin / destination (O / D) pairs by using small number of links is the primary concern of hub location problems (HLPs). Hub facilities can be used as transshipment, consolidation, or sorting points in transportation, telecommunication and computer networks. In hub location problems, flows which have the same origin but different destinations are consolidated in hubs, and combined with other flows that have different origins but the same destination. Therefore, the main objective of these problems is reducing setup costs, centralizing commodity handling and sorting operations, and achieve economies of scale on routing costs through the consolidation of flows. Decision process of HLPs embodies two levels. The first level is the selection of hub facilities among a set of nodes, where the second level is dealing with the design of hub network by determining the links to connect origins, destinations and hubs with the routing of flows through the network. Commodity can be in the form of people, goods, or information (Daskin, 2013; Contreras, 2015).

2.2.13.8 Location-routing Models

The location-routing problem (LRP) is a research area in location analysis which is the extension of classical vehicle routing problems (VRPs) and concentrates on the underlying issues of vehicle routing (Nagy & Salhi, 2007). VRP determines the set of routes, each performed by a single vehicle which starts and ends in its own depot, to minimize the global transportation cost while meeting the demand of customers and satisfying operational constraints. In some cases, customers do not travel to the facilities to get service and the server visits the customer to provide the service. The server can visit the customers in two different ways. The server may perform direct trips by returning to the facility after serving each customer like fire engines or the server may perform tour trips by visiting many customers in a tour like postmen. If there are direct trips, then the problem is a location-allocation problem. Moreover, if there are tour trips, the problem is a LRP (Anahita Hassanzadeh et al., 2009). LRPs are location problems where the service is supplied by a fleet of vehicles in less-than-truckload routes and more than one customer can be served in one vehicle route from a facility. Thus, in LRP the cost of servicing a customer does not only depend on the facility that is assigned to, but also on the route taken by the vehicle to serve that customer (Albareda-Sambola, 2015). LRP is determining the locations of facilities (depots) and the routes of the vehicles which are kept in these facilities in order to minimize the total cost including the fixed cost of locating facilities, distance-related travel costs, and fixed costs associated with using the vehicles (Daskin, 2013). LRP has many applications such as food and drink distribution, waste collection and blood bank location (Anahita Hassanzadeh et al., 2009).

The location-arc routing problem (LARP) should be discriminated from the classical LRPs where the customers are located at the nodes. In LARP, customers are located on the links of the network (Albareda-Sambola, 2015).

2.2.13.9 Dispersion models

There are two dispersion models which are generally used for the obnoxious facility location models: p-dispersion and anti-covering. In dispersion models, we are interested in the distance between the facilities. P-dispersion model aims to locate exactly p facilities in order to maximize the minimum distance of separation between any pair of facilities in such a way as to affect each other the least possible (Krarup et al., 2002; Daskin, 2013). P-dispersion models are regarded as maximin models. Anti-covering (or r-separation) location problem intends to maximize the number of facilities that are being located, so that each facility is no closer than specified distance or time to its closest facility (Niblett & Church, 2015).

2.2.13.10 Anti-median and Anti-center Models

Maxisum models are the mostly used location models for the noxious location problems. In maxisum models, the total demand-weighted distance between demand nodes and the nearest facility is maximized. The formulation of these models seems identical to p-median problem except the objective function of p-median problem which is minimizing the total demand-weighted distance (Daskin, 2013). The aim of such models is minimizing the detrimental effects of these facilities on environment and population

(Krarup et al., 2002). Moreover, maximax models, which intend to maximize the maximum distance between any pair of facilities and demand nodes, can also be utilized for these location problems. Maxisum and maximax models are also referred as anti-median and anti-center models respectively (Colebrook & Sicilia, 2007). In these models, we are interested in the distance between the facilities and demand nodes; on the contrary of dispersion models.

2.3 Descriptive Dimensions of Location Problems

All of the descriptive dimensions are investigated for both mathematical optimization problems and problems that do not include any mathematical optimization models.

2.3.1 Application Field

Application field of the problem shows the sectors or subsectors that the location problem designed and computational experiment is conducted for.

Application fields are categorized based upon the framework of North American Industry Classification System (NAICS) (*North American Industry Classification System*, 2017) and provided in Table 2.2. Sectors and the subsectors defined in the NAICS classifications are considered as application field with small modifications.

We intended to classify application fields as Accommodation; Arts, Entertainment, and Recreation; Banking; Food Services; Health Care & Social Assistance; Refueling; Retail Trade; and Other. Other category comprises Postal Service; Public Administration; Real Estate and Rental & Leasing; and Other Personal Services. However, due to the insufficient number of papers on “Accommodation” and “Arts, Entertainment, and Recreation”, these fields are also included it in the “Other” category. Furthermore, one can notice that “Refueling” does not stands on its own as a sector in NAICS, but we consider it as a separate application field since there are large number of studies and refueling facilities have distinctive characteristics which differs them from other facilities.

Table 2.2: Application Fields

Banking		
Food Services		
Health Care & Social Assistance		
Refueling		
Retail Trade		
Other	Accommodation	
	Arts, Entertainment, and Recreation	
	Other Types of Services	Postal Service
		Public Administration
		Real Estate and Rental & Leasing
		Other Personal Services

2.3.2 Application Facility

The considered facility type is another classification that is used in our location problems taxonomy. Facility type consists of different facilities such as electric vehicle charging stations; gasoline stations; ATMs; bank branches; health care facilities; stores; hotels; and restaurants.

The frequency of the papers that are published on each application field are presented in Figure 2.4.

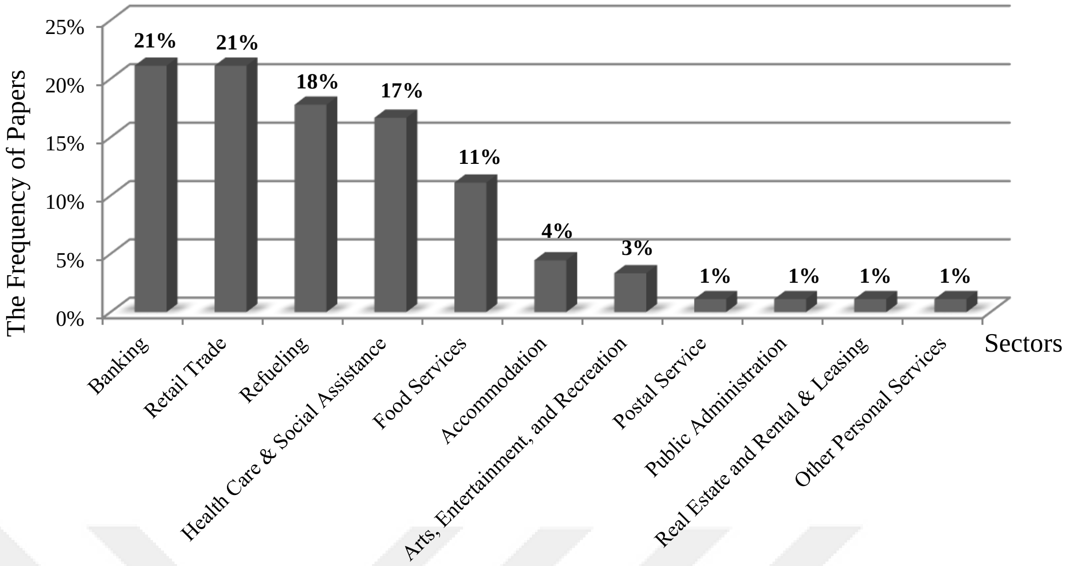

Figure 2.4: Frequency of Papers

It is seen that Banking, Retail Trade, Refueling and Health Care & Social Assistance are the fields that the researchers investigated most frequently.

Reviewed papers are given in chronological order with journal / conference proceedings name, application field and application facility in Table 2.3.

Table 2.3: Reviewed papers with application field and application facility

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
1	Modrego et al. (2000)	Planning Practice & Research	Arts, Entertainment, and Recreation	Theme park
2	Min & Melachrinoudis (2001)	International Transactions in Operational Research	Banking	Banking facilities
3	Morrison & O'Brien (2001)	Applied Geography	Banking	Bank branches
4	Tawarmalani et al. (2002)	Journal of Global Optimization	Food Services	Restaurants
5	G. H. Tzeng et al. (2002)	Hospitality Management	Food Services	Cuisine restaurants
6	Q. Wang et al. (2002)	Annals of Operations Research	Banking	Bank branches
7	Jayaraman et al. (2003)	European Journal of Operational Research	Other Services	Postal service facilities
8	Q. Wang et al. (2003)	Computers & Operations Research	Banking	Bank branches
9	T.-H. Wu & Lin (2003)	European Journal of Operational Research	Retail Trade	Convenience stores
10	Stummer et al. (2004)	Health Care Management Science	Health Care & Social Assistance	Medical departments
11	Cheng, Li, & Yu (2005)	Construction Innovation	Retail Trade	Shopping malls
12	Kuby & Lim (2005)	Socio-Economic Planning Sciences	Refueling	Alternative-fuel vehicle refueling stations
13	Narasimhan et al. (2005)	Journal of Operations Management	Other Services	Public administration- state agencies
14	Burnaz & Topcu (2006)	Journal of Multi-Criteria Decision Analysis	Retail Trade	Stores
15	Cheng, Li, & Yu (2007)	Building and Environment	Retail Trade	Shopping malls
16	Y.-W. Wang (2007)	Transportation Research Part D	Refueling	Electric scooter recharge stations
17	C.-R. Wu et al. (2007)	Building and Environment	Health Care & Social Assistance	Hospitals
18	T.-Y. Chou et al. (2008)	International Journal of Hospitality Management	Accommodation	Hotels

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
19	Syam (2008)	Computers & Operations Research	Health Care & Social Assistance	Healthcare system
20	L. Zhang & Rushton (2008)	Computers & Operations Research	Banking	Bank branches
21	Aldajani & Alfares (2009)	Computers & Industrial Engineering	Banking	ATMs
22	Çetin & Sarul (2009)	European Journal of Pure and Applied Mathematics	Health Care & Social Assistance	Blood banks
23	Çınar (2009)	International Scholarly and Scientific Research & Innovation	Banking	Bank branches
24	Guo (2009)	Information Sciences	Food Services	Rotisserie restaurants
25	Y. Li et al. (2009)	International Conference on Information Technology and Computer Science	Banking	ATMs
26	Ming et al. (2009)	International Conference on Service Operations, Logistics and Informatics	Banking	Bank branches
27	Qadrei & Habib (2009)	International Conference on Intensive Applications and Service	Banking	ATMs
28	Upchurch et al. (2009)	Geographical Analysis	Refueling	Alternative-fuel vehicle refueling stations
29	Vahidnia et al. (2009)	Journal of Environmental Management	Health Care & Social Assistance	Hospitals
30	Y.-W. Wang & Lin (2009)	Transportation Research Part E	Refueling	Battery electric vehicle charging stations
31	T.-H. Chang (2010)	IEEE International Conference on Industrial Engineering and Engineering Management	Food Services	Restaurants
32	Koçak (2010)	European Journal of Social Sciences	Retail Trade	Shopping malls
33	Lim & Kuby (2010)	European Journal of Operational Research	Refueling	Hydrogen-refueling stations

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
34	Neema & Ohgai (2010)	Computers, Environment and Urban Systems	Arts, Entertainment, and Recreation	Urban parks and open spaces
35	Önüt et al. (2010)	Expert Systems with Applications	Retail Trade	Shopping centers
36	Y.-W. Wang & Wang (2010)	Transportation Research Part E	Refueling	Alternative-fuel vehicle refueling stations
37	Xia et al. (2010)	IEEE Transactions on Automation Science and Engineering	Banking	Bank branches
38	Alhaffa et al. (2011)	International Journal of Machine Learning and Computing	Banking	ATMs
39	J. Wu et al. (2011)	Information Systems Frontiers	Banking	Bank branches
40	Byers et al. (2012)	Asia-Pacific Journal of Operational Research	Banking	ATMs
41	Erbıyık et al. (2012)	Procedia - Social and Behavioral Sciences	Retail Trade	Stores
42	Grabis et al. (2012)	Computers & Industrial Engineering	Food Services	Fast food restaurants
43	Hamidi et al. (2012)	International Journal of Management, IT and Engineering	Banking	ATMs
44	Mimis (2012)	Geo-spatial Information Science	Banking	Bank branches & ATMs
45	Prayag et al. (2012)	International Journal of Contemporary Hospitality Management	Food Services	Restaurants
46	Rahgan & Mirzazadeh (2012)	Research Journal of Applied Sciences, Engineering and Technology	Banking	Bank branches
47	Saidani et al. (2012)	European Journal of Operational Research	Retail Trade	Retail facilities
48	Shariff et al. (2012)	Computers & Industrial Engineering	Health Care & Social Assistance	Healthcare facilities
49	Tanaka & Furuta (2012)	Geographical Analysis	Retail Trade	Convenience stores & Supermarkets

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
50	He et al. (2013)	Transportation Research Part B	Refueling	Hybrid electric vehicle charging stations
51	Ho et al. (2013)	International Journal of Systems Science	Food Services	Restaurants & Coffee shops
52	Juan & Lin (2013)	Tourism Economics	Accommodation	Hotels
53	Kim & Kim (2013)	Annals of Operations Research	Health Care & Social Assistance	Healthcare facilities
54	Kwak et al. (2013)	International Journal of Smart Home	Retail Trade	Shopping malls
55	Roig-Tierno et al. (2013)	Applied Geography	Retail Trade	Supermarkets
56	Xi et al. (2013)	Transportation Research Part D	Refueling	Electric vehicle charging stations
57	Gavranović et al. (2014)	Procedia Computer Science	Refueling	Electric vehicle charging station
58	Kerzmann et al. (2014)	Sustainable Energy Technologies and Assessments	Refueling	Natural gas fueling station
59	W.-S. Lee (2014)	International Journal of Information Technology & Decision Making	Other Services	Real estate brokerage service facilities
60	Müller & Haase (2014)	Business Research	Retail Trade	Furniture stores
61	Shariff et al. (2014)	Statistics and Operational Research International Conference	Health Care & Social Assistance	Public healthcare facilities
62	F. Wang et al. (2014)	Cities	Retail Trade	Retail stores
63	J. Yu et al. (2014)	International Conference on Agro-Geoinformatics	Arts, Entertainment, and Recreation	Urban parks
64	Allahi et al. (2015)	Proceedings of the 2015 Industrial and Systems Engineering Research Conference	Banking	Bank branches
65	Beheshtifar & Alimoahmmadi (2015)	International Transactions in Operational Research	Health Care & Social Assistance	Healthcare facilities (clinics)
66	Bhatti et al. (2015)	Annals of Operations Research	Refueling	Alternative fuel stations

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
67	K.-L. Chang et al. (2015)	Asia Pacific Management Review	Accommodation	Service apartments
68	Elkady & Abdelsalam (2015)	Science and Information Conference	Health Care & Social Assistance	Healthcare facilities
69	M. Hosseini & Mirhassani (2015)	Transportation Research Part E	Refueling	Alternative fuel permanent & Portable stations
70	Jelokhani-Niaraki & Malczewski (2015)	Land Use Policy	Other Services	Parking areas
71	Koç & Burhan (2015)	Advances in Management & Applied Economics	Retail Trade	Carglass stores
72	Marić et al. (2015)	Annals of Operations Research	Health Care & Social Assistance	Long-term care facilities
73	Ventura et al. (2015)	Computers & Operations Research	Refueling	Alternative fuel stations
74	Y. Yang et al. (2015)	International Journal of Hospitality Management	Accommodation	Hotels
75	Y. Zhang (2015)	International Journal of Production Economics	Retail Trade	Stores
76	Zhou & Clapp (2015)	Regional Science and Urban Economics	Retail Trade	Anchor stores
77	Ait Bassou et al. (2016)	Journal of Theoretical and Applied Information Technology	Retail Trade	Stores
78	Carrillo & López (2016)	IEEE International Conference on Fuzzy Systems	Food Services	Coffee shops
79	R.-C. Chen & Suen, (2016)	Mathematical Problems in Engineering	Retail Trade	Stores
80	L.-F. Chen & Tsai (2016)	Tourism Management	Food Services	Restaurants
81	D. Chen et al. (2015)	Mathematical Problems in Engineering	Refueling	Charging stations & Gasoline stations
82	Elkady & Abdelsalam (2016)	International Journal of Business and Systems Research	Health Care & Social Assistance	Healthcare facilities

No	Author(s) (Year)	Journal / Conference Proceedings Name	Application Field	Application Facility
83	Giménez-Gaydou et al. (2016)	International Journal of Sustainable Transportation	Refueling	Battery electric vehicle charging station
84	Ouyang et al. (2016)	Proceedings of the 2016 International Conference on Industrial Engineering and Operations Management	Health Care & Social Assistance	Healthcare facilities
85	Sloan et al. (2016)	Journal of Business Venturing Insights	Food Services	Restaurants
86	S.-P. Wang et al. (2016)	Mathematical Problems in Engineering	Refueling	Gasoline stations
87	Ye & Kim (2016)	GeoJournal	Health Care & Social Assistance	Healthcare facilities
88	W. Zhang et al. (2016)	Computers, Environment and Urban Systems	Health Care & Social Assistance	Public healthcare facilities
89	ELSamen & Hiyasat (2017)	Journal of Retailing and Consumer Services	Retail Trade	Shopping malls
90	Raghu Kisore & B Koteswaraiah (2017)	Information Sciences	Banking	ATMs

2.3.3 Solution Method Category

Solution Method Category is stated as another dimension which mainly includes three different categories such as Optimization, Multi-attribute Decision Making (MADM) and Spatial Analysis techniques. However, there are various optimization methods used for solving the location problems. Therefore, we based our classification on the study of (Ahmadi-Javid et al., 2017) and consider two main subclasses for optimization methods.

Optimization methods that are in the first subclass are called accurate methods. These methods find either optimal (exact) or near-optimal (perturbed) solution with a known deterministic error bound on the (relative or absolute) optimality gap of the resulting solution in a given time period. The second subclass includes inaccurate methods, i.e. heuristic and metaheuristic, which do not provide an error bound and cannot determine the quality of resulting solutions (Ahmadi-Javid et al., 2017).

The accurate methods are common and useful for small and medium problems. However, it is not always possible to solve complex and large-size problems with these methods. Therefore heuristics and metaheuristic methods are used for such problems (Seyedhosseini et al., 2016).

Consequently, we categorize location problems into four different classes in terms of solution method category, i.e. accurate, heuristic, metaheuristic, MADM, and spatial analysis. The solution methods which are not fit in with one of these classes regarded as "Other" category.

2.3.4 Solution Methods

In the solution methods dimension, we specified all the methods that are utilized in the related paper as they are given.

2.3.5 Computational Experiment

If the suggested solution method is used to solve the problem, then we regard the problem as it has computational experiment. Moreover, it is not necessary that the problem is solved by using software; it can also be solved through manual computations. The only criterion for considering the problem as it has computational experiment is that solution method should be utilized to test the performance of the suggested method.

2.3.6 Real Data in Computational Experiment

Some of the problems use real world data whereas others use data that is generated based on a distribution or randomly generated data in their computational experiments. The usage of real data in computational experiment can be considered as the approximation of the real world problem as it enables the decision maker to interpret the quality of the model in more accurate way.

2.3.7 Software & Programming Language

The software packages and the programming languages used to solve the problem are investigated under this dimension. Matlab, Gams, Lindo, Expert Choice, and ArcGIS are some of the software that are included in this category whilst C++, C#, and Pascal are the examples of programming languages that are considered.

2.4 Review of the Service Facility Location Problems

There are three types of sectors, i.e. primary, secondary and tertiary in a broad perspective. The primary sector refers to the raw materials industry which extracts or cultivates resources as primary goods including iron ore, petroleum, grains, fruits, fish, and cattle (Riedinger, 2016). Secondary sector denotes manufacturing industries which produce goods whilst tertiary sector represents the service industry that consists of profit earning businesses named private sector and non-profit businesses named public sector (Gertz, 2016).

It is important to differentiate the facilities that operate in different sectors from each other with respect to facility location problems. Some researchers have addressed these differences mainly between manufacturing and services but not usually in the scope of location science. However, even the general distinction provides useful insights to understand the nature of these sectors. Xing et al. (2013) differentiate services from manufacturing in three fundamental aspects. Initially, the resources of service industry have inconstant features and may vary even for the same activity whilst the number and the composition of the resources (typically machines and tools) are generally fixed. Secondly, the production and delivery are immediate in service industry compared to manufacturing industry that has substantial production and delivering processes. Thirdly, services are intangible and can have thousands of forms unlike manufacturing. Silvestro et al. (1992) also mentioned the differences between service and manufacturing operations based on the affect of volume change in the processes. Additionally, service sector is not homogenous even in itself. On the other hand, apart from these researches Jirásková (2015) made a research on the comparison of location factors evaluation for the secondary and tertiary sectors, as he considered these sectors as the main power of the economy. Moreover, Eiselt et al. (2015) referred to the difference between primary and tertiary sectors relating to facility locations. They pointed out that in the primary sector it is important to site facilities close to sources whereas in the tertiary sector, generally facilities are intended to be placed in close proximity to customers, as there is an inevitable interaction between the customer and the facility (service provider).

Moreover, a variety of attempts also have been made to group services into categories in order to gain strategic and operational insights for different purposes such as design, management of processes and marketing other than industry classifications (Verma, 2000; Shafti et al., 2007).

Service is an emerging and important sector for the economic growth in the 21st century and according to the World Bank data, it accounted for 69.05% of world value added GDP in 2015. Additionally, it covers a wide range of industries from medical care to financial services (J. Wu et al., 2008) as in NAICS determines 15 of 20 sectors as “Service Providing Industries” (“Industries at a Glance,” 2017). Furthermore, service sector embodies real management challenges where one of the most critical issues is site selection. Location selection is a systematic and complex problem and success or failure of facilities partially depends on the chosen sites for facilities (J. Wu et al., 2008; Daskin, 2013).

Within this scope, we investigate reviewed papers based on the proposed classification framework.

Before examining the papers, all the characteristics that are given in the taxonomy are presented with their symbols in Table 2.4.

Table 2.4: Characteristic used in the taxonomy

Problem Characteristic		Code	Problem Characteristic		Code
Model Type	Fixed charge	FC	**Time**	Static	St
	Flow capturing	FLC		Dynamic	Dy
	Hierarchical	H	**Parameters**	Deterministic	Det
	Maximal covering	MC		Probabilistic	Pro
	P-center	PC	**Competition**	Competitive	Comp
	P-median	PM		Noncompetitive	Ncomp
	Set covering	SC	**Capacity**	Capacitated	Cap
	Other	O		Uncapacitated	Uncap
Space	Discrete	D	**Number of Facilities**	Single	Sin
	Network	N		Multiple	Mul
	Continuous	C		Not applicable	Na

Problem Characteristic		Code	Problem Characteristic		Code
Number of Objectives	Single	S	**Facilities**	Exogenous	Ex
	Multiple	M		Endogenous	En
Different facility type	Considering different facility types	Yes	**Solution Method Category**	Accurate	Ac
	Considering only single facility type	No		Heuristic	Heu
Distance	Shortest Travel Paths	Stp		Metaheuristic	Mheu
	Euclidean	Eu		MADM techniques	MADM
	Manhattan	Mht		Spatial analysis	Span
	Other	Oth		Other	Oth
	Not given	Ng	**Computational Experiment**	Including a computational experiment	Yes
	Not applicable	Na		Not including a computational experiment	No
Purpose	Location selection	LS	**Real Data in Computational Experiment**	Real data	Yes
	Locational analysis	LA		Generated data based on a distribution or randomly generated data	No
				Not applicable	Na

Moreover, the abbreviations that are considered for solution methods are provided in Table 2.5 in alphabetic order.

Table 2.5: Abbreviations used for solution methods

Definition	Abbreviation	Definition	Abbreviation
Analytical Hierarchy Process	AHP	Fuzzy AHP	FAHP
Artificial Neural network	ANN	Fuzzy C means clustering algorithm	FCMC
Analytic Network Process	ANP	Fuzzy Density-based spatial clustering of applications with noise	FDBSCAN
Approximate solution method	APSM	Fuzzy Data Envelopment Analysis	FDEA
Active-set algorithm	AS	Genetic algorithm	GA
Branch & Bound Algorithm	BB	Greedy-adding algorithm	GAD
Bayesian probability inferences	BPI	Greedy-adding with substitution algorithm	GADS
Boosted regression	BR	Greedy dropping heuristic	GD
Borda voting method	BVM	Generalized Density-based spatial clustering of applications with noise	GDBSCAN
Chance-constraint Goal Programming	CCGP	Gradient descent method	GDM
Complete enumeration approach	CEA	Gradient descent method with multiple random starting points	GDMMRSP
Conditional logit model	CLM	Generalized Fuzzy Density-based spatial clustering of applications with noise	GFDBSCAN
Density-based spatial clustering of applications with noise	DBSCAN	Greedy interchange algorithm	GI
Data Envelopment Analysis	DEA	Geographic Information System	GIS
Decision Making Trial and Evaluation Laboratory	DEMATEL	Gravity model	GM
Directed Tabu Search	DTS	Goal Programming	GP
Evolutionary Approach	EA	Greedy algorithm	GR
ELimination and Choice Expressing Reality	ELECTRE	Genetic Simulated Annealing algorithm	GSA
Exchange local search procedure	ELSP	Heuristic Approach using Convolution	HAC
Exact polynomial algorithm	EP	Huff model	HM
Evidential Reasoning	ER	Integer linear programming	ILP
Exhaustive search	ES	K-density method	KDM

Definition	Abbreviation	Definition	Abbreviation
Kernighan–Lin algorithm based heuristic	KLA	Particle Swarm Optimization	PSO
K-means clustering algorithm	KMC	Rank Based Genetic Algorithm using convolution	RGAC
Linear-Fractional Programming	LFP	Rough Set Theory	RST
Lagrangian relaxation	LR	Simulated Annealing	SA
Multi-attribute decision making	MADM	Simulated Annealing using Convolution	SAC
Monte Carlo algorithm	MCA	Simulation model	SM
Multi-choice goal programming	MCGP	Subgradient optimization methods	SOM
Monte Carlo simulation	MCS	Support vector regression	SVR
Marginal increment algorithm	MIA	Two-dimensional convolution based heuristic	TDC
Nondominated sorting GA II	NSGA-II	The Technique for Order of Preference by Similarity to Ideal Solution	TOPSIS
Ordinary Least Squares	OLS	Time-Resistance Approach	TRA
OWA-based method	OWABM	Tabu Search	TS
Preference Disaggregation Analysis	PDA	Two-stage noncooperative game	TSNCG
Partial enumeration method	PEM	Voronoi diagrams	VD
Path-following approach	PFA	Vlsekriterijumsko KOmpromisno Rangiranje	VIKOR
Probabilistic Latent Semantic Analysis	PLSA	Variable Neighborhood Search method	VNS
Projection pursuit regression	PPR	Weighted sum method	WSM
Polynomial regression method	PRM		

In order to overview all the key features of mathematical optimization problems, reviewed papers are presented in Table 2.6. Key features for location problems which do not include any mathematical optimization model are also reported in Table 2.7. The papers in the tables are sorted according to their application field and in each application field they are sorted into chronological order.

Table 2.6: Key features of mathematical optimization problems

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Min & Melachrinoudis (2001)	LS	H	N	M	(1) Max. of the market profitability of open banks (2) Max. of the customer drawing power of open banks (3) Min. of all the risks associated with resource commitments made to open banks	St	Pro	Ncomp	Stp	Ex	Mul	Yes	Cap
Q. Wang et al. (2002)	LS	O	N	S	Min. of customers' total traveling cost and waiting cost	St	Pro	Ncomp	Eu	En	Mul	No	Cap
Q. Wang et al. (2003)	LS	PM	N	S	Min. of total weighted travel distance for customers	St	Pro	Ncomp	Eu	Ex	Mul	No	Uncap
L. Zhang & Rushton (2008)	LS	O	N	S	Max. of consumer utility	St	Pro	Comp	Ng	En	Mul	Yes	Uncap
Aldajani & Alfares (2009)	LS	SC	D	S	Min. of total number of facilites	St	Det	Ncomp	Eu , Mht	En	Mul	No	Uncap
Y. Li et al. (2009)	LS	O	C	S	Max. of return on investment of the located facility	St	Det	Ncomp	Na	Ex	Sin	No	Uncap
Ming et al. (2009)	LS	MC	D	S	Max. of total coverage of demand	St	Det	Ncomp	Ng	En	Mul	No	Uncap
Qadrei & Habib (2009)	LS	FC	D	S	Min. of total cost (including set-up, maintenance, residual cost associated with bank and travel cost associated with customers)	St	Pro	Ncomp	Mht	En	Mul	Yes	Cap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Xia et al. (2010)	LS	MC	D	S	Max. of the facility network's profits (total revenue of covered demands minus the costs of sited facilities)	St	Det	Ncomp	Ng	En	Mul	Yes	Uncap
Alhaffa et al. (2011)	LS	MC	D	M	(1) Max. of percentage coverage (PC) (2) Min. of total number of facilities	St	Det	Comp	Mht	En	Mul	No	Uncap
Hamidi et al. (2012)	LS	O	N	M	(1) Min. of the expected customers' total time including travel time to the facilities and waiting time at the facility (2) Min. of the ATM idle times	St	Pro	Ncomp	Ng	En	Mul	No	Cap
Mimis (2012)	LS	H	C	S	Min. of the average distance traveled by the users	St	Det	Ncomp	Eu , Stp	Ex	Sin	Yes	Uncap
Allahi et al. (2015)	LS	MC	D	S	Max. of the demand coverage	St	Det	Ncomp	Ng	Ex	Mul	No	Uncap
Tawarmalani et al. (2002)	LS	MC	D	S	Max. of weighted market share	St	Det	Ncomp	Ng	Ex	Mul	No	Uncap
Grabis et al. (2012)	LS	MC	D	M	Max. of the weighted sum of individual facility goodness indicators including: (1) number of customers (2) number of competitors (3) real-estate cost	St	Pro	Comp	Eu	En	Mul	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Ho et al. (2013)	LS	O	D	M	(1) The rent cost of the location (2) Lot size (3) The average score of public transportation (4) The average parking capacity (5) The average pedestrian volume (6) The average size of commercial area (7) The average score of proximity of public facilities (8) The number of competitors (9) The average score of landscaping (10) The average score of safety	St	Det	Ncomp	Na	Ex	Sin	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Stummer et al. (2004)	LS	FC	N	M	(1) Min. of total travel costs incurred by patients (2) Min. of total costs associated with a location–allocation hospital plan (3) Min. of the number of patients who would have to be rejected in department as a consequence of low service capacities (4) Min. of the number of unit moves necessary to restructure the current allocation	Dy	Det	Ncomp	Eu	En	Mul	Yes	Cap
Syam (2008)	LS	PM , SC	N	S	Min. of the total cost (including fixed costs, overhead costs, transportation costs, processing costs, staffing costs, and waiting costs)	St	Pro	Ncomp	Ng	Ex	Mul	No	Cap
Çetin & Sarul (2009)	LS	FC , SC	C	M	(1) Min. of the total fixed cost of locating blood banks (2) Min. of the total traveled distance from hospitals to blood banks (3) Min. of inequality index	St	Det	Ncomp	Eu	En	Mul	No	Cap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Shariff et al. (2012)	LS	MC	N	S	Max. of the population assigned to a facility within the coverage distance	St	Det	Ncomp	Ng	En	Mul	No	Cap
Kim & Kim (2013)	LS	MC	D	S	Max. of the number of served patients	St	Det	Comp	Ng	En	Mul	No	Cap
Shariff et al. (2014)	LS	PM , MC	N	S	Max. of the assignment of the total demand volume within the coverage distance S and simultaneously min. of the total travelled distance by the uncovered volume	Dy	Det	Ncomp	Ng	En	Mul	No	Cap
Beheshtifar & Alimoahmmadi (2015)	LS	PM , PC	N	M	(1) Min. of travel costs (2) Min. of unequal access to clinics (3) Max. of selected site suitability and compatibility of land use (4) Min. of cost of land purchase and facility establishment	St	Det	Ncomp	Stp	Ex	Mul	No	Cap
Elkady & Abdelsalam (2015)	LS	MC	N	S	Min. of the maximum uncovered demand deviation from the total demand	St	Pro	Ncomp	Ng	En	Mul	No	Cap
Marić et al. (2015)	LS	O	N	S	Min. of maximum number of patients assigned to established facilities	St	Det	Ncomp	Ng	En	Mul	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Elkady & Abdelsalam (2016)	LS	MC	N	M	(1) Max. of demand coverage (2) Min. of the travelled distance of the uncovered demand nodes	St	Det	Ncomp	Ng	En	Mul	No	Cap
Ouyang et al. (2016)	LS	O	D	S	Min. of the total cost of building and maintaining all the facilities in the considered time horizon	Dy	Det	Ncomp	Eu	En	Mul	No	Cap
Ye & Kim (2016)	LS	MC , SC	N	S	(1) Min. of total number of facilities (2) Max. of overall covered demand	St	Det	Ncomp	Stp	Ex	Mul	No	Cap
W. Zhang et al. (2016)	LS	PC , MC	D	M	(1) Min. of inequity of accessibility (2) Max. of accessibility for the whole population (3) Min. of the number of people who fall outside an acceptable travel distance to at least one facility (4) Min. of the cost of building new public health-care facilities	St	Det	Ncomp	Ng	Ex	Mul	No	Cap
Kuby & Lim (2005)	LS	FLC	N	S	Max. of the total flow volume refueled	St	Det	Ncomp	Stp	Ex	Mul	No	Uncap
Y.-W. Wang (2007)	LS	FC	D	S	Min. of the cost of locating recharge stations	St	Det	Ncomp	Oth	En	Mul	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Upchurch et al. (2009)	LS	FLC	N	S	Max. of vehicle-miles traveled	St	Det	Ncomp	Stp	Ex	Mul	No	Cap
Y.-W. Wang & Lin (2009)	LS	SC , FLC	N	S	Min. of the total costs of locating the stations	St	Det	Ncomp	Ng	En	Mul	No	Uncap
Lim & Kuby (2010)	LS	FLC	N	S	Max. of the total flow volume refueled	St	Det	Ncomp	Stp	Ex	Mul	No	Uncap
Y.-W. Wang & Wang (2010)	LS	MC , SC	N	M	(1) Min. of cost of locating stations (2) Max. of population coverage	St	Det	Ncomp	Stp	En	Mul	No	Uncap
He et al. (2013)	LS	O	N	S	Max. of social welfare associated with the coupled networks	St	Pro	Ncomp	Ng	En	Mul	No	Uncap
Xi et al. (2013)	LS	FLC	D	S	Max. of the number of electric vehicles charged	St	Pro	Ncomp	Ng	En	Mul	Yes	Cap
Kerzmann et al. (2014)	LS	MC	D	S	Max. of total coverage of traffic	St	Pro	Ncomp	Ng	Ex	Mul	No	Uncap
Gavranović et al. (2014)	LS	PM	N	S	Min. of the weighted distances between the customers and charging stations divided by the preference score for that location	St	Det	Ncomp	Oth	Ex	Mul	No	Cap
Bhatti et al. (2015)	LS	MC	N	S	Max. of expected total profit	Dy	Pro	Ncomp	Ng	En	Mul	No	Uncap
D. Chen et al. (2015)	LS	FLC	N	S	Min. of the refueling vehicles' detour time	St	Pro	Ncomp	Ng	En	Mul	No	Cap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
M. Hosseini & Mirhassani (2015)	LS	FLC	N	S	Max. of amount of total flows serve under different scenarios	St	Pro	Ncomp	Stp	Ex	Mul	No	Cap
Ventura et al. (2015)	LS	FLC	N	S	Max. of the traffic flow in round trips/day covered by the station	St	Det	Ncomp	Stp	Ex	Sin	No	Uncap
Giménez-Gaydou et al. (2016)	LS	MC	N	S	Max. of the charging coverage of users weighted by their adoption potential (target) market	St	Det	Ncomp	Eu	Ex	Mul	No	Uncap
S.-P. Wang et al. (2016)	LS	O	D	M	(1) Max. of average fuel consumption (2) Max. of average swipe rate (3) Max. of the percentage of neighbors willing to accept the new technology (4) Max. of average number of cars (5) Min. of waiting time (6) Max. of average number of motorcycles (7) Min. of the number of competitors (8) Max. of the number of gas pump islands (9) Max. of the number of gas pumps (10) Max. of the floor area size	St	Det	Ncomp	Na	Ex	Sin	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
T.-H. Wu & Lin (2003)	LS	FLC	N	S	Max. of the flow captured	St	Det	Comp	Oth	Ex	Mul	No	Uncap
Koçak (2010)	LS	SC	D	S	Min. of the total Euclid distance of districts suitable for shopping mall site selection to the potential point proportional to its weight	St	Det	Comp	Eu	En	Mul	No	Uncap
Saidani et al. (2012)	LS	O	C	S	Max. of profit	St	Pro	Comp	Eu	Ex	Sin	No	Uncap
Tanaka & Furuta (2012)	LS	H , FLC	N	S	Max. of the total flow that can be serviced at facilities	St	Det	Ncomp	Eu , Stp	En	Mul	Yes	Uncap
Müller & Haase (2014)	LS	FLC	D	S	Max. of the total patronage for the facilities	St	Pro	Ncomp	Eu	Ex	Mul	No	Uncap
Y. Zhang (2015)	LS	O	N	S	Max. of the annual profit (which is equal to the annual revenue minus the purchase cost and fixed location cost)	St	Pro	Comp	Mht	Ex	Mul	No	Uncap
Ait Bassou et al. (2016)	LS	PM	N	S	Min. of the cost for establishing a store and the cost due to a level service that should be in a given facility	St	Det	Ncomp	Ng	Ex	Mul	No	Cap
R.-C. Chen & Suen (2016)	LS	SC	D	M	(1) Min. of the total profit loss (profit difference before and after closure) (2) Min. of the total distance from the selected store to its nearby stores	St	Det	Ncomp	Ng	Ex	Mul	No	Uncap

Author(s) (Year)	Purpose	Model Type	Space	Number of Objectives	Objective Function	Time	Parameters	Competition	Distance	Facilities	Number of Facilities	Different Facility Type	Capacity
Neema & Ohgai (2010)	LS	O	C	M	(1) Min. of the distances from parks and open spaces (POSs) to highly populated areas (2) Min. of the distances from POSs to areas with high air pollution (3) Min. of the distances from POSs to noisy areas (4) Min. of the distances from POSs to areas without POSs	St	Det	Ncomp	Eu	En	Mul	No	Uncap
J. Yu et al. (2014)	LS	PM , MC	C	S	Min. of the sum of distances from the urban parks to all the residential districts, while maximizing the covered population of these parks	St	Det	Ncomp	Stp	Ex	Mul	No	Uncap
Jayaraman et al. (2003)	LS	H , MC	N	S	Max. of the amount of demand covered	St	Det	Ncomp	Eu	En	Mul	Yes	Cap
Narasimhan et al. (2005)	LS	O	D	S	Min. of the number of branch offices in the state	St	Pro	Ncomp	Na	En	Mul	No	Cap

Table 2.7: Key features of problems which do not include mathematical optimization model

Author(s) (Year)	Purpose	Number of Facilities	Author(s) (Year)	Purpose	Number of Facilities
Morrison & O'Brien (2001)	LS	Mul	Cheng et al. (2007)	LS	Mul
Çınar (2009)	LS	Mul	Önüt et al. (2010)	LS	Sin
J. Wu et al. (2011)	LS	Mul	Erbıyık et al. (2012)	LS	Sin
Byers et al. (2012)	LS	Sin	Kwak et al. (2013)	LS	Mul
Rahgan & Mirzazadeh (2012)	LS	Mul	Roig-Tierno et al. (2013)	LS	Sin
Raghu Kisore & B Koteswaraiah (2017)	LS	Mul	F. Wang et al. (2014)	LA	Na
G. H. Tzeng et al. (2002)	LS	Mul	Koç & Burhan (2015)	LS	Sin
Guo (2009)	LS	Sin	Zhou & Clapp (2015)	LA	Na
T.-H. Chang (2010)	LS	Sin	ELSamen & Hiyasat (2017)	LA	Mul
Prayag et al. (2012)	LA	Na	T.-Y. Chou et al. (2008)	LS	Sin
Carrillo & López (2016)	LS	Sin	Juan & Lin (2013)	LS	Sin
L.-F. Chen & Tsai (2016)	LS	Mul	K.-L. Chang et al. (2015)	LS	Sin
Sloan et al. (2016)	LA	Na	Y. Yang et al. (2015)	LS	Mul
C.-R. Wu et al. (2007)	LS	Sin	Modrego et al. (2000)	LS	Sin
Vahidnia et al. (2009)	LS	Sin	W.-S. Lee (2014)	LS	Sin
Cheng et al. (2005)	LS	Sin	Jelokhani-Niaraki & Malczewski (2015)	LS	Mul
Burnaz & Topcu (2006)	LS	Sin			

Furthermore descriptive dimensions for all location problems are reviewed in Table 2.8. The papers in the table are first sorted based on their application field and then sorted into chronological order.

Table 2.8: Descriptive dimensions of problems

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
Min & Melachrinoudis (2001)	CCGP	Ac	Yes	Yes	LINGO
Morrison & O'Brien (2001)	GIS , HM	Span	Yes	Yes	Ng
Q. Wang et al. (2002)	GDH , TS , ε-optimal BB , LR	Ac , Heu , Mheu	Yes	Yes	Visual Studio C++
Q. Wang et al. (2003)	GI , TS , LR, ILP	Ac , Heu , Mheu	Yes	Yes	Visual Studio C++ , CPLEX
L. Zhang & Rushton (2008)	GA	Mheu	No	Na	Na
Aldajani & Alfares (2009)	ILP , ES , TDC	Ac , Heu	Yes	No	Matlab
Çınar (2009)	FAHP , TOPSIS	MADM	Yes	Yes	Ng
Y. Li et al. (2009)	PSO , GIS	Mheu , Span	Yes	Yes	Self-developed software
Ming et al. (2009)	MIA , GAD	Heu	Yes	Yes	Java
Qadrei & Habib (2009)	Custom-made GA	Mheu	Yes	No	C-Sharp (C#)
Xia et al. (2010)	GIS , NPA	Mheu , Span	Yes	Yes	Ng
Alhaffa et al. (2011)	HAC , RGAC , SAC	Heu , Mheu	Yes	Yes	SPSS , Matlab
J. Wu et al. (2011)	KMC , GIS , PLSA , BPI	Span , Oth	Yes	Yes	Matlab
Byers et al. (2012)	TSNCG	Oth	No	No	Na
Hamidi et al. (2012)	LFP , GP	Ac	Yes	No	GAMS , LINGO , Genetics
Mimis (2012)	GIS , VD , DTS	Mheu , Span	Yes	Yes	Mapbasic scripting language of MapInfo , Matlab
Rahgan & Mirzazadeh (2012)	FAHP , Interval ER approach	MADM	Yes	Yes	Self-developed software
Allahi et al. (2015)	AHP , GIS , ILP	Ac , MADM , Span	Yes	Yes	ArcGIS , LINGO

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
Raghu Kisore & B Koteswaraiah (2017)	K-means ++ , FCMC , DBSCAN , FDBSCAN , GDBSCAN , Modified version of GFDBSCAN , VD	Span	Yes	Yes	Matlab , Scikitlearn , Google Maps
Tawarmalani et al. (2002)	NLP , BB , MINLP , GA , GIS	Ac , Mheu , Span	Yes	No	BARON , OSL , MINOS , CPLEX
G. H. Tzeng et al. (2002)	AHP , VIKOR	MADM	Yes	Yes	Ng
Guo (2009)	FDEA	Oth	Yes	Yes	Ng
T.-H. Chang (2010)	FAHP	MADM	Yes	No	Ng
Grabis et al. (2012)	KLA , MILP , GIS	Ac , Heu , Span	Yes	Yes	Ng
Prayag et al. (2012)	GIS	Span	Yes	Yes	GPS Visualizer's Address Locator (gpsvisualizer.com) , ArcGIS
Ho et al. (2013)	AHP , MCGP	Ac , MADM	Yes	Yes	LINGO , Self-developed LDSS
Carrillo & López (2016)	ELECTRE III , PDA	MADM	Yes	Yes	SADGAGE
L.-F. Chen & Tsai (2016)	Data mining based on RST	Oth	Yes	Yes	RSES (Rough Set Exploration System)
Sloan et al. (2016)	OLS	Oth	Yes	Yes	Ng
C.-R. Wu et al. (2007)	AHP , Delphi method	MADM , Oth	Yes	Yes	Expert Choice
Syam (2008)	LR , GR	Heu	Yes	No	Ng
Çetin & Sarul (2009)	MINLP , GP , GM	Ac , Oth	Yes	No	Ms Excel Solver
Vahidnia et al. (2009)	GIS , FAHP	MADM, Span	Yes	Yes	ArcGIS

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
Shariff et al. (2012)	GA , LR , ILP	Ac, Heu, Mheu	Yes	Yes	CPLEX , LINDO
Kim & Kim (2013)	ILP , LR , SOM	Ac , Heu	Yes	Yes	CPLEX , C++
Shariff et al. (2014)	GA	Mheu	Yes	Yes	Ng
Beheshtifar & Alimoahmmadi (2015)	GIS , NSGA-II , TOPSIS	Mheu	Yes	Yes	Ng
Elkady & Abdelsalam (2015)	MCS , PSO	Mheu , Oth	Yes	No	Matlab
Marić et al. (2015)	BB, MILP , EA , VNS , ELSP	Ac , Mheu , Heu	Yes	Yes	C-Sharp (C#) , CPLEX
Elkady & Abdelsalam (2016)	PSO , NS , WSM , TOPSIS	Ac , Mheu , MADM	Yes	No	Ng
Ouyang et al. (2016)	ILP	Ac	Yes	No	CPLEX
Ye & Kim (2016)	ILP , GIS	Ac , Span	Yes	Yes	CPLEX , ArcGIS
W. Zhang et al. (2016)	GA based MOO	Mheu	Yes	Yes	Ng
Kuby & Lim (2005)	MILP , GAD	Ac , Heu	Yes	No	Mosel modeling language , Xpress
Y.-W. Wang (2007)	ILP	Ac	Yes	Yes	LINDO
Upchurch et al. (2009)	GAD	Heu	Yes	Yes	Xpress
Y.-W. Wang & Lin (2009)	MILP	Ac	Yes	Yes	IBM ILOG
Lim & Kuby (2010)	MILP , GAD , GADS , GA	Ac , Heu , Mheu	Yes	Yes	Xpress , C-Sharp (C#)
Y.-W. Wang & Wang (2010)	WSM	Ac	Yes	Yes	LINGO
He et al. (2013)	AS	Heu	Yes	Yes	Ng
Xi et al. (2013)	ILP , SM	Ac , Oth	Yes	Yes	Ng
Kerzmann et al. (2014)	MCA	Oth	Yes	Yes	Ng

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
Gavranović et al. (2014)	ILP	Ac	Yes	Yes	IBM ILOG , CPLEX
Bhatti et al. (2015)	NLIP , APSM , MILP	Ac	Yes	Yes	C++ , CPLEX
D. Chen et al. (2015)	GSA	Mheu	Yes	Yes	TransCAD
M. Hosseini & Mirhassani (2015)	MILP , GR	Ac , Heu	Yes	Yes	AIMMS , CPLEX
Ventura et al. (2015)	EP	Ac	Yes	No	Na
Giménez-Gaydou, et al. (2016)	ILP	Ac	Yes	No	Xpress
S.-P. Wang et al. (2016)	AHP , MCGP	Ac , MADM	Yes	Yes	Expert Choice , LINGO
T.-H. Wu & Lin (2003)	GAD , CEA , ILP , GM	Ac , Heu , Oth	Yes	Yes	LINGO , Turbo C++
Cheng et al. (2005)	ANP , AHP	MADM	Yes	No	Ms Excel Solver
Burnaz & Topcu (2006)	ANP	MADM	Yes	Yes	Super Decisions
Cheng et al. (2007)	GIS	Span	Yes	Yes	Ng
Koçak (2010)	NLP	Ac	Yes	Yes	Ms Excel Solver
Önüt et al. (2010)	FAHP , Fuzzy TOPSIS	MADM	Yes	Yes	Ng
Erbıyık et al. (2012)	AHP	MADM	Yes	Yes	Expert Choice
Saidani et al. (2012)	Interval BB , PRM , PEM , HM	Ac , Heu , Oth	Yes	No	C++ , Matlab
(Tanaka & Furuta, 2012)	ILP , LR	Ac , Heu	Yes	Yes	CPLEX , Visual Studio C++
Kwak et al. (2013)	AHP , Delphi method	MADM, Oth	Yes	Yes	Expert Choice
Roig-Tierno et al. (2013)	AHP , GIS , KDM	MADM, Span	Yes	Yes	ArcGIS
Müller & Haase (2014)	Multinomial logit model , MINLP	Ac , Oth	Yes	Yes	CPLEX

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
F. Wang et al. (2014)	GIS , KDM	Span	Yes	Yes	ArcGIS
Koç & Burhan (2015)	AHP	MADM	Yes	Yes	Expert Choice
Y. Zhang (2015)	GDM , GDMMRSP , PFA , GR , TS , GA	Heu , Mheu	Yes	Yes	Visual Studio C++ , COUENNE
Ait Bassou et al. (2016)	VNS , ILP	Ac , Mheu	Yes	No	C-Sharp (C#) , CPLEX
Zhou & Clap, (2015)	KDM , CLM	Span	Yes	Yes	Ng
R.-C. Chen & Suen (2016)	GIS , KMC , NBMOGA	Mheu , Span , Oth	Yes	Yes	Visual Studio C++
ELSamen & Hiyasat (2017)	TRA , GIS	Span	Yes	Yes	ArcGIS
T.-Y. Chou et al. (2008)	FAHP , Ideal and anti-ideal concepts	MADM	Yes	Yes	Ng
Juan & Lin (2013)	Diamond model of Porter (1990) , AHP , Delphi method	MADM , Oth	Yes	Yes	Expert Choice
K.-L. Chang et al. (2015)	Fuzzy Delphi method , ANP , TOPSIS	MADM , Oth	Yes	Yes	Ng
Y. Yang et al. (2015)	PPR , ANN , SVR , BR , DEA	Oth	Yes	Yes	Self-developed web GIS
Modrego et al. (2000)	GIS , Delphi method	Span , Oth	Yes	Yes	Ng
Neema & Ohgai (2010)	GA based MOO , GIS	Mheu , Span	Yes	Yes	C++ , ArcGIS
J. Yu et al. (2014)	PSO , GIS	Mheu , Span	Yes	Yes	Self developed tool in ArcGIS environment with Microsoft C-Sharp (C#) , .NET
Jayaraman, et al. (2003)	ILP , Heuristic based LR , LR , SOM	Ac , Heu	Yes	Yes	Pascal , CPLEX
Narasimhan et al. (2005)	DEA , MILP	Ac , MADM	Yes	Yes	Ng

Author(s) (Year)	Solution Method	Solution Method Category	Computational Experiment	Real Data in Computational Experiment	Software & Programming Language
W.-S. Lee (2014)	DEMATEL , DEMATEL-based ANP , VIKOR	MADM	Yes	Yes	Ng
Jelokhani-Niaraki & Malczewski (2015)	OWABM , BVM , GIS	Span	Yes	Yes	Google Web Toolkit and Google Maps APIs , MySQL database in the Java IDE environment IntelliJ IDEA

Moreover, as we mentioned earlier papers are categorized according to their application fields which are organized based on the sectors' definitions provided in the last version of NAICS (2017). Chronological order relating to publication date is followed in each application field without considering application facility type to present the development of each field. Furthermore, we briefly summarized each paper by following the classification framework that is aforementioned. However, more details on some papers are provided based on our personal judgment about their importance or differences from other problems. At the end of each application field section, we summed up the characteristics that are used.

2.4.1 Banking

Min and Melachrinoudis (2001) introduced a stochastic, three-hierarchical location-allocation model for banking facilities. They considered ATMs, bank branches, and main bank as three levels of the successively inclusive hierarchical system in which the higher-level facility provides services available at lower-level facilities in addition to the unique services offered by the higher level. Chance-constrained Goal Programming (CCGP) was employed due to conflicting goals, uncertain and risky nature of parameters and constraints (e.g., bank loan portfolios, bank patronage patterns, service mix, or government regulations) in the problem.

Morrison and O'Brien (2001) developed GIS (Geographic Information System) based on spatial interaction model which utilized Huff model to help banks making the decision of which branches to close. In the introduced model, customers decide their choice of branch in two stages; where they choose the bank itself in the first stage and select the branch in the second stage. However, Morrison and O'Brien (2001) assumed that their model starts in the second stage as the bank choice of customer is regarded as given.

Q. Wang et al. (2002) studied a facility location problem with stochastic customer demand and immobile servers and modelled it as an M / M / 1 queueing system. Their problem has constraints on the number of facilities that may be opened and allowable expected waiting time at a facility. Three heuristic algorithms were developed, including a greedy dropping procedure, a tabu search approach and an ε-optimal branch-and-bound method using lagrangian relaxation to find a lower bound. These heuristics were compared computationally on a bank location data set for branch location problem.

Q. Wang et al. (2003) investigated a budget constrained location problem in which they simultaneously considered opening some new facilities and closing some existing facilities. They formulated a mathematical programming model and developed three heuristic algorithms (greedy interchange, tabu search and lagrangian relaxation approximation) to solve the problem. They performed the application of the problem in the context of locating / relocating bank branches in a large-size town. The performances of the heuristics were compared with the optimal solution.

L. Zhang and Rushton (2008) worked on a multi-site location-allocation model which aims to select locations for franchise systems or retailers with multiple outlets in competitive service systems. M / M / m queuing system as well as opening and closing facilities were considered simultaneously. The objective function is the maximizing customer utility where utility value is related to both the size of the facility and the distance between the demand node and the facility. Moreover, customers choose from among competing facilities according to the probabilities that are determined by utility function. The model also considers the facilities' service quality in terms of waiting time of the customers and it determines the optimal locations and sizes of the facilities. They developed the model in the context of the bank branch location problem and recommended genetic algorithm (GA) as a solution procedure but they did not carry out a computational experiment.

Aldajani and Alfares (2009) proposed an ATM placement algorithm which finds the minimum number of ATMs and their locations such that service supply exceeds the arbitrary demand by a fixed amount. They formulated a mathematical model of the problem and developed a new heuristic algorithm based on the two-dimensional convolution. They also compared the optimum solutions produced by integer programming and exhaustive search with the heuristic solutions.

Çınar (2009) discussed a location selection model that aims to find the most appropriate city for opening a bank branch among six alternatives. Five main criteria and twenty one sub-criteria were investigated in the problem. FAHP (Fuzzy Analytical Hierarchy Process) was applied for determining the weights of the criteria and TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) was used for ranking the candidate cities with respect to each sub-criteria and main criteria using their weights.

Y. Li et al. (2009) addressed an ATM planning and location model in which they integrated GIS technology with the mathematical model. They utilized Particle Swarm Optimization (PSO) algorithm to solve the model and also presented a survey about the relationship between locations and return value of ATMs.

Ming et al. (2009) presented a new assignment algorithm to solve a bank branch location problem by dividing the whole location space into small regions. They considered the population density of the regions in partitioning phase. A heuristic method based on marginal increment algorithm was developed to determine the number of facilities in each small region and assign them into these regions. Greedy adding algorithm was also used to evaluate the performance of the proposed algorithm.

Qadrei and Habib (2009) formulated ATM location-allocation problem in order to find the number of ATMs and their locations. The problem aims to minimize deployment and operational costs subject to the customers' satisfaction and the bank's requirements. They also took different ATM types into consideration and used an M / M / 1 queuing system, which deals with the negative exponential arrival rates and service times. They proposed a custom-made genetic algorithm for searching the best possible deployment of ATMs with least cost.

Xia et al. (2010) studied a facility location problem which is an extension of maximal covering location problem (MCLP) and aimed to maximize the profits produced by the facilities. They considered both the revenue and the cost for the profit function. The revenue is a function of the covered demand within a certain range of facilities whilst the cost is the sum of operational and rental cost that is dependent on the location and the type of the facility. They employed a hybrid approach which combines mathematical programming with the nested partitions algorithm for the bank branch location problem.

Alhaffa et al. (2011) investigated market based ATM deployment problem that considers dual objective in order to achieve maximum percentage coverage and minimum number of ATMs required for covering intended area of study. They designed and compared three algorithms for the problem called heuristic approach using convolution, rank-based genetic algorithm using convolution and simulated annealing using convolution.

J. Wu et al. (2011) developed a joint learning scheme which looks for the best locations based on the combined data of surrounding business performances and the geographical information. K-means clustering, GIS and Probabilistic Latent Semantic Analysis (PLSA) were integrated for branch location selection. Their joint methodology initially clustered existing locations into groups with different performances. Then, they applied PLSA on the re-organized GIS data to examine the existing locations and their surrounding businesses such as shopping mall, department store, office building, and park. Finally, the data obtained from two previous methods was combined by the Bayesian probability inferences to extract knowledge for site selection.

Byers et al. (2012) modeled a competitive Hotelling-style market with two symmetric banks which decide the location and pricing of their own ATMs. They analyzed and compared two different systems in their study in order to examine the effect of surcharge bans on the location decisions, fee structures, bank profits, and consumer total cost. First model is an "unregulated" model in which surcharges are allowed. The second model is a "regulated" model in which surcharges are banned. They applied a two-stage non-cooperative game where banks first choose locations for their ATMs and then determine the prices including surcharges and / or foreign fees.

Hamidi et al. (2012) presented a linear approximation of nonlinear queuing model which was suggested by Pasandideh and Niaki (2012) and where each facility behaves like M / M / 1 queue. They initially employed linear-fractional programming to transform a nonlinear model to a linear model. Then, they used goal programming model to minimize customer waiting time and percentage of idle time for ATM.

Mimis (2012) introduced a methodology for solving the problem of finding optimum locations for a number of bank branches and ATMs entering an existing hierarchical network. GIS, where the cost function was evaluated, was used and directed tabu search was employed for continuous nonlinear optimization model. The proposed methodology also applied the voronoi diagrams to define the service areas of the facilities.

Rahgan and Mirzazadeh (2012) combined the Fuzzy AHP and Interval Evidential Reasoning (ER) approach for a location problem that aims to select the most appropriate site for a bank branch among five alternatives. FAHP was used to determine the weights of attributes and sub-attributes where five main attributes and fourteen sub-attributes were taken into account. Additionally, the Interval ER algorithm was applied to rank the alternatives.

Allahi et al. (2015) designed an integrated model which combines AHP, GIS and maximal covering location problem (MCLP) to choose the locations for bank branches. The model applied AHP to quantify the most commonly used criteria for branch location where seven initial criteria and twenty two sub-criteria were considered. GIS was utilized to determine the potential sites based on the determined criteria weights and MCLP was employed to select the optimal sites.

Raghu Kisore & B Koteswaraiah (2017) employed an analytic-based approach to optimize ATM deployment considering the financial and social behavior of the people living in a geographical area. The proposed approach consists of a three-stage process. The first stage is identifying the key socio-economic factors that determine ATM deployment where second stage is clustering the geographical area of ATM deployment using a modified version of the generalized fuzzy density-based clustering algorithm (GFDBSCAN). Lastly, third stage assesses the number and location of ATMs with the use of voronoi diagrams by evaluating various ATM deployment strategies that are measured in terms of coverage area and turnaround time. They also compared the results of their clustering algorithm with K-means ++, fuzzy C means, density-based spatial clustering of applications with noise (DBSCAN), fuzzy DBSCAN, generalized DBSCAN and generalized fuzzy DBSCAN clustering algorithms.

According to Table 2.6 “Model Type” column, a large majority of the papers that are applied in Banking sector consider maximal covering location models and models that are classified in “Other” category. Furthermore, it can be said that hierarchical, p-median and set covering models are also used for the Banking sector.

Discrete space is widely preferred in Banking location problems; moreover, network space also follows discrete space very closely. Unsurprisingly, only 15% of the problems consider continuous space.

Another important conclusion on the Banking location problems is that most of them take into account single objective and do not consider the multiobjectivity.

It is also worth noting that all the papers in this section handle the location problems in static time as none of them has investigated dynamic time element.

If the parameter type of the paper is discussed, almost half of the papers deal with probabilistic models. Therefore, it can be said that location science community attaches equal importance to deterministic and probabilistic parameters in Banking sector.

It is seen that almost all the papers deal with location problems without considering competitiveness. The exceptions are the papers, L. Zhang and Rushton (2008) and Alhaffa et al. (2011).

Distance parameter is not applicable or it is not specified that which distance measure is applied in approximately 50% of the investigated papers. Additionally, Euclidean and Manhattan distance are widely used metrics in these problems. It also drew our attention that Aldajani and Alfares (2009) utilized more than one distance metric in their paper.

The location problems, that incorporate the number of facilities as an input to the problem, constitute a majority compared to endogenous problems. Furthermore, the great number of papers also take into account multiple facilities which we usually expect to see in real life problems. More than half of the papers deal with single facility type but it should be also mentioned that there are several problems that consider different facility types.

Another observation is that uncapacitated location problems have attracted much more attention than capacitated location problems in Banking sector.

In Banking location problems metaheuristic, spatial analysis and accurate methods are mostly used solution methods.

Only two of the papers; L. Zhang and Rushton (2008) and Byers et al. (2012) did not perform computational experiments where for the most part, papers use real data in their experiments. Matlab and Lingo are the generally used computing environment and optimization software respectively for the application of location problems in this section.

2.4.2 Food Services

Tawarmalani et al. (2002) proposed a branch and bound algorithm to solve a discrete p-choice facility location problem for locating set of ten restaurant franchises where the objective function is the maximization of market share. Saipe's algorithm (Saipe, 1975) and Genetic Algorithm were used to perform upper bounding and lower bounding steps respectively. The market share of a location was calculated in terms of the ratio of the utility of related location to sum of the utilities of all available locations to the customers. Moreover, the utility of an alternative location to a customer at a particular demand node was estimated using a multiplicative competition interaction criterion as a function of distance, accessibility, and a number of attractiveness factors. Moreover, they used GIS data to calculate the centroids of demand zones and candidate location zones and their inter-spatial distances.

G. H. Tzeng et al. (2002) addressed a restaurant location problem where they aimed to evaluate four alternative locations. They developed AHP with five aspects and eleven criteria in order to assess the location criteria. They ranked the alternative locations by using compromise ranking method (known as VIKOR) and proposed two of them to the decision maker as compromise solutions.

Guo (2009) developed fuzzy Data Envelopment Analysis (DEA) model as an extension of CCR model for solving a location problem. They conducted a case study of a Japanese-style rotisserie restaurant location decision where they seek the best location for the given business requirements. Five location factors and four location alternatives were considered in the problem.

T.-H. Chang (2010) applied AHP model to choose a restaurant location by utilizing reciprocal additive consistent fuzzy preference relations. In the application phase, they presented an illustrative example where a restaurant manager intends to select the best location among four feasible locations based on five evaluation criteria including eleven sub-criteria.

Grabis et al. (2012) formulated a multiobjective facility location model in which they aim to maximize an aggregated facility goodness indicator by considering three different objectives. Moreover, they proposed a computational approach which requires both spatial and non-spatial data and embodies gathering and processing input data, model-solving and representation of modeling results. In the proposed model, customer demand is approximated by the demand density around the potential facility differently from the traditional discrete facility location models in which customer demand is defined at discrete data points. They demonstrated the model with an application of fast food restaurant location problem and developed a simple heuristic based on the Kernighan–Lin algorithm (Newman, 2010) that used for network clustering.

Prayag et al. (2012) studied the evolution of restaurant locations in the city of Hamilton over a 12-year period by focusing on locational patterns with the use of GIS techniques. Retail theories such as central place, spatial interaction and principle of minimum differentiation were employed in the restaurant setting. The findings of the research enables the identification of land use patterns and addresses potential areas where new restaurants could be opened.

Ho et al. (2013) adapted an integration of AHP and multi-choice goal programming (MCGP) to select an appropriate location for restaurants / coffee shops from many alternatives. The study used AHP results in order to derive the weights of goals in MCGP where multi-aspiration levels were set for each location goal. Moreover, they designed a location decision support system (LDSS) based on the proposed method to evaluate different locations and provided a real case study with a conducted experiment to test the effectiveness of LDSS.

Carrillo and López (2016) evaluated six potential location alternatives to determine a suitable commercial location to install a franchise coffee shop. They presented a group multi-criteria ranking problem where they consider nine location criteria. ELECTRE III methodology and preference disaggregation analysis (PDA) were employed to aid group members to reach a consensus ranking.

L.-F. Chen and Tsai (2016) developed a data mining approach based on Rough Set Theory (RST) to support location selection decisions. They used this approach to draw potentially useful rules from location data for predicting store performance with location factors. Twenty location factors relevant to five location aspects were examined. The validity of the proposed method was demonstrated with an emprical study on a restaurant chain. Moreover, as a result of the study, the most important factors were also found which the decision makers should pay attention in location selection decisions.

Sloan et al. (2016) analyzed the impact of various violent crimes (e.g. burglaries, assaults, rapes, and murders) on restaurant location decisions in the city of Memphis. The crimes and restaurants in parcels were matched based on the location information on crimes and newly opened restaurants. Each crime found positively related to the number of new restaurants in a parcel, according to the regression analysis which is performed with Ordinary Least Squares (OLS). Moreover, it is indicated that population density can make a location attractive even it has a crime problem.

When we look at the researches in Food Services, it is seen that there are only three papers which consider optimization methods and two of them deal with maximal covering location model.

From the Table 2.6 “Space” column, it can be concluded that all Food Services location problems are considered in discrete space. Two of the papers handle the multiobjective location problem where one of them does not take into account multiobjectivity.

Papers in this section only investigate static problems. Moreover, both deterministic and probabilistic parameters are used in the problems where one of the problems addresses probabilistic parameters.

It should be mentioned that two of the papers do not include the competitiveness in the problems. Euclidean distance is used in Grabis et al. (2012), as the other papers do not clarify the distance metric that is utilized.

Two of the papers study exogenous location problems and 50% of the papers have an interest in finding the location of multiple facilities. All the problems are formulated with single facility type and as uncapacitated.

MADM techniques take the lead where accurate, spatial analysis and other methods are equally utilized in the location problems. Additionally, LINGO, CPLEX and ArcGIS are used as software in these papers.

All researches in Food Services perform computational experiment and large majority of them use real data in the problem, except Tawarmalani et al. (2002) and T.-H. Chang (2010).

2.4.3 Health Care & Social Assistance

Stummer et al. (2004) developed a two-phase solution procedure for the multiobjective decisions on the location and size of medical departments in a given hospital network. Moreover, the proposed model with three objectives, does not allocate patients to another hospital if the demand exceeds the hospital's capacity; alternatively imposes a penalty for the requested service. They applied tabu search as the first phase of the solution procedure to determine efficient (feasible) allocations, whilst used cluster analysis in the second phase for exploring solution space in order to determine the most preferred location-allocation alternative.

C.-R. Wu et al. (2007) presented AHP-based evaluation model for determining the optimal location of a regional hospital in regard to competitive advantage. Therefore, they identified the location criteria based on Porter's diamond model (Porter, 1990). AHP and modified Delphi method were applied to evaluate three locations under six criteria and eighteen sub-criteria.

Syam (2008) had a research on service system design by developing a nonlinear location-allocation model that consists of several relevant costs and considerations such as set-up costs, service costs and waiting costs, queuing system with multiple servers, multiple order priority levels, multiple service sites, and service distance limits. The model primarily determines the locations of pre-specified number of service centers, their capacities and allocation of customers to the selected centers. Healthcare systems were examined with the use of developed methodology based on Lagrangian relaxation and several experiments were conducted to analyze different system designs.

Çetin and Sarul (2009) developed a multiobjective location model as a hybrid form of the set covering model of discrete location models and the center of gravity method of continuous location models. This model considers that demand can be aggregated to the discrete points while facilities can be located anywhere in the region. Nonlinear goal programming with three objectives was employed for the solution of the model which finds locations of blood banks and assigns hospitals to appropriate blood banks.

Vahidnia et al. (2009) adopted an integrated multi-criteria decision analysis process for a hospital site selection decision. GIS analysis was employed to analyze and organize relevant spatial data, whilst FAHP was used to evaluate the decision factors and their impacts on alternative locations. Five criteria and five alternative sites were considered in the problem. The usefulness of the selected site was assessed by calculating an accessibility index, which is the ratio of population density to travel time, for each pixel in the GIS.

Shariff et al. (2012) addressed a healthcare facility location-allocation problem and proposed a new solution approach based on genetic algorithm to examine the coverage of the existing facilities. The results of the algorithm were initially evaluated on a set of test problems taken from (Haghani, 1996). They also compared their results with the GA proposed by (Jaramillo et al., 2002), Lagrangian heuristics and optimal solutions. Moreover, past location decisions were compared to the results obtained using optimization software package CPLEX. Then, the algorithm was extended to solve a real data set from Malaysia. The solution of the algorithm was used to identify whether there is a need for additional new facility or there is a need for additional increase in capacity.

Kim and Kim (2013) addressed a healthcare facility location problem in which there are two types of patients, low-income patients and middle and high-income patients. In their problem, first type of patients can use only public facilities, while the second type can use both public and private facilities. Additionally, they aimed to determine the locations of public facilities and allocate patients to these facilities in the environment where competition with private facilities exists. They also considered the preference of patients for the public and private facilities. A heuristic algorithm based on lagrangian relaxation and subgradient optimization methods was developed. The results of the heuristic were compared with the results of a general-purpose commercial solver for integer programs on a number of test problems.

Shariff et al. (2014) examined a dynamic location problem for public primary healthcare facilities. The problem aims to evaluate the location of the existing facilities and establish additional facilities or upgrade the existing facilities. They also analyzed the effect of population growth on the performance of the primary health care service by considering the percentage of coverage as the measurement. Genetic Algorithm was used to take the best location allocation decision.

Beheshtifar and Alimoahmmadi (2015) presented a location model which integrates GIS analysis with a multiobjective genetic algorithm to decide the location of new clinics and assign the people to selected clinics. In order to decide optimal location-allocation, four objective functions were defined. The NSGA-II algorithm was employed to handle the variability of chromosomes' length and TOPSIS was adapted as a posteriori preference method to compare the Pareto-optimal solutions for determining the best solution.

Elkady and Abdelsalam (2015) combined Monte Carlo simulation with PSO to solve healthcare location allocation problem. They introduced a modified version of capacitated maximal covering location problem where stochastic demand is considered.

Marić et al. (2015) discussed the network design problem of long-term care facilities. The problem deals with determining locations of facilities among given potential sites and allocates patient groups to its closest facility. They developed a hybrid method which integrates Evolutionary Approach (EA) with modified Variable Neighborhood Search (VNS) method and additionally improved the hybrid method with an Exchange local search procedure. The results of the proposed VNS-EA implementation were compared with branch and bound method, and modified Add-Drop-Interchange heuristic from (Kim & Kim, 2010), pure EA method and optimal solutions presented in (Stanimirovi´c et al. 2012).

Elkady and Abdelsalam (2016) proposed a two-loop PSO algorithm to solve multiobjective facility location-allocation problem for providing healthcare services. Modified PSO was applied with nondominated sorting algorithm and TOPSIS was utilized to choose the appropriate pareto front solutions based on the decision maker's preferences through different weight values for objective functions. The results were compared with the result of weighted sum method.

Ouyang et al. (2016) presented a study that was concentrated on healthcare facility location problem in which long term demand is taken into acount. They used the concept of grid-based location problems to divide the area of interest into discrete cells. The model simultaneously decides the optimal locations of facilities for the present time and future time horizon, and solved with the CPLEX solver.

Ye and Kim (2016) proposed a network-based covering location problem by incorporating sub-models which are network-based maximal covering location problem (Net-MCLP) and network-based location set covering problem (Net-LSCP). A spatial optimization approach was employed with an integration of mathematical programming and GIS to support location decisions of healthcare facilities. They solved both sub-models seperately and performed a joint result analysis. Moreover, they mentioned that the locations which were found by these two models are the most critical ones since these locations both satisfy spatial equity and economic efficiency.

W. Zhang et al. (2016) considered public health-care facility location-allocation problem for the future decision where a number of new facilities were aimed to be located. A genetic algorithm based multiobjective optimization (MOO) approach was employed to find the compromising solution that yields in the most practical tradeoffs between four objectives which are conflicting.

Almost half of the papers that are studied in Health Care & Social Assistance formulated their problems as maximal covering location models. P-median, set covering, p-center, and fixed charge are other location models that are applied.

Network decision space is generally preferred in the location problems that are presented in this section. Moreover, there are several papers that consider discrete space where only Çetin and Sarul (2009) develops a continuous location model.

For the most part, Health Care & Social Assistance location problems investigate single objective. However, 38% of the papers deal with multiobjectivity.

The papers considerably focus on static problems, on the other hand Stummer et al. (2004), Shariff et al. (2014) and Ouyang et al. (2016) take into account the dynamic nature of the problems.

Deterministic parameters are employed with 85% in the location problems where only Syam (2008) and Elkady and Abdelsalam (2015) use probabilistic parameters.

Almost all the papers, except Kim and Kim (2013), assume that location problems arise in a noncompetitive environment.

Most of the papers do not explicate the distance metric that they use, whereas there are papers which specify the usage of Euclidean and Shortest travel paths distance.

Endogenous facilities are examined in more than half of the papers. Nonetheless, great majority of the papers in this section address multi facility locations. Almost all the location problems consider single facility type and capacity constraint. Exceptions are Stummer et al. (2004) who introduced different facility types and Marić et al. (2015) who studied on uncapacitated facility problem.

Metaheuristic and accurate methods are widely used in Health Care & Social Assistance location problems. Heuristic, MADM tecniques, and spatial analysis methods are also employed in these problems.

All the papers conduct a computational experiment, however 67% of them use real data in their problems. CPLEX is mostly utilized as an optimization software package. Additionally, ArcGIS and C++ are also used for the solutions of these problems.

2.4.4 Refueling

Kuby and Lim (2005) extended flow-capturing models and developed flow refueling location model (FRLM) to locate predetermined number of refueling stations for range-limited alternative-fuel (alt-fuel) vehicles such as hydrogen fuel cells or natural gas. They did not develop any heuristic solution method, however used mixed-integer programming software to simulate how a greedy-adding algorithm would perform in terms of optimality.

Y.-W. Wang (2007) examined an establishment problem of recharge stations for electric scooters and modeled it using an integer programming. The purpose of the model was deciding the optimum number of stations and their locations. Sensitivity analyses were conducted for determining the minumum recharge time and the length of stay at each station.

Upchurch et al. (2009) studied alternative-fuel vehicle refueling stations and modified the original FRLM by considering the capacity of fueling stations. They limited the number of vehicles refueled at each station while optimizing their locations with greedy-adding algorithm.

Y.-W. Wang and Lin (2009) improved the Wang's model (Y.-W. Wang, 2008) by relaxing the restriction of the trip length in the refueling station location problem in order to consider the refueling requirements of long-distance (intercity) journeys. They followed the concept of set cover location model where all flow-refueling demand is along the paths of interest to be covered by located charging stations within the specific coverage distance. Mixed integer programming was used to locate charging stations that serve battery electric vehicles.

Lim and Kuby (2010) addressed a flow-refueling location model (FRLM) that aims to find optimal locations for a given number of refueling stations for alternative-fuels such as hydrogen, ethanol, biodiesel, natural gas, or electricity. Three algorithms were developed (i.e. the greedy-adding, greedy-adding with substitution and genetic algorithm) and compared based on the optimality gap.

Y.-W. Wang and Wang (2010) formulated the refueling station location problem for alternative-fuel vehicles to serve intercity (long-distance) travel among the large cities and simultaneously cover intra-city (short-distance) trips. In order to avoid double-counting and cannibalization issues, the flows on the intercity tours along the shortest paths among cities were taken into account and each station was assumed uncapacitated. Weighted sum method was employed to decide the number and locations of refueling stations for providing service to both types of demand, i.e. passing flows and nodal points.

He et al. (2013) introduced an equilibrium modeling framework to decide an optimal allocation of public charging stations to metropolitan areas in the region. The developed framework also encompasses the modeling of travel demand distribution of PHEVs (plug-in hybrid electric vehicles), prices of electricity and PHEVs' choices of destinations and routes. Thus, they offered a strategic plan that concentrates on interconnectivity between urban transportation and power distribution network in order to maximize the social welfare associated with the coupled networks. The allocation model was built as a mathematical program and solved with active-set algorithm.

Xi et al. (2013) developed a simulation-optimization model that decides the number and locations of electric vehicle (EV) charging stations that use slow charging technologies. The model also takes into account different types of chargers and determines which type of charger to locate at each location. They developed a simulation model to estimate the expected number of EVs and employed a linear integer programming model to determine the location and size of charging stations.

Kerzmann et al. (2014) proposed a new model for the location of natural gas fueling stations for a given number of stations. Monte Carlo algorithm as a statistical optimization method was adopted to find the optimum distribution of fueling stations based on the local volume of traffic.

Gavranović et al. (2014) adopted the classic capacitated p-median location model for the solution of electric charging stations in which the number of charging stations is known in advance. They developed a mathematical model as an optimization model which incorporates the location preferences into the objective function.

Bhatti et al. (2015) studied the optimal location decision for alternative fuel stations (AFS) where the demand rate for the refueling service can be learned over time and the learning time is determined as a result of the service provider's deployment action. They developed a two-stage location model. In the first stage, the service provider enters the market by deploying a set of stations where the demand is uncertain and in the second stage the demand is actively learned and the service provider can add more stations or sticks to the first stage's plan. An approximate solution method that aims to achieve a desired error rate of accuracy in the optimal solution was proposed.

D. Chen et al. (2015) aimed to develop an optimal urban refueling station plan through a three-stage method that shortens the detour time of refueling vehicles. The first stage identifies the most frequently traveled road segments for deploying refueling stations by using stochastic user equilibrium. The second stage seeks for additional refueling stations to serve vehicles whose demands are not directly met by the stations identified in the first stage. Third stage adjusts and optimizes the refueling station plan proposed by the first two stages and considers the redistribution of the paths for refueling vehicles due to traffic congestion and refueling station capacities. Genetic algorithm and simulated annealing were combined to solve the problem in the second stage. This algorithm named genetic simulated annealing algorithm and the results were compared to genetic algorithm.

M. Hosseini and Mirhassani (2015) proposed a two-stage stochastic refueling station location model where different scenarios were investigated. In the first stage, permanent stations are constructed with limited information on hand as the service provider does not know the exact values of the traffic flow. However, the permanent stations are not able to cover maximum traffic flow under different scenarios. Therefore, in the second stage the uncertain factors are realized and observed and portable stations are constructed based on the decisions of the first stage. They solved the LP-relaxation of the capacitated model to determine the subset of potential nodes and greedy algorithm was applied to locate the facilities.

Ventura et al. (2015) investigated a refueling station location problem which is a common structure in numerous toll roads worldwide. The problem intends to place a single alternative-fuel refueling station on a tree network so as to maximize the the traffic flow in round trips / day that is covered by the station. Intially, two properties regarding reduction of the problem size and some optimality conditions were derived and then an exact polynomial algorithm was developed.

Giménez-Gaydou et al. (2016) introduced a new approach to decide the optimal locations of battery electric vehicles (BEV) charging stations and solved the problem with exact optimization software. The developed approach aims at obtaining the largest benefits for both users and operators. Additionally, the approach consists of four stages where the first stage is estimating the charging needs of a standard BEV, the second stage is evaluating how these needs can be met through charging stations, third stage is estimating the target market and the final stage is combining the information obtained from previous stages to determine locations.

S.-P. Wang et al. (2016) investigated a multiobjective location problem where a fuel company intends to select one of its traditional gas stations in order to transform into a self-service. They integrated AHP and MCGP to select appropriate gas station from eight alternative locations and considered three criteria and ten sub-criteria. In the study, AHP was used to obtain weights of goals in MCGP which was employed for ranking candidate sites.

Half of the papers that make researches on Refueling base their problems on flow capturing models. It can be said that maximal covering models are also applied every so often to Refueling location problems.

One can conlude that from Table 2.6 “Space” column, Network space is widely considered as these papers constitute 75% of all papers. There are also papers which deal with location problems in discrete space, but none of the researches considers continuos space in this area.

Incorporating multiple objectives in the location problems only arouse interest in a few papers which are Y.-W. Wang and Wang (2010) and S.-P. Wang et al. (2016). For the most part, papers deal with single objective location problems.

Almost all the papers in Refueling, regard the time element as Static, except Bhatti et al. (2015) who introduced a dynamic location model.

It should be noted that 63% of the location problems in this section work on deterministic location problems, while 37% include probabilistic parameters in their models.

All the Refueling location problems assume that there are no other players in the market and facilities operate in a noncompetitive environment.

According to Table 2.6 “Distance” column, it is seen that most of the papers do not specify the distance metric used. Moreover, when we review the papers that provide the distance metric, it is seen that Shortest travel paths are widely applied.

Over 50% of the papers investigate exogenous facilities, whereas 44% of the papers cover endogenous facilities.
Refueling location problems concentrate on finding the location of multiple facilities, however only Ventura et al. (2015) and S.-P. Wang et al. (2016) who study on alternative fuel stations and gasoline stations respectively consider single facility. Furthermore, almost all the papers, except Xi et al. (2013), handle single facility type location problems.

Table 2.6 indicates that uncapacitated location problems are much more popular than the capacitated location problems.

None of the researches in this section employ spatial analysis. By contrast, almost all the papers apply accurate methods generally as the standalone methods. Heuristics are sometimes also used in these papers.

All the papers present a computational experiment to demonstrate their developed models and methodologies. However, approximately 20% of these papers do not use real data. Xpress optimization software is widely applied in Refueling location problems and chased by CPLEX, IBM ILOG and LINGO software.

2.4.5 Retail Trade

T.-H. Wu and Lin (2003) addressed a competitive flow capturing location allocation problem for convenience store location decision. The gravity model was adapted since it has been widely used in continuous competitive location models. They presented an optimal mathematical model, greedy heuristic and a complete enumeration approach that guarantees to find the optimum solution.

Cheng et al. (2005) employed ANP to select the best site for a shopping mall from two alternative sites. They investigated twenty four criteria which were classified into seven categories. They also compared the results of ANP with AHP in order to clarify the difference between these two methods.

Burnaz and Topcu (2006) examined a retail location problem that evaluates possible retail locations for the apparel stores. Twenty three criteria clustered into five groups were considered and ANP was employed to select the suitable retail location type from two alternatives.

Cheng et al. (2007) applied GIS in a shopping mall location selection problem. They combined spatial (geographical) and non-spatial (market-oriented) data to build visualized information and created queries to find optimal solutions for different type of location problems which are minimum distance, maximum demands coverage, maximum incomes coverage, and optimal center.

Koçak (2010) aimed to select the high-potential shopping mall location between eleven alternative districts. Convex programming which is a specific case of nonlinear programming was utilized for the solution of the problem.

Önüt et al. (2010) introduced a shopping center site selection problem which aims to determine the most suitable location. The problem consists of a number of conflicting qualitative and quantitative criteria; therefore they presented an integrated Multiple Criteria Decision Making (MCDM) approach that combines Fuzzy AHP and Fuzzy TOPSIS techniques. Fuzzy AHP was used to assign weights of eight criteria for site selection and Fuzzy TOPSIS was utilized to decide the shopping center location among six location alternatives.

Erbıyık et al. (2012) handled a retail store location selection problem where fifteen criteria within five clusters were analyzed for a milk and dairy products company. They applied AHP to determine the most suitable alternative among three different locations.

Saidani et al. (2012) developed a two-stage method (including location and quality decision) in order to locate a retail facility on the plane and to determine its service quality. The facility is regarded as competitive and the problem considers the reactions of the facilities already in the market. The market share of each facility depends on its distance to customers and its quality was estimated by a probabilistic Huff-like model. In quality decision stage, the competitive decision process was modeled as a game and quality of each facility was obtained by its Nash equilibrium. Polynomial regression method was also proposed to approximate the reaction functions of the competitors. Moreover, in the location decision stage, the location of the new facility was determined based on best qualities of the facilities by using an interval branch and bound algorithm. In order to validate the presented method, results were compared with partial enumeration method which was used to find a high quality near optimal solution.

Tanaka and Furuta (2012) developed a hierarchical flow capturing location problem (HFCLP) and capitalized on Lagrangian heuristic solution method. The classical flow capturing location model was extended by allowing decision maker to select the size of the facilities with different size alternatives. In the proposed model, customers may deviate from their preplanned routes based on the size of the facility and the deviation distance is measured. The model, which finds the number of facilities of each size and their locations, was applied for convenience stores or supermarkets.

Kwak et al. (2013) constructed a decision model for a shopping mall site selection problem. AHP was used for measuring the relative importance of four criteria and ten sub-criteria that determine the location attractiveness. Additionally, Delphi method was applied to assess the qualitative variables subjectively. Four alternative locations were evaluated based on the measurement variables.

Roig-Tierno et al. (2013) integrated GIS and AHP to select locations for new outlets of retail chains. They applied the proposed methodology to location selection of a new supermarket. Geodemand was analyzed for locating the customers where geocompetition analysis was performed for locating the firm’s competititors. Kernel density analysis was also applied to identify the possible commercial retail sites for new stores with the use of geodemand and geocompetition. Finally, they employed AHP to determine the factors that affect the success of a supermarket and to rank the possible sites for selecting the best location.

Müller and Haase (2014) addressed a hypothetical branch extension problem for a furniture store company to maximize company's patronage in which the demand is defined by a multinomial logit model (MNL). They performed customer segmentation based on customers' characteristics in order to reduce the bias to the objective. The problem attempts to find out the optimal locations for a predetermined number of new facilities by using MNL model within a mixed-integer program.

F. Wang et al. (2014) investigated the location pattern of six types of retail stores (i.e. specialty stores, construction material markets, consumer product stores, department stores, supermarkets, furniture stores) with the use of GIS. They employed centrographic method, the nearest neighbor analysis and the proximity to central business district (CBD) to obtain some baseline analyses of their spatial distributions. These analyses were utilized to clarify the issues based on the store types, such as the clustering and dispersion around the city center, the trend of particular direction and the statistical significance of clustering and dispersing. Street centrality indices were specified in terms of a node's closeness, betweenness and straightness on the road network. The Kernel density estimation (KDE) was applied to transform the store locations and centrality values at nodes which are in different scales to the same unit for correlation analysis. Then, the correlation between the distribution of stores and the centrality values were examined. Finally, the correlation analysis between the store types and the centrality values were performed.

Koç and Burhan (2015) studied a store selection problem for a carglass company. They employed AHP due to tangible and intangible criteria. Their problem consists of five category and sixteen criteria and three alternative locations were analyzed to select a new business store location.

Y. Zhang (2015) addressed a location and pricing model for a retailer which sells a homogeneous product in a competitive environment. The model intends to locate a prespecified number of stores while also determining the mill price charged at each open store. A solution approach including two phases (location and pricing) was developed to solve the problem. Three pricing heuristics (gradient descent method, gradient descent method with multiple random starting points, and path-following approach) were utilized to determine the optimal price at each open store. Moreover, three location heuristics (greedy algorithm, tabu search procedure, and genetic algorithm) were used to find the best set of open stores. They suggested to use path-following approach for pricing and a tabu search procedure for location based on the results of computational experiments.

Zhou and Clapp (2015) analyzed the intra-metropolitan location decisions of retail stores by focusing on the openings of anchor stores. Initially, they compared the location pattern of existing and new stores by using nonparametric K-density procedure and concluded that the population-weighted probabilities poorly predict the location pattern of new stores. Afterwards, a conditional logit model (CLM) was applied and it is deduced that the location choices of new anchors can be associated with zoning, population, central business district and highway proximity, potential revenue and revenue growth, cannibalization, competition and localization economies. They tested the CLM whether it effectively explains the location pattern of new stores by using the probabilities from the model to calculate K-density measures of concentration.

Ait Bassou et al. (2016) presented a solution for a facility location allocation problem in a distribution network where they focused on opening a new store. They modeled the problem as two level capacitated location allocation problem since it considers warehouses, stores and demand points. However, the problem focuses on the selection of stores locations and allocation of warehouses and demand points to stores. VNS algorithm was developed to resolve the problem and results compared with exact solution.

R.-C. Chen and Suen (2016) proposed a three-phase decision framework that aims to aid retail industry practitioners to decide which stores to close. In the first phase of the methodology, they used GIS and K-means clustering algorithm to group all stores into clusters based on their geographic distribution. In the second phase, strategically desirable stores were selected, where in the third phase, a neighborhood-based multiobjective genetic algorithm (NBMOGA) was applied to determine which stores to close.

ELSamen and Hiyasat (2017) evaluated the existing major shopping mall locations in western Amman in Jordan and provided appropriate alternatives to serve the city's needs better. They followed the Time-Resistance Approach where GIS tool was used to calculate the travel distance in terms of minutes to reach each shopping mall.

It is seen that flow capturing location models are used in the 38% of the papers on Retail Trade whereas set covering and "Other" category models are both applied with 25%.

Half of the Retail Trade problems prefer network space and the rest of the problems are modeled in discrete space with the exception of (Saidani, Chu, & Chen, 2012) in which continuous space is investigated.

Almost all the location problems are with single objective except the one that is handled in the paper of (R.-C. Chen & Suen, 2016).

None of the papers considers dynamic time element as all the papers deal with static location problems.

Saidani et al. (2012), Müller and Haase (2014) and Y. Zhang (2015) include the probabilistic parameters in their model whilst the rest of the papers examine deterministic location problems.

"Competition" column in Table 2.6 implies that competitive and noncompetitive location problems are of equal importance for the researchers who are interested in Retail Trade problems.

It is noteworthy to mention that Euclidean distance metric is far more preferred than the other distance metrics.

For the most part, exogenous facility location problems are addressed in the papers. Exceptions are Koçak (2010) and Tanaka and Furuta (2012) as they study on endogenous facility locations.

Another conclusion that can be derived is that locations of multiple facilities are common concern for the researchers in Retail Trade. Moreover, almost all the papers have an interest in single facility type location problems except (Tanaka & Furuta, 2012) which considers different facility sizes.

Only Ait Bassou et al. (2016) work on capacitated location problem and all the other papers do not take into account the capacity of the facilities.

MADM techniques and spatial analysis are widely used and mostly as standalone methods in the Retail Trade papers. Moreover, accurate and heuristics methods are almost equally applied for the solution. C++ is widely used in Retail Trade location problems, additionally CPLEX, ArcGIS and Expert Choice are also utilized in these problems.

All the papers conduct a computational experiment and most of them use real data in these experiments.

2.4.6 Other

2.4.6.1 Accommodation

T.-Y. Chou et al. (2008) presented a paper that develops a fuzzy multi-criteria decision making (FMCDM) model by combining the concepts of fuzzy set theory, hierarchical structure analysis, ideal and anti-ideal concepts, and AHP for international tourist hotel location selection. They investigated twenty one criteria and evaluated three different locations to select a new tourist hotel location.

Juan and Lin (2013) examined a resort location selection problem that aims to maximize competitive advantage. Porter's Diamond model (Porter, 1990) and the Delphi method were applied to identify the evaluation criteria for selecting location and twenty two criteria were determined. Additionally, AHP was used to rank four potential resort locations.

K.-L. Chang et al. (2015) presented an integrated framework to select optimal locations for service apartments which provide long-term hotel services for businessmen. The study combines fuzzy Delphi method, ANP, and TOPSIS to construct an effective location selection methodology. The fuzzy Delphi method was applied to revise the previous studies and construct a hierarchy. Three main criteria and twelve sub-criteria were selected and ANP was used to obtain the weights of the criteria, whilst TOPSIS was employed to rank three locations.

Y. Yang et al. (2015) designed an automated web GIS application to evaluate the potential sites based on the proposed hotel characteristics (business success indicators) by calculating and visualizing the predicted business performance of each potential site. The scores from DEA are also considered as one of these characteristics. The application utilizes a set of machine learning algorithms (such as projection pursuit regression, artificial neural network, support vector regression, and boosted regression) to predict several business success indicators related to location sites. It is asserted that various data-related problems (e.g. models, such as the nonlinearity of relationships, the presence of noise, and the absence of necessary information) in the simple linear regression models are overcome by using machine learning models.

2.4.6.2 Arts, Entertainment, and Recreation

Modrego et al. (2000) conducted a study to plan the location of a new theme park in the Valencian community. They utilized a wide variety of criteria provided from the GIS. They employed a procedural approach that contains three successive phase in order to evaluate the characteristics of alternative locations. In each phase, a set of quantifiable criteria were identified which correspond to the objectives determined in respect of the typology of the theme park required and the potential sites were narrowed down based on the criteria. Then, the preselected locations were evaluated according to the criteria through an assessment scale which includes three levels. Delphi method was utilized to select the best site for locating the park in the assessment phase.

Neema and Ohgai (2010) formulated a multiobjective facility location model to obtain the optimum locations urban parks and open spaces (POSs) by considering four objectives. Facilities were allowed to be located anywhere in the given space. The GA-based multiobjective optimization model (GAMOOM) was employed to achieve nondominated Pareto optimal solutions and provide a set of alternative solutions to decision makers.

J. Yu et al. (2014) introduced a spatial location allocation method for urban parks based on PSO and GIS. Three factors: population density, accessibility and competitiveness, were taken into account to decide the location of a specified number of parks.

2.4.6.3 Other Types of Services

Jayaraman et al. (2003) investigated a hierarchical model for the location of service facilities where demand cannot be queued and a backup unit is required. They developed an integer linear programming model for establishing facilities that provide several layers of service. Lagrangian relaxation methodology combined with a heuristic, which was developed as an integral part of the subgradient optimization, applied to the problem in the context of postal services. Lagrangian solution was used as a starting point in producing feasible solutions for the original problem. Additionally, the gap between lagrangian solution and the heuristic solution was regarded as the indicator of the heuristic procedure's quality.

Narasimhan et al. (2005) dealt with a service location design for branch offices of a government agency provide a variety of services including automobile registrations, issuance of driver licenses, recreational vehicle registration, and personal identification registry. They focused on the performance-based configuration and resource allocation issues in the location design and discussed the affect of branch closure on channel management decisions. The introduced approach consists of DEA and mixed integer programming (MIP) model. DEA was used to calculate the efficiency of the branch offices, whilst MIP was applied to identify the offices needed to be kept open and allocations of their capacities.

W.-S. Lee (2014) used a new hybrid MCDM model for the selection of a site for real estate brokerage services. They applied to the Decision Making Trial and Evaluation Laboratory (DEMATEL) and DEMATEL-based ANP to analyze the location selection factors and sub-factors and to compute their relative weights where there are four location selection factors and eleven sub-factors. Then, the VIKOR method was utilized for determining the best location among three alternatives.

Jelokhani-Niaraki and Malczewski (2015) intended to select a parking site(s) among twenty alternatives by considering eight criteria and utilizing a web-based group GIS-MCDA (Multi-criteria Decision Analysis) procedure and tool. GIS and MCDA were integrated into a web platform to provide an effective Multi-criteria Spatial Decision Support System (MC-SDSS) which involves decision group in the site selection process. The purpose of building this decision support system is reconciling conflicting objectives and enabling the majority acceptance for the final decision. A two-stage decision rule procedure was applied that uses OWA-based method for modeling individual decision making based on individual preferences and the Borda voting method (collective decision rule) for combining individual preferences to produce a group solution.

There are only four papers that employ optimization methods as a solution approach in the category of Other Sectors. Models that are in “Other” category and maximal covering models are widely used in Other application fields. P-median and hierarchical models are also applied in these problems.

Continuous location problems are addressed in two of the papers while others consider discrete and network location problems.

Neema and Ohgai (2010) is the only paper that deals with multiple objectives and the rest of the papers ignore the multiobjectivity.

According to Table 2.6 “Time Element” and “Parameters” column, all the papers in this category handle static location problems and only one of them embraces the probabilistic parameters.

All the Other category location problems assume that the market environment is non-competitive.

Euclidean distance and Shortest travel paths are specified in more than half of the researches in this area and none of the papers applies Manhattan distance.

Moreover, almost all the papers show interest in endogenous facilities, except (J. Yu et al., 2014) which regards the number of facilities as an input to the model.

From Table 2.6 and Table 2.7 “Number of Facilities” column, it is seen that single facility and multiple facility location problems are equally preferred. Additionally, different facility type is only incorporated in one of these problems which is studied in Jayaraman et al. (2003). Nevertheless, the attention to capacitated and uncapacitated location problems is evenly balanced.

MADM techniques and spatial analysis are mostly employed in the Other category location problems and these methods are occasionally applied with the integration of other methods.

Computational experiments are performed and real data is used in all of the papers without exception.

Almost none of the software or programming language differentiates from each other with the usage frequency. ArcGIS, Expert Choice, IBM ILOG, Pascal, C-Sharp (C#) and C++ are applied in the papers.

2.5 Discussion

Almost all the papers study service facility location problems for the purpose of location selection. However, location problems that do not include mathematical optimization model have the intention of location analysis which are carried out on Food Services and Retail Trade.

When we look at the papers that are published on service facility location problems, it is concluded that flow capturing model is the most widely used location model in Refueling and Retail Trade problems. By contrast, maximal covering location model is generally preferred in all other application fields.

Papers in Refueling, Health Care & Social Assistance and Retail Trade application fields mainly adapt network decision space to the location problems. On the other hand, discrete space is the mostly considered in Banking and Food Services location problems, whilst continuous space is mainly investigated in the category of Other application fields.

Almost in all application fields, single objective location problems are studied without taking into account multiobjectivity. The exception is Food Services, in which location problems with multiple objectives are examined. When the objectives of the problems which are given in detail in Table 2.6 are analyzed, it is seen that maximizing demand coverage / customers served, minimizing customers' travel distance / cost and waiting time / cost, minimizing number of facilities, minimizing cost of locating facilities and maximizing profit are the most widely considered objectives.

Static location problems are focused on extensively in all application fields. However, there are only a few papers that develop dynamic location problems.

Deterministic and probabilistic location problems are evenly interested in Banking location problems whereas deterministic parameters are mostly taken into account in all other application fields.

For the most part, researches on service facility assume that the market is non-competitive. Retail Trade is the only application field that shows interest both in competitive and noncompetitive location problems in the same degree.

It should be noted that Shortest travel paths distance metric is widely used only in Refueling. On the contrary, Euclidean is generally utilized in all other application fields.

In Food Service, Refueling and Retail Trade location problems, the number of facilities to be located is preset, and consequently exogenous facilities are considered in these application fields. However, the aims of the problems, which arise in other application fields, are finding the number of facilities as well as deciding the locations.

One can conclude that service facility location problems generally investigate multiple service facilities in Banking, Health Care & Social Assistance and Refueling. Nevertheless, the concentration moves to single facility location problems from multiple facilities in Food Services, Retail Trade and Other application fields.

Single facility type is taken into account in almost all of the service facility location problems without excluding any application field while only several papers investigate different facility type location problems.

Health Care & Social Assistance is differentiated from other application fields as they mostly focus on capacitated location problems. However, almost all other application fields do not pay too much attention on the limited capacity of the facilities. Other category, which considers both problems, can be regarded as exception.

Since we concentrated on service facility location problems relating to applications of these problems, there are only a few papers which do not include a computational experiment and these papers are conducted in the Banking application field.

Generally, all of these papers use real data in their computational experiment without discrimination of any application field.

MADM techniques and spatial analysis are the mostly applied methods in Retail Trade and Other application fields. On the other hand, it can be said that papers on Refueling apparently avoid using spatial analysis methods. Moreover, heuristic and metaheuristic methods are preferred in Banking, Refueling and Health Care & Social Assistance location problems while accurate methods are applied to almost all problems.

CPLEX, C++, ArcGIS, Matlab, LINGO and Expert Choice are widely used software and programming languages in service facility location problems. Furthermore, researches on Refueling clearly choose Xpress, whereas CPLEX is obviously preferred as optimization software in Health Care & Social Assistance problems. Additionally, C++ is the most widely used programming language in Retail Trade and ArcGIS is used in the problems that utilize spatial analysis as a solution method.

Literature of service facility location problems is reviewed that has been published since 2000. Papers that embody application of proposed solution methods are concentrated in the review. Thirteen key features which form the main characteristics of location models and seven descriptive dimensions that are related to application phase of the problems are defined as a classification framework. Furthermore, reviewed papers are categorized according to the application field of the problems and investigated based on each characteristic where a comparative analysis is provided. The results of the survey revealed that, problems belong to the same application field have several common characteristics. On the other hand, there is also valuable information and insights in location problems which arise in different fields. Therefore, we focus on the service facility location problems in the survey in order to provide useful insights into service facility location science for finding desirable or optimal locations.

After analyzing the literature on service facility location problems, it is concluded that most of the researches in the literature do not consider multi-criteria nature of the problems. Moreover, there are only a few studies that apply accurate methods within multiobjectivity and multi-attribute decision making analysis together. On the other hand, none of these researches are conducted for ATM deployment problem. Since there *are various attributes and multiple objectives that should be included in ATM location decision, in 3rd Chapter, we delved more deeply into multiple criteria decision making and its main methods in two categories which are multi-attribute decision making and multiobjective decision making.*

The organization of Chapter 3 has the following outline: In section 1, we first introduce the multi-criteria decision making (MCDM) approach. Then, multi-attribute decision making and its most applicable methods are presented in the 2nd section as a branch of MCDM. Lastly, another branch of MCDM namely, multiobjective decision making approach is provided with its main terminology used and primary solution methods in section 3.

3. MULTIPLE CRITERIA DECISION MAKING APPROACH

Multiple criteria (Multi-criteria) decision making (MCDM) is a well developed branch of Operations Research that is designed to aid the decision maker (DM) with finding compromise solutions in the presence of multiple and conflicting criteria (Lootsma, 1999). Multi-criteria decision analysis (MCDA) is another term that is also used as a replacement for MCDM. "Decision analysis" is used instead of "decision making" to emphasize that the methods should help DMs in taking better decisions (Løken, 2007).

Using MCDM methods is a way of dealing with complex problems by breaking them into smaller pieces, after making judgments about smaller pieces, and then these pieces are put together to show the overall picture to DM. Furthermore, MCDA methods help DMs to organize and synthesize the information collected, eventually make them confident about their decisions (Løken, 2007).

MCDM methods are utilized to decide a preferred alternative, to classify the alternatives in a number of categories, and / or to rank the alternatives in a preference order. They are sometimes also used to allocate scarce resources to the alternatives on the basis of the results of the analysis (Lootsma, 1999).

There are numerous MCDM methods that have been utilized to support decision making process. Each of these methods has its advantages and drawbacks. Moreover, these methods differ from each other in theoretical background; type of questions asked and type of results generated (Løken, 2007). On the other hand, According to Belton and Stewart (2002) MCDM methods have common inherent properties that make them attractive and practically useful (Mendoza & Martins, 2006):

- Considering multiple and conflicting criteria,
- Helping to structure the management problem,

- Providing a model to discuss problem in detail,
- Leading rational and justifiable decision.

Pohekar and Ramachandran (2004) mention that incomparable units and difficulty in selection of alternatives are other characteristics of these methods.

However, it is not possible to conclude that one method is generally superior to another and selecting the most suitable MCDM method can be considered as a multi-criteria decision on its own (Al-Shemmeri et al., 1997). Thus, most analysts deal with similar problems in the literature in order to decide the correct method. Another approach is applying more than one method and comparing their results (Salminen et al., 1998) before choosing the most appropriate one. Employing combined methods is also a good choice to make use of the strengths of those methods and to get broader decision for the DM (Gilliams et al., 2005; Løken, 2007). Additionally, there are studies, such as Al-Shemmeri et al. (1997) and Kornyshova and Salinesi (2007), which propose some methods for selecting the right MCDM techniques.

There are two types of criteria: attributes and objectives and therefore two distinct branches of MCDM appears in the literature: multi-attribute decision making (MADM) and multiobjective decision making (MODM) (Antunes et al., 2016).

The primary difference between these two branches is that former focuses on discrete decision spaces and applied in evaluation aspect, whilst the second concentrates on problems with continuous decision spaces and concerned with design / planning aspect (Pedrycz et al., 2011; G.-H. Tzeng & Huang, 2011). Moreover, MADM generally refers to the selection, ranking and categorization methods that deal with finite set of alternatives and MODM is applied to the problems in which large number of alternatives are implicitly defined by set of constraints (Antunes et al, 2016).

A more detailed comparison between these MADM and MODM approaches was drawn by (Malczewski, 1999) based on the differences addressed by (Hwang & Yoon, 1981) and (Zeleny, 1982) (Mendoza & Martins, 2006) in Table 3.1.

Table 3.1: Comparison of MADM and MODM approaches (Malczewski, 1999)

Criteria for Comparison	**MADM**	**MODM**
Criteria defined by	Attributes	Objectives
Objectives defined	Implicitly	Explicitly
Attributes defined	Explicitly	Implicitly
Constraints defined	Implicitly	Explicitly
Alternatives defines	Explicitly	Implicitly
Number of alternatives	Finite (small)	Infinite (large)
Decision maker's control	Limited	Significant
Decision modelling paradigm	Outcome-oriented	Process-oriented
Relevant to	Evaluation / choice	Design / search

Since ATM location problem requires considering multiple criteria, we delve into multi-criteria decision making methods in this Chapter. A clear distinction is tried to be drawn between MADM and MODM methods as the methods differentiate from each other due to their intention and problem solving approach. Morever, our problem is investigated in two main stages where each stage handle its subproblem (i.e. criteria priroritization and most promising locations considering limited resources) by utilizing MADM and MODM methods respectively.

3.1 Multi-attribute Decision Making

Multi-attribute decision making (MADM) is related to making preference decision, which is comparison, choice, prioritization, and / or ordering, over the available alternatives that are associated with a level of achieving a set of attributes. The final decision is made based on these attributes which are usually conflicting (Kahraman & Çebi, 2009; Ekel et al., 2016).

3.1.1 Multi-attribute Decision Making Methods

MADM methods can be split into three categories based on the approach followed in the solution process (Ishizaka & Nemery, 2013; Mendoza & Martins, 2006) and here we present the most applicable methods of MADM:

a) *Full aggregation approach (or American school)*: These methods are also called value measurement methods. One advantage of defining utility functions is that options of the decision problem have a global score that represents the degree of preference for the option. A score is assigned to each criterion and these scores are synthesized into a global score for each option. Based on this global score, all options can be compared and ranked from best to worst where equal rankings are allowed. This is regarded as complete ranking and in this approach; a bad score on one criterion can be compensated by a good score on another criterion.

b) *Outranking approach (or French school)*: These methods compare options two-by-two with regard to preference or outranking degree. The preference or outranking degree shows how much better one option is than another. Some options may be incomparable since some of these options may be better based on one set of criteria and the others may be better based on another set of criteria. Hence a complete ranking is not always possible and this can be considered as partial ranking.

c) *Goal, aspiration or reference level models*: Desirable or satisfactory levels of achievement are defined for each criterion. Then, the closest options to achieve these desirable goals or aspiration levels are identified.

3.1.1.1 Full Aggregation Approach

3.1.1.1.1 Analytic Hierarchy Process (AHP)

AHP is a method that was developed by T. L. Saaty (1980) to reflect the way people actually think. It embodies decomposing the decision problem into its objectives, criteria and alternatives which are organized in the form of a hierarchy. AHP hierarchy can have many levels as required to structure a particular decision making problem. Moreover, AHP employs a unidirectional hierarchical relationship among different decision levels and only considers the dependence of lower-level elements on higher-level elements. Subjective judgments and multiple decision makers can also be included in the solution process where tangible as well as non-tangible attributes can be dealt with successfully. Solution process initially, evaluates the relative importance of criteria and performance of alternatives based on the criteria, then calculates overall ranking of the alternatives based on the criteria (Karsak et al., 2002; Vyas & Misal, 2013; Samant et al., 2015).

3.1.1.1.2 Analytic Network Process (ANP)

ANP was proposed by Saaty (1996) for extending the AHP by removing the restriction of the hierarchical structure (G.-H. Tzeng & Huang, 2011). Decomposition principle in which the decision problem is broken down in the hierarchical form is replaced by the network form. Therefore, a hierarchy is not necessary in the ANP model, where clusters take place of levels and may contain several elements. ANP is used for more complex decision problems as many problems cannot be structured hierarchically since the interaction and dependence can arise between any of the elements in the decision problem (i.e. alternatives, criteria, sub-criteria, and the objective) not just between the different levels of the hierarchy (Ishizaka & Nemery, 2013; May et al., 2013). In other words, unlike the AHP, ANP does not rest on an assumption that there is an independence of higher level elements from lower level elements and also the elements within the same level (T. L. Saaty, 1999).

3.1.1.1.3 Multi-attribute Value Theory (MAVT)

MAVT is an additive value function where DM defines weights and specifies value functions for the criteria. The weights should reflect how much the DM is willing to accept the tradeoff between two criteria. In MAVT, first partial value functions that indicate each alternative's performance on each criterion are calculated and total score for each alternative are computed. It is important that the partial value functions are normalized to some convenient scale (e.g. 0-100). Utility is the indicator of desirability or satisfaction and provides a uniform scale to compare and / or combine quantitative and qualitative factors. Then, the alternative with the highest value score is preferred (Løken, 2007; Sanayei et al., 2008).

3.1.1.1.4 Multi-attribute Utility Theory (MAUT)

MAUT, which can be regarded as an extension of MAVT, is first proposed by (Keeney & Raiffa, 1976). MAUT is a more exact method than MAVT since it incorporates risk preferences and uncertainty into the solution process. Multi-attribute utility functions in which the risk preferences are directly reflected in the values should be defined instead of value functions (Løken, 2007). Complete compensation is permitted among all the attributes in MAUT, thus it is defined as a complete compensatory model (Ananda & Herath, 2005).

3.1.1.2 Outranking Approach

3.1.1.2.1 PROMETHEE (Preference Ranking Organization METHods for Enrichment Evaluations)

PROMETHEE family performs a pairwise comparison of alternatives in order to evaluate and rank them based on preference degrees with respect to a number of criteria. It can simultaneously handle qualitative and quantitative criteria (Pohekar & Ramachandran, 2004; Vyas & Misal, 2013). These methods require information on the weight of each criterion and decision maker's preference function to compare the contribution of alternatives in terms of each criterion (Samant, Deshpande, & Jadhao, 2015). More clearly, preference function is used to define the preference degree ranging from 0 to 1 by calculating the difference between the evaluations (i.e. scores) of two alternatives in terms of particular criterion (Behzadian et al., 2010).

PROMETHEE I and PROMETHEE II was developed by Brans (1982) and further extended by Brans and Vincke (1985) in 1985 (Macharis et al., 2004). PROMETHEE I provides partial ranking of alternatives which means this ranking may be incomplete in some cases since some alternatives cannot be compared. Furthermore, PROMETHEE II provides a complete ranking of the alternatives from the best one to the worst one (Macharis et al., 2004). Additionally, there is PROMETHEE III which is used for ranking based on interval and PROMETHEE IV which was introduced for complete or partial ranking of the alternatives when the set of feasible solutions is continuous (Behzadian et al., 2010; G.-H. Tzeng & Huang, 2011).

3.1.1.2.2 ELECTRE (The ELimination Et Choix Traduisant la REalit´e)

The first ELECTRE (Elimination and Choice Expressing Reality) method was developed by Benayoun et al. (1966). Several other ELECTRE methods such as ELECTRE II (Roy, 1971), ELECTRE III (Roy, 1978), ELECTRE Iv (Roy & Hugonnard, 1982), ELECTRE IV (Roy & Bouyssou, 1983), ELECTRE TRI (W. Yu, 1992; Roy & Bouyssou, 1993) and ELECTRE Is (Roy & Bouyssou, 1993) were established during the following two decades (Govindan & Jepsen, 2016).

ELECTRE methods deal with both quantitative and qualitative criteria. The main idea of these methods is eliminating less favorable alternatives, hence they are suitable when working on a decision making problem with a few criteria and large number of alternatives. These methods choose alternatives which are preferred over most of the criteria and do not result in an unacceptable level of contentment for any of the criterion. Concordance, discordance indices and threshold values are used in these methods. Graphs for strong and weak relationships are built up and these graphs are used to rank the alternatives. ELECTRE methods are sometimes unable to identify preferred alternatives as the methods are not complete (Pohekar & Ramachandran, 2004; Velasquez & Hester, 2013).

One of the advantages of ELECTRE is that they consider uncertainty and vagueness. Another advantage is that these methods avoid compensation between criteria and any normalization process that distorts the original data (Ishizaka & Nemery, 2013).

ELECTRE Iv and ELECTRE Is are used to solve choice problems which aim to find the smallest subset of alternatives including the best options. The only difference of ELECTRE Iv from ELECTRE I is the introduction of the veto concept. Veto concept is considering an alternative as outranked as it performs badly on one criterion compared to another alternative, regardless of its performance on the other criteria. The originality of ELECTRE Is, which also deals with choice problems, is the use of pseudo-criteria. Pseudo-criteria enable that the DM may not have a preference between two alternatives for a criterion when the difference in these alternatives' performance is smaller than the indifference threshold. This method also allows that the preference might be strong if the difference in their performance is higher than the preference threshold. ELECTRE II, ELECTRE III and ELECTRE IV are ranking methods which may cause partial order on set of alternatives. ELECTRE III differs from ELECTRE II by the use of pseudo-criteria and outranking degrees (instead of binary outranking relations). On the other hand, ELECTRE IV does not need the relative importance (i.e. the weights) of the criteria. ELECTRE-Tri is a sorting (classification) method that provides the independent assignment of a set of alternatives to one or several predefined categories. However, owing to preference relation amongst the categories, they can be ranked from best to worst (Ishizaka & Nemery, 2013).

3.1.1.3 Goal, Aspiration or Reference Level Models

3.1.1.3.1 TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution)

TOPSIS assumes that each criterion has a tendency of monotonically increasing or decreasing utility that enables to determine positive and negative ideal solutions. The main idea of this method is to evaluate the relative Euclidean distance of the alternatives from the ideal and negative-ideal solution. Initially, the various criteria dimensions are converted into non-dimensional criteria similar to ELECTRE method. Then, positive and negative ideal solutions are defined. Finally, a series of comparison of relative distances provides the preference order of alternatives where the shortest distance to positive ideal solution and farthest distance to negative ideal solution is preferred (Opricovic & Tzeng, 2004; Aruldoss et al., 2013).

3.1.1.3.2 VIKOR (The VlseKriterijumska Optimizacija I Kompromisno Resenje)

VIKOR was developed by Opricovic in 1979 for multi-criteria optimization of complex systems. This method focuses on ranking and selecting from a set of alternatives when there is conflicting criteria and it is used when DM needs a solution nearest to ideal. Each alternative is evaluated based on each criterion function and the compromise ranking is performed by comparing the measure of closeness to the ideal alternative. The measure for compromise ranking is established according to L_p metric used as an aggregating function in compromise programming method (P.-L. Yu, 1973; Zeleny, 1982) (Opricovic & Tzeng, 2004; Opricovic et al., 2015).

3.1.1.3.3 Data Envelopment Analysis (DEA)

DEA was designed by Charnes et al. (1978, 1981) and it is a non-parametric approach for measuring relative efficiency that produces a single aggregate measure of relative efficiency among comparable units (called DMUs). DEA defines relative efficiency by means of a function which is the ratio of the sum of weighted outputs to the sum of weighted inputs. In DEA, the inputs and outputs can remain in their natural physical units without normalizing them, in other words transforming them into some common metric. Inputs can be considered as criteria to be minimized and outputs can be considered as criteria to be maximized for the analogy with other MCDM methods. However, the weights of the criteria are produced by a linear optimization procedure and they are not determined by DM in DEA (Klimberg & Ratick, 2008; Ishizaka & Nemery, 2013).

3.2 Multiobjective Decision Making

Mathematical programming which is also called (mathematical) optimization, aims to minimize or maximize a function that chooses the values of variables from an allowed (feasible) set and it consists of three set of elements: decision variables, objective functions and constraints (G. Zhang, Lu, & Gao, 2015).

Mathematical programming with single objective tries to achieve one objective, such as maximizing total profit or minimizing total cost. More precisely, its aim is to find the decision that gives the best possible value for the objective from amongst the set of possible decisions. However, usually this one objective approach does not work in real life because there are multiple objectives in a problem that the DM wants to achieve (Hillier & Lieberman, 2001; Jones & Tamiz, 2010).

Making decisions when there are multiple objectives is called multiobjective decision making. MODM, which is also named as Multiobjective programming (MOP) or multiobjective optimization (MOO), is utilized for dealing with optimization problems where several conflicting and non-commensurable objectives are needed to be considered (G.-H. Tzeng & Huang, 2011). In MOP, the concept of optimal solution becomes meaningless since, generally, a feasible solution that simultaneously optimizes all the objectives does not exist (Antunes et al, 2016). Therefore, MOP adopts a concept from the work of Italian economist Vilfredo Pareto into the field of decision making. This concept, in which DM deals with a large or infinite number of efficient solutions, is called Pareto optimality (Jones & Tamiz, 2010). On the other hand, DM has the chance to make tradeoffs as the improvement of one objective results in loss in another objective.

3.2.1 Main Terminology and Notations Used

In order to understand the basic concepts of multiobjective optimization, we present the main terminology and notations that are based to a large extent on definitions of Miettinen (2008).

Generally, single objective optimization problem can be formulated as follows (Caramia & Dell'Olmo, 2008):

$$\begin{aligned} &minimize \quad f(x) \\ &subject\ to \quad x \in S, \end{aligned} \tag{3.1}$$

where f is a scalar function and S is the (implicit) set of constraints that can be described as:

$$S = \{x \in R^n : h(x) = 0, g(x) \geq 0\} \tag{3.2}$$

Multiobjective optimization problem can be formulated as follows (Miettinen, 2008):

$$\begin{gathered} minimize\ [f_1(x), f_2(x), \dots, f_k(x)] \\ subject\ to\ \ x \in S, \end{gathered} \tag{3.3}$$

where S is a set of constraints defined as above and k (≥ 2) objective functions $f_i: R^n \rightarrow R$ that we want to minimize simultaneously. The decision (variable) vectors $x = (x_1, x_2, \dots, x_n)^T$ belong to feasible region $S \subset R^n$. Objective vectors are the images of decision vectors and consist of objective (function) values $z = f(x) = \left(f_1(x), f_2(x), \dots, f_k(x)\right)^T$. Moreover, the image of the feasible region in the objective space is called a feasible objective region $Z = f(S)$.

In multiobjective optimization, objective vectors are considered to be optimal if none of them can be improved without deterioration in at least one of the other components. In other words, a decision vector $x' \in S$ is called *Pareto optimal* if there does not exist another $x \in S$ such that $f_i(x) \leq f_i(x')$ for all $i = 1, \dots, k$ and $f_j(x) < f_j(x')$ for at least one index j. The set of Pareto optimal decision vectors can be denoted by $P(S)$. Accordingly, an objective vector is Pareto optimal if the corresponding decision vector is Pareto optimal and the set of Pareto optimal objective vectors can be denoted by $P(Z)$.

The ranges of the Pareto optimal solutions provide valuable information about the problem considered. Lower bounds of the Pareto optimal set can be attained by the *ideal* *objective vector* $z^* \in R^k$. Its components z_i^* are obtained by minimizing each objective functions individually subject to feasible region. A vector strictly better than z^* is called *utopian objective vector* z^{**}. In practice, we set $z_i^{**} = z_i^* - \varepsilon$ for $i = 1, \ldots, k$ where ε is some small positive scalar.

The upper bounds of Pareto optimal set which are the components of *nadir objective vector* z^{nad}, are usually difficult to determine. However, payoff table can be used to approximate the components of nadir objective vector.

Since the objective vectors cannot be ordered completely, all the Pareto optimal solutions can be regarded equally desirable in the mathematical sense.

The set of Pareto optimal solutions is a subset of the set of weakly Pareto optimal solutions. A decision vector is $x' \in S$ is *weakly Pareto optimal* if there does not exist another $x \in S$ such that $f_i(x) < f_i(x')$ for all $i = 1, \ldots, k$. As mentioned before, two sets corresponding to decision and objective vectors can be denoted by $WP(S)$ and $WP(Z)$, respectively.

Kuhn and Tucker (1951) introduced *properly Pareto optimal* solutions and suggested that Pareto optimal solutions be divided into properly and improperly Pareto optimal ones (Miettinen, 1998). The properly Pareto optimal set is a subset of the Pareto optimal set which is a subset of weakly Pareto optimal set. According to the Geoffrion (1968): a decision vector is $x' \in S$ is *properly Pareto optimal* if there is some real number M such that for each f_i and each $x \in S$ satisfying $f_i(x) < f_i(x')$, there exist at least one f_j such that $f_j(x') < f_j(x)$ and

$$\frac{f_i(x') - f_i(x)}{f_j(x) - f_j(x')} \leq M \tag{3.4}$$

An objective vector is *properly Pareto optimal* if the corresponding decision vector is properly Pareto optimal. From the definition it is seen that a solution is *properly Pareto* *optimal* if there is at least one pair of objectives in which a finite decrease in one objective is possible only at the expense of some reasonable increase in the other objective.

Pareto optimality, weakly Pareto optimality and proper Pareto optimality concepts and their relationships are depicted in Figure 3.1. In the figure, the set of weakly Pareto optimal solutions is showed by a bold line. The endpoints of the Pareto optimal set are marked with circles and the endpoints of the properly Pareto optimal set are denoted by short lines (note that these sets can be disconnected).

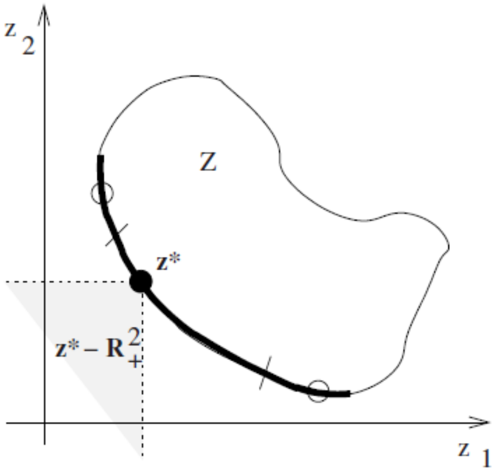

Figure 3.1: Sets of properly, weakly and Pareto optimal solutions (Miettinen, 2008)

There is a wide variety of methods that are used for multiobjective optimization. It is not possible to say that one of them is generally superior to all others. When choosing a solution method, the specific features of the considered problem must be taken into account. Additionally, the opinions of the decision maker are also important and the analyst should not simply prefer some method (Miettinen, 2008).

3.2.2 Multiobjective Decision Making Methods

MODM solution methods can be classified according to the participation of the decision maker in the solution process (Rangaiah, 2009) and here we present the primary methods of MODM:

1) *No-preference methods*: These methods do not require any information from the decision maker as they only produce one Pareto optimal solution.

2) *Posteriori methods*: These methods produce many pareto optimal solutions and the decision maker evaluates these solutions to select one of them.

3) *Priori methods*: Preference information of the decision maker is included in the formulation of the problem.

4) *Interactive methods*: Interaction with the decision maker is required during the solution process. After an iteration of these methods DM reviews Pareto optimal solution(s) obtained and articulates the desired change in each objective function. Then, these preferences of DM are included in the next iteration. At the end of the iterations, one or several Pareto optimal solutions are produced.

3.2.2.1 No-preference Methods

3.2.2.1.1 Method of Global Criterion

In the method of global criterion, the distance between some desirable reference point in the objective space and feasible objective region is minimized. Ideal or utopian objective vector is considered to be the reference point. *Lp*-metric can be used to measure the distance as it is seen in Equation 3.5 (Miettinen, 2008).

$$\text{minimize } \left(\sum_{i=1}^{k} |f_i(x) - z_i^*|^p\right)^{1/p} \quad \text{subject to } x \in S \tag{3.5}$$

Moreover, Zeleny (1973) noted that the set of solutions is substantially small part of the Pareto optimal set (Miettinen, 1998).

3.2.2.1.2 Neutral Compromise Solution

Neutral compromise solution method, which is another way of generating solution without the involvement of the DM, is suggested in Wierzbicki (1999). The main idea of this method is to project a point that is located 'somewhere in the middle' of the ranges of objective values in the Pareto optimal set to become feasible. Components of such point can be obtained as the average of ideal (or utopian) and nadir values of each objective function. We can get a neutral compromise solution by solving the problem with Equation 3.6 where the solution is weakly Pareto optimal (Miettinen, 2008):

$$\text{minimize } max_{i=1,\dots,k}\left[\frac{f_i(x)-\left(\left(z_i^{*}+z_i^{nad}\right)/2\right)}{z_i^{nad}-z_i^{**}}\right] \quad (3.6)$$

$$\text{subject to } x \in S.$$

The ideal values in the numerator can be taken as utopian values of the each objective function.

3.2.2.2 Posteriori Methods

3.2.2.2.1 Weighted Sum

This method, which is presented in (Gass & Saaty, 1955; L. Zadeh, 1963), also called weighting or scalarization method. Each objective function is associated with a weighting coefficient. However, the weighting coefficients do not always correspond directly to the relative importance of the objective functions. The method transforms multiple objective functions into a single objective function by minimizing the weighted sum of the objectives. The weighting coefficients w_i are real numbers such that $w_i \geq 0$ for all $i = 1, \dots, k$ and $\sum_{i=1}^{k} w_i = 1$. The problem is solved as follows (Miettinen, 2008):

$$\text{minimize} \sum_{i=1}^{k} w_i f_i\,(x) \qquad \text{subject to } x \in S. \tag{3.7}$$

where $w_i \geq 0$ for all $i = 1, \dots, k$ and $\sum_{i=1}^{k} w_i = 1$.

The solution of weighted sum method is weakly Pareto optimal. Moreover, the solution is Pareto optimal if the weighting coefficients are positive, that is $w_i > 0$ for all $i = 1, \dots, k$ (Miettinen, 1998).

3.2.2.2.2 ε-Constraint Method

Haimes et al. (1971) introduced ε-constraint method in which one of the objectives is selected to be optimized and all other objective functions are converted into constraints by setting an upper bound to each of them. The problem becomes solving Equation 3.8 (Miettinen, 1998):

$$\begin{aligned} &\text{minimize } f_l(x) \\ &\text{subject to } f_j(x) \leq \varepsilon_j \text{ for all } j = 1, \dots, k,\ j \neq l, \\ &x \in S. \end{aligned} \tag{3.8}$$

where $l \in \{1, \dots, k\}$. The solution of ε-constraint method is weakly Pareto optimal. Nonetheless, the method especially regarded as inefficient if the considered problem has more than two objectives (Caramia & Dell’Olmo, 2008).

3.2.2.2.3 Method of Weighted Metrics

The method of weighted metrics is a generalization of global criterion method where the distance between some reference point and the feasible objective region is minimized. The difference with global criterion is that metrics are weighted in this method which is also sometimes called compromise programming (Zeleny, 1973). Additionally, the solution obtained is based greatly on the distance metric used. For $1 \leq p \leq \infty$, we have a problem (Miettinen, 2008):

$$\text{minimize } \left(\sum_{i=1}^{k} w_i |f_i(x) - z_i^*|^p\right)^{1/p} \tag{3.9}$$

Alternatively, a weighted Chebyshev problem can be used by dropping the exponent $1/p$.

$$\begin{gathered} \text{minimize } max_{i=1,\dots,k}[|w_i(f_i(x) - z_i^*)|] \\ \text{subject to } x \in S. \end{gathered} \tag{3.10}$$

Absolute values are ignored as it is assumed that global ideal (or utopian) objective vector is known. The solution of Equation 3.9 is Pareto optimal if either the solution is unique or all the weights are positive. On the other hand, every Pareto optimal solution can be obtained by altering the weights in Equation 3.9 if the problem is convex. Moreover, the solution of Equation 3.10 is weakly Pareto optimal for positive weights and it has at least one Pareto optimal solution (Miettinen, 2008).

3.2.2.3 Priori Methods

3.2.2.3.1 Value Function Method

In the value function method, it is assumed that decision makers reach their decisions on the basis of an underlying mathematical function ($U: R^k \rightarrow R$) which is called value function and represents her / his preferences globally (Keeney & Raiffa, 1976):

$$\begin{aligned} &\text{maximize } U\big(f(x)\big) \\ &\text{subject to } x \in S. \end{aligned} \tag{3.11}$$

Sometimes, utility function term is also used instead of value function. Value function method provides a total (complete) ordering of the objective vectors and therefore the method produces the best Pareto optimal solution. The method seems very simple as it maximizes a single objective. However, it is very difficult for a decision maker, if not impossible, to specify mathematically the function behind her / his decision. Furthermore, DM cannot be sure about the validity of the function, hence wants to investigate different alternative solutions before selecting final solution (Miettinen, 1998).

3.2.2.3.2 Lexicographic Ordering

In lexicographic ordering (Fishburn, 1974), DM must arrange the objective functions according to their absolute importance where a more important objective is infinitely more important than a less important objective. After the ordering, the most important objective is minimized subject to original constraints. If this problem has a unique solution, then the solution process ends and the found solution is regarded as the final solution. Otherwise, the second most important objective is minimized and a new constraint is included in the problem to guarantee that the most important objective function preserves its optimal value. If this problem has a unique solution, then the solution process ends. Otherwise, the process goes on as aforementioned (Miettinen, 2008).

The Lexicographic ordering problem can be written as:

$$\begin{aligned} &\text{lex minimize } f_1(x), f_2(x), \dots, f_k(x) \\ &\text{subject to } x \in S. \end{aligned} \tag{3.12}$$

The solution of the lexicographic ordering is Pareto optimal.

3.2.2.3.3 Goal Programming

The main idea in goal programming (Charnes et al., 1955; Charnes & Cooper, 1961) is that decision maker states the aspiration levels for the objective functions and any deviations from these aspiration levels are minimized. Aspiration level of the objective function f_i is represented by $\bar{z}_i$ for $i = 1, \dots, k$. For minimization problems goals are in the form of $f_i(x) \leq \bar{z}_i$ whilst for the maximization problems goals are in the form of $f_i(x) \geq \bar{z}_i$. Goals may also be represented as equalities or ranges. Deviational variables are denoted by δ_i which may have positive or negative values depending on the problem. Deviational variable is the difference between two positive variables, that is, $\delta_i = {\delta_i}^- - {\delta_i}^+$. We can write $f_i(x) + {\delta_i}^- - {\delta_i}^+ = \bar{z}_i$ for all $i = 1, \dots, k$, where ${\delta_i}^-$ is a negative deviation or underachievement and ${\delta_i}^+$ is a positive deviation or overachievement in relation to the aspiration level. It is valid that ${\delta_i}^-. {\delta_i}^+ = 0$ for all $i = 1, \dots, k$ (Miettinen, 2008).

Goal programming has different variants and mostly used variants are weighted goal programming presented in Equation 3.13 and lexicographic goal programming presented in Equation 3.14 (Miettinen, 2008):

$$\begin{aligned} &\text{minimize } \sum_{i=1}^{k} w_i \delta_i \\ &\text{subject to } f_i(x) - \delta_i \leq \bar{z}_i \text{ for all } i = 1, \dots, k, \\ &\delta_i \geq 0 \text{ for all } i = 1, \dots, k, \\ &x \in S. \end{aligned} \tag{3.13}$$

$$\begin{aligned} &\text{lex minimize } f_1(x), f_2(x), \dots, f_k(x) \\ &\text{subject to } f_i(x) - \delta_i \leq \bar{z}_i \text{ for all } i = 1, \dots, k, \\ &\delta_i \geq 0 \text{ for all } i = 1, \dots, k, \\ &x \in S. \end{aligned} \tag{3.14}$$

The solution of a weighted or a lexicographic goal programming problem is Pareto optimal if either the aspiration levels form a Pareto optimal reference point or all the deviational variables δ_i have positive values at the optimum (Miettinen, 2008).

3.2.2.4 Interactive Methods

In interactive methods, DM directs the solution process and only a part of the Pareto optimal solutions is generated and evaluated. Moreover, DM can specify and change her / his preferences and selections during the solution process, as she / he gets to know the problem, its possibilities and limitations. Therefore, it is believed that interactive methods overcome weaknesses of a priori and a posteriori methods and generate the most satisfactory results. On the other hand, it should be noted that there are some important assumptions such as DM has enough time and capabilities for co-operation. Briefly, the main steps of a general interactive method are as follows (Miettinen et al., 2008):

a. Initialize: e.g. compute ideal and nadir values and show them to the DM.

b. Generate Pareto optimal starting point: some neutral compromise solution or solution provided by DM can be used.

c. Ask for preference information from the DM: e.g. aspiration levels or number of new solutions to be generated,

d. Generate new Pareto optimal solution(s) according to the preferences and present it / them to the DM. If several solutions were produced, ask the DM to choose the best solution so far.

e. Stop, if the DM wants to. Otherwise, go to step c.

Interactive methods can be classified into three main categories. The most applied methods that belong to each category are presented below (Miettinen et al., 2008):

1. **Methods based on trade-off information:** ISWT (Interactive Surrogate Worth Trade-Off) method (Chankong & Haimes, 1983), The Zionts-Wallenius (Z-W) method (Zionts & Wallenius, 1976), The Geoffrion-Dyer-Feinberg (GDF) method (Geoffrion et al., 1972), SPOT method (Sakawa, 1982), GRIST method (J.-B. Yang, 1999).

2. **Reference point approaches:** Tchebycheff method (Steuer, 1986), Pareto Race (Korhonen & Laakso, 1984), REF-LEX method (Miettinen & Kirilov, 2005).

3. **Classification-based methods:** The step method (STEM) (Benayoun et al., 1971), The satisficing trade-off method (STOM) (Nakayama & Sawaragi, 1984; Nakayama, 1995), The NIMBUS method (Miettinen, 1998).

The Analtytic Network Process and Global Criterion Method are selected as the solution methods after the examination of the multiple criteria decision making methods. The reasons for selecting these methods are given in detail in the next Chapter in which we provide the proposed methodology and application together.

In the 1st section of Chapter 4, we initially introduce our whole approach that is adopted to the ATM deployment problem. Further details of ANP with Chang's Extent Analysis and Global Criterion Method are presented in the 2nd section. In addition, 3rd section demonstrates each phase and its steps with the related part of the problem application.

4. PROPOSED METHODOLOGY AND APPLICATION

4.1 Proposed Methodology

Banks invest in ATM network and select ATMs locations to satisfy their existing customers and also to gain the potential customers. Location of ATMs and therefore their accessibility became a part of competitive strategy for the banks as well as low transaction fees. However, locating ATMs still do not get the attention that it deserves. Traditionally, most of the banks make the ATM location decision based on some figures that DM thinks they are important and DM's past experience. Ultimately, the decision is made instinctively and it is not possible to conclude if the location is actually the best decision. Moreover, a wrong positioned ATM would cause customer loss and the cost of ATM repositioning. Consequently, there is a need for an analytical approach in the area of ATM management for location selection.

In this study, we propose a hybrid approach for ATM location selection problem that applies to Fuzzy Analytic Network Process (FANP) and Global Criterion Method (GCM) to make sound location decisions. The decision process addresses the problem of determining the number and locations of ATMs and can be divided into five major phases.

Briefly, in the first phase as a result of the interviews and literature surveys conducted, the location factors were identified. Pairwise comparisons were carried out and weights of location factors were obtained with the use of FANP in the second phase. Third phase uses the weights of location factors as an input in the calculation of the scores for subregions. In the fourth phase, GCM model, which considers the scores of subregions as one of its objectives, was constructed. Scenario analyses were also performed to evaluate different location alternatives. Google Maps was used as a visualization tool in the last phase. Then, location decision was made as a consequence of evaluating different scenario analyses and the locations on the map. The proposed approach, which is detailed with the application of the methodology in the following section, is presented in Figure 4.1.

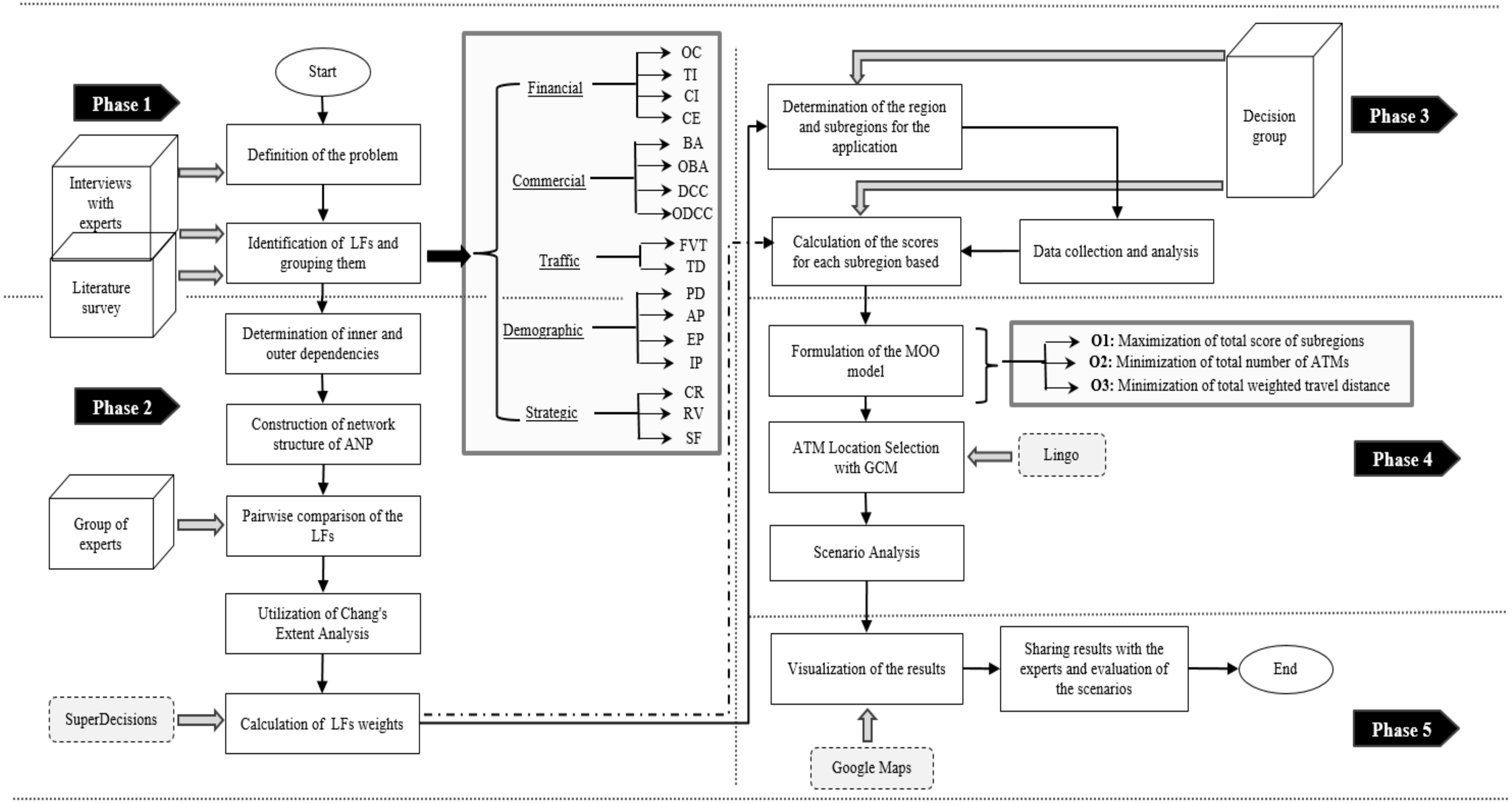

Figure 4.1: Proposed Methodology for ATM Deployment Problem

4.2 Solution Methods

Decision-making problems in the real world usually take place in a fuzzy environment where the information is hard to come by and uncertain (Yeh & Deng, 2004; Ding & Liang, 2005). The thinking, feelings and perceptions of people are often vague and cannot be expressed precisely. For instance, when the scales in the questionnaires are the same, the interpretations of the respondents are still different. In these cases, the problem can be represented in a better way using fuzzy numbers instead of crisp numbers to evaluate the related factors. Therefore, Fuzzy Set Theory is adopted in this study. ANP is used in fuzzy environment as the relationships between the dimensions (or so-called factors) are usually interdependent and sometimes even exert feedback effects; thus, FANP with Chang's Extent Analysis is utilized for evaluating the ATM deployment problem criteria.

4.4.1 ANP

Multi-criteria Decision Analysis (MCDA) is a suitable approach that handles conflicting and both qualitative and quantitative criteria while evaluating strategic options (Ram et al., 2011). ANP is one of the most widely used MCDA techniques which is a general theory of relative measurement.

ANP is a method, whose main strength is its ability to deal with dependence and feedback, was first introduced by Saaty (1996) to generate priorities for decisions. Since then it has been used in numerous different decision-making stages and its success has been accepted (Guneri et al., 2009). To take the place of a linear top-to-bottom form of a strict hierarchy, the ANP model provides a network structure that makes it possible for the representation of all decision-making problems. The major difference between the well-known AHP and ANP is that ANP is capable of handling the interdependence of higher-level elements and lower level elements, without making any assumptions about the independence of the elements within a level (Saaty, 1999). Therefore, ANP is a comprehensive decision-making technique which is applicable with both quantitative and qualitative data and it is competent to cope with interdependence and feedback among criteria or alternatives to enable a more systematic analysis (X. Wang et al., 2015).

We applied ANP in the proposed methodology as ATM deployment problem requires considering multiple criteria which some of them are quantitative whilst some are qualitative. Additionally, these criteria have interdependence between each other.

The fundamental steps of the ANP model are presented as follows:

(1) The first step of ANP is developing the network structure of the problem. This consists of defining its main objective, factors and subfactors that influence the decision, and the alternatives or options. Objective, factors and alternatives are represented by clusters (nodes) where subfactors are presented as elements in the clusters. After defining the problem; the relationships (dependencies) between all elements must be identified (Bottero & Ferretti, 2011). The structural model may incorporate two types of dependence - outer dependence and inner dependence. The former is the dependence between clusters and the latter is the dependence within the cluster. The directions of the arc (or arrow) and loop signify the dependence between elements (Promentilla et al., 2008). Determining the approach that will be followed in the analysis is important while defining the relationships, thereby constructing the pairwise comparison questions. In ANP, questions are formulated in terms of dominance or influence. It is possible to ask questions in two different ways, however the perspective should not be changed during the analysis: Given a control criterion, which of two elements being compared has greater influence (is more dominant) with respect to that control criterion? Or, which is influenced more with respect to that control criterion? (Saaty, 1999; Saaty, 2003).

(2) Second step involves forming pairwise comparison matrices and priority vectors. Decision elements in each cluster are compared on a pairwise basis with respect to their control criterion. The relative importance values are settled on a nine-point scale of Saaty's which changes from 1 to 9, where "1" represents equal importance between the two elements and "9" indicates extreme importance of one element versus the other one (Meade & Sarkis, 1999). Local priority vector is derived from each pairwise comparison and the consistency ratio (CR) is calculated. The comparisons are found acceptable if the consistency ratio is less than 10% (Ayag & Samanlioglu, 2010).

(3) After the comparison of all the elements, a three-phase supermatrix calculation operation is performed. The supermatrix is a partitioned matrix, in which each submatrix consists of a set of relationships between two clusters in a connection network structure (Saaty, 1999; Chang et al., 2015). Initially, the unweighted supermatrix W is formed directly from local priority vectors. Secondly, the weighted supermatrix is computed by multiplying the values of the unweighted supermatrix W with their related cluster weights. By normalizing the weighted supermatrix W^*, it is made column stochastic using the basic concept of the Markov Chain. That is, the sum of the priorities under each column of the matrix is equal to 1. In the final phase, the normalized supermatrix W^* is multiplied by a sufficiently large power φ; then, the weights of ANP is obtained with $\lim_{\varphi \to \propto}(W^*)^{\varphi}$ shown as follows (Reynolds et al., 2007; Chang et al., 2015) :

$$\frac{1}{n}\sum_{j=1}^{n}\left(lim_{\varphi \to \propto}(W^*)^{\varphi}\right)_j \tag{4.1}$$

where W^* is the weighted supermatrix, n indicates the number of criteria in the weighted supermatrix W^*, and φ is an arbitrary large number that is determined by iteration. W_j denotes the j^{th} limiting supermatrix. Therefore, Equation 4.1 demonstrates the process of limiting the supermatrix. Based on Equation 4.1, the final priority weights $(w_1, \ldots, w_j, \ldots, w_n)$ are derived by the limiting super matrix (Niemira & Saaty, 2004). Limiting priority values within this supermatrix indicates the flow of influence of an individual element toward the overall goal.

If the supermatrix formed in step (3) only consists of interrelated factors and subfactors, the priority weights for these elements can be derived from the related column of the component in the limiting supermatrix. On the other hand, if the supermatrix covers the whole network, including the alternatives cluster, then the priority weights of alternatives can be found in the column of alternatives in the limiting supermatrix. Best alternative can be selected based on these weights.

4.4.2 Triangular Fuzzy Number and Chang's Extent Analysis

Since Zadeh introduced Fuzzy Set Theory (FST) in 1965 (Zadeh, 1965), many researchers have applied FST to solve complicated and vague problems for ranking and selection other than location decisions, such as banking, coastal, construction, environment, logistics, supply chain, technology, and human resources management.

One of the major characteristics of FST is its capability of expressing vague data with linguistic variables and FST handles vague data as possibility distributions in terms of set memberships (Ding & Liang, 2005). A linguistic variable is a variable whose values are stated in words or sentences of natural or artificial language (Zadeh, 1975). For example, "weight" is a linguistic variable, with values of Very Low, Low, Medium, High, Very High, etc. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership; and described by a membership function that distributes to each object a grade of membership ranging between zero and one (Chou et al., 2013; Chang et al., 2015).

Triangular Fuzzy Number (TFN) and Trapezoidal Fuzzy Number (TrFN) are the most used fuzzy numbers. However, TFNs are easier to use and interpret (T.-Y. Chen & Ku, 2008; Ertuğrul & Karakaşoğlu, 2009; X. Wang et al., 2015). According to the definition of Van Laarhoven and Pedrycz (1983), a TFN can be represented as $\widetilde{M} = (l, m, u)$, where $l \leq m \leq u$. The value l denotes the smallest possible value; the value m denotes the most promising value; and the value u denotes the largest possible value. The TFN membership function is shown in Equation 4.2 and triangular fuzzy number $\widetilde{M}$ is shown in Figure 4.2 (B. Chang et al., 2015):

$$\mu_M(x) = \begin{cases} \dfrac{x}{m-l} - \dfrac{l}{m-l}, & x \in [l, m], \\ \dfrac{x}{m-u} - \dfrac{u}{m-u}, & x \in [m, u] \\ 0, & otherwise \end{cases} \tag{4.2}$$

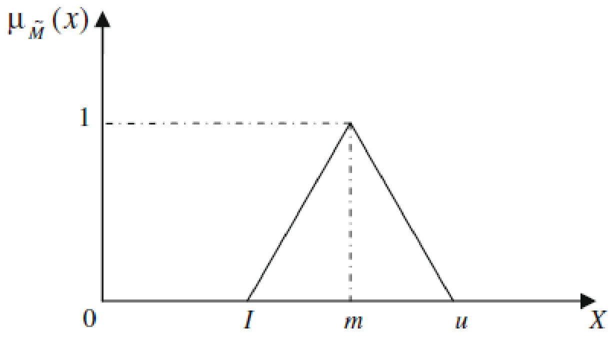

Figure 4.2: Triangular fuzzy number, $\widetilde{\mathbf{M}}$ (Seçme, Bayrakdaroğlu, & Kahraman, 2009)

Variety of methods such as geometric mean method, fuzzy modification of the logarithmic least squares method, Chang's extent analysis, fuzzy least square method, direct fuzzification method, fuzzy preference programming and two-stage logarithmic programming have been proposed by researchers to attain the priorities in FAHP (Kabir & Sumi, 2014). However, most of the researchers applied Chang's Extent Analysis method in their problems by addressing its computational simplicity and effectiveness (G. Kumar & Maiti, 2012; Y. Wang et al., 2014). It is possible to see Chang's extent analysis method called (fuzzy) synthetic extent analysis or (fuzzy) extent analysis method.

It should be mentioned that there are some researchers who criticize using FST with AHP and ANP such as T. L. Saaty (2006), T. L. Saaty and Tran (2007) and Zhü (2014). They advocate that there is no need to use fuzzy AHP and ANP, additionally they also argue that using FAHP and FANP oppose the basic principles of the original methods. Moreover, Chang's extent analysis is denounced by Y. M. Wang et al. (2008) and Promentilla et al. (2008). They addressed some disadvantages of using this method such as it assigns zero weight to some decision criteria and these criteria are ignored in the decision making process, it does not make full use of all the fuzzy comparison matrices information, and the weights determined by the extent analysis method do not represent the relative importance of decision criteria. On the other hand, Vahidnia et al. (2009) states that these drawback are important features of the site selection process.

This research adopts the fuzzy extent analysis proposed by D.-Y. Chang (1996) to combine the FST and the conventional ANP. The main reason behind using FANP in this study is that ANP is insufficient in explaining the vagueness of human feeling. Therefore, in order to obviate this shortcoming Fuzzy ANP is utilized by employing Chang's Extent Analysis to evaluate the ATM deployment criteria. Furthermore, while the experts were performing pairwise comparisons between the criteria, the related data on these criteria was not available as the assessment of criteria did not handle for a specific case.

The extent analysis method can be stated by the following steps:

Pairwise comparison matrix is built for each question by using the corresponding triangular fuzzy values for the linguistic variables based on the responses of the questionnaire.

Assume that $X = \{x_1, x_2, \dots, x_n\}$ is an object set and $G = \{g_1, g_2, \dots, g_m\}$ is a goal set. According to the method of fuzzy extent analysis (D.-Y. Chang, 1996), each object is taken and extent analysis is performed for each goal (g_i) respectively. Therefore, m extent analysis values for each object can be obtained, as follows:

$$M_{g_i}^1, M_{g_i}^2, \dots, M_{g_i}^m, i = 1,2, \dots, n \quad (4.3)$$

where all the $M_{g_i}^j$ $(j = 1,2, \dots, m)$ are triangular fuzzy numbers representing the performance of the object x_i with regard to each goal u_j. By using fuzzy extent analysis, the value of fuzzy synthetic extent value (S_i) with respect to the i^{th} object x_i $(i = 1,2, \dots., n)$ that represents the overall performance of the object across all goals can be determined by;

$$S_i = \sum_{j=1}^{m} M_{g_i}^{j} \otimes \left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{g_i}^{j}\right]^{-1} \tag{4.4}$$

To obtain $\sum_{j=1}^{m} M_{g_i}^{j}$, fuzzy addition operation of *m* extent analysis values for a particular matrix is performed as follows:

$$\sum_{j=1}^{m} M_{g_i}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \tag{4.5}$$

and to obtain $\left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{g_i}^{j}\right]^{-1}$, perform the fuzzy addition operation of $M_{g_i}^{j}(1,2, \ldots, m)$ values such that

$$\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{g_i}^{j} = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \tag{4.6}$$

Then compute the inverse of the vector in Equation 4.6 such that

$$\left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{g_i}^{j}\right]^{-1} = \left(\frac{1}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{u_i}}, \frac{1}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{m_i}}, \frac{1}{\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{l_i}}\right) \tag{4.7}$$

The degree of possibility of $M_2 \geq M_1$ is defined as Equation 4.8:

$$V(M_2 \geq M_1) = sup_{y \geq x}\left[min\left(\mu_{M_1}(x), \mu_{M_2}(y)\right)\right] \tag{4.8}$$

where x and y values are the axis of membership function of each goal, and Equation 4.8 can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \tag{4.9}$$

$$= V(M_2 \geq M_1) = \begin{cases} 1, & if\ m_2 \geq m_1, \\ 0, & if\ l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag{4.10}$$

d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} (see Fig. 4.3).

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

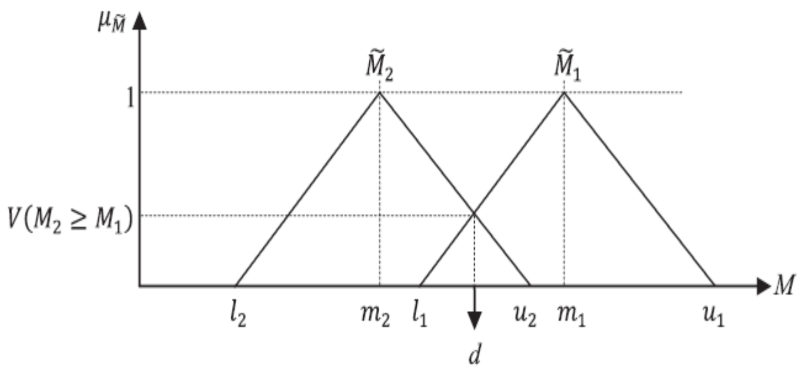

Figure 4.3: The intersection between M_1 and M_2 (Ertuğrul & Karakaşoğlu, 2009)

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1,2, \dots, k)$ can be defined by;

$$V(M \geq M_1, M_2, \dots, M_k) =$$
$$V[(M \geq M_1)\ and\ (M \geq M_2) and \dots and \dots\ (M \geq M_k)] \tag{4.11}$$
$$= \min V\ (M \geq M_i), i = 1,2, \dots, k$$

Assume that,

$$d'(A_i) = \min V\ (S_i \geq S_k), \tag{4.12}$$

for $k = 1,2, \dots, n;\ k \neq i$. Then the weight vector is given by,

$$\boldsymbol{W}' = (\boldsymbol{d}'(\boldsymbol{A_1}), \boldsymbol{d}'(\boldsymbol{A_2}), \dots, \boldsymbol{d}'(\boldsymbol{A_n})^{\boldsymbol{T}} \tag{4.13}$$

where A_i $(i = 1,2, \dots, n)$ are n elements.

Via normalization, the normalized weight vectors are,

$$W = (d(A_1), d(A_2), \dots, d(A_{n1}))^T \tag{4.14}$$

where W is a non-fuzzy number.

4.4.3 GCM

The distance between some desirable reference point in the objective space and feasible objective region is minimized in the method of global criterion (see (P.-L. Yu, 1973; Zeleny, 1973)), which is also called global criterion method (GCM). A reference point is set as the ideal objective vector or the utopian objective vector and the analyst selects the metric for measuring the distance. In this way, the multiple objective functions are converted into a single objective function where solutions that are closest to ideal solution are identified. The ideal solution provides the optimal value for each of the objectives, which is typically infeasible for the multiobjective model. The solution with the smallest distance to the ideal solution is found as the "best compromise solution". L_p -metric can be used to measure the distance as it is seen in Equation 4.15 (Miettinen, 2008; Roozbahani et al., 2015).

$$\begin{gathered} \text{minimize } \left(\sum_{i=1}^{k} |f_i(x) - z_i^*|^p\right)^{1/p} \\ \text{subject to } x \in S. \end{gathered} \tag{4.15}$$

Chebyshev metric (also known as L_∞-metric) can be also used by dropping the exponent $1/p$ as in Equation 4.16.

$$\begin{gathered} \text{minimize } max_{i=1,\dots,k}[|f_i(x) - z_i^*|] \\ \text{subject to } x \in S. \end{gathered} \tag{4.16}$$

For linear problems, the solutions obtained by L_p-problems where $1 < p < \infty$ are between the solutions obtained by the L_1- and L_∞- problems. Zeleny (1973) noted that this set of solutions is substantially small part of the Pareto optimal set (Miettinen, 1998). Determining the p value is an issue in this method (Chiandussi et al., 2012). However, the choice of the parameter p depends on the problem type and desired solution. Changing parameter p between 1 and ∞, enables the analyst to move from minimizing the sum of individual regrets due to not achieving the ideal solution (i.e. having a perfect compensation among the objectives) to minimizing the maximum regret (i.e. having a no compensation among the objectives) in the decision process (Tecle et al., 1998; Roozbahani et al., 2015). The contours of for $p = 1$, $p = 2$, and $p = \infty$ are depicted in Figure 4.4.

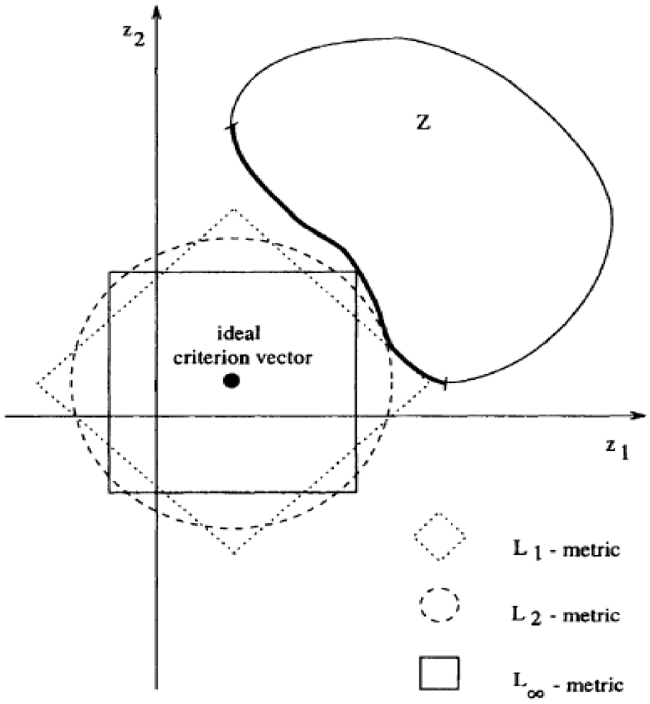

Figure 4.4: Different metrics in global criterion method (Miettinen, 1998)

Note that if the real ideal objective vector is known, than absolute value signs can be ignored as the difference is always positive. In addition, if the objective functions have different magnitudes, the method requires normalization to work properly (Miettinen, 2008). Normalization of the objective functions is needed to transform all the objective function values into commensurable values and accordingly to avoid scale effect in the compromise solution (Tecle, Shrestha, & Duckstein, 1998). In order to scale the objective functions, denominator is added to the problem which may be $|z_i^*|$ or $|z^{nad} - z_i^*|$ (Miettinen, 1998).

Although there are other methods that can used for solving the multiobjective location problem, Global criterion method was selected due to its simplicity and ability to find Pareto optimal solutions. Moreover, this method does not require any information from decision maker as it does not include the weights of the objectives and it incorporates reference points, which can be found by the analyst, into the model.

4.5 Application of the Solution Methodology for ATM Deployment Problem

ATMs were first used in 1987 in Turkey as cash dispensing machines. After the 2001 financial crisis that Turkey faced with, banking regulation rules were changed and consequently, transformed the banking concept. This transformation brought forth the conversion of the banking system technologies. The number of ATMs was a few and they were barely used before the 2001 crisis. However, after 2001 usage of ATMs increased substantially (Fırat, 2013) . Number of ATMs was 11,397 by the end of 2000 and it became 48,678 at the end of the third quarter of 2017 with the increase of 327.1% (“The Interbank Card Center Reports: Number of POS, ATM, Cards,” 2017).

In Turkey, today there are 47 banks who try to survive in a very competitive environment which makes earning profit difficult. Therefore, banks attempt to increase their sustainability. The most effective way to achieve this is to minimize operational costs by improving alternative distribution channels and shift customers to these channels from more costly ones. Making ATMs more accessible by locating them to the right places is very important within this context.
A real world case study, which is conducted for a Turkish bank, is presented as an attempt to support decision makers in their complex location decisions. The bank has almost 700 branches and 5,000 ATMs in Turkey by the end of 2016. Furthermore, almost 25% of the branches and 15% of the ATMs are located in Istanbul.

4.5.1 Phase 1: Defining the Problem and Identification of Location Factors

In the first phase of the process, a series of interviews were conducted with experts, who are involved in ATM deployment management problem, to define the ATM location problem and identify the factors that affect location decision. The followed steps of Phase 1 are depicted in Figure 4.5.

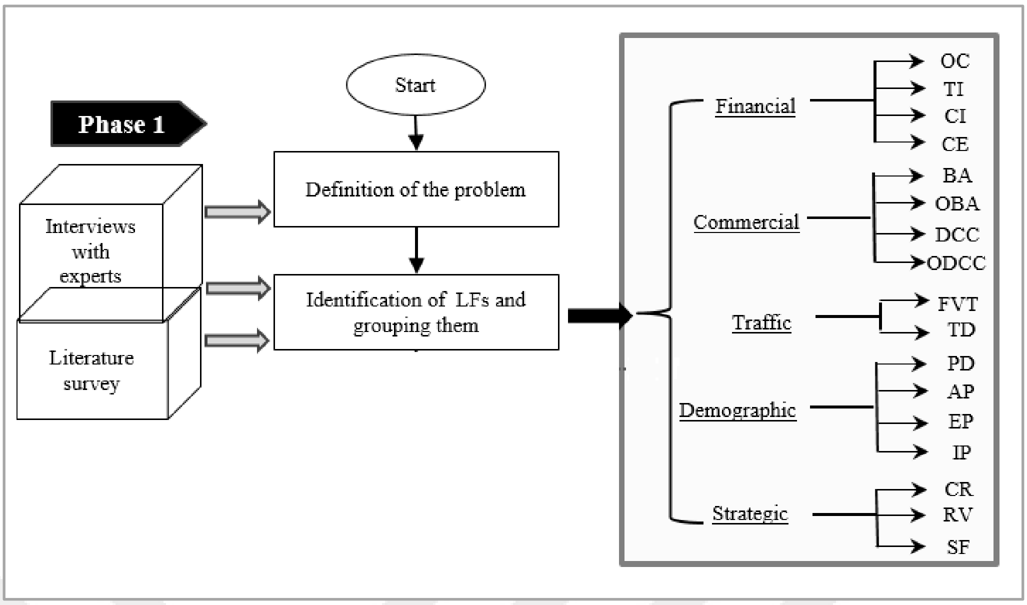

Figure 4.5: Steps of the Phase 1

The experts are composed of managers of related departments who work in different banks (i.e. head of ATM management department, branch and ATM planning department, ATM operations department, branchless banking department, construction and real estate department and branch manager), experts from banking industry (i.e. head of business solutions in a software development company and a manager of a company that provide services for ATM operations) and academicians. The aim of the interviews is to reflect the general case for the application and deal with the problem in a broad perspective by including different views.

4.5.1.1 Definition of the problem

It is noticed that there is a need for a systematic method to make location decisions. As a result of interviews, the problem was defined as deciding where to deploy new ATMs and which of the existing ATMs should maintain their positions or which of them were not located properly, hence should be removed.

4.5.1.2 Identification of Location Factors

Identification of factors, which we call location factors (LFs), that affect the ATM location selection decision is a pivotal and tough task in the deployment problem. Moreover, understanding these factors is critical to achieve sound decisions. The factors should cover multiple dimensions of the location; therefore a comprehensive research was applied to determine the criteria in this study. Literature was reviewed based on service facility location problems. In order to analyze the factors that have been investigated in the literature, the factors which influence the selection of location for the service facilities are summarized in Table 4.1.

Some similar criteria are combined in a one group to avoid counting them twice. The researches which studied on service facilities such as bank branch, automatic teller machines, health center, hospital, tourist hotel, coffee shop, restaurant, store and shopping mall were considered. However, ATM location problem has its own characteristics and specific criteria that should be taken into account. Therefore, the views of the experts related to location factors were obtained in the interviews in order to strengthen the validity of the study. During the interviews it was seen that just one of the banks consider the location selection factors, whilst the others have not paid enough attention to this issue.

Table 4.1: Factors analyzed in the service facility location selection problems

	Authors												
Criteria	Adams (1991)	Boufounou (1995)	Stevenson (2002)	Tzeng et al. (2002)	Cheng et al. (2005)	T.-Y. Chou et al. (2008)	Yang et al. (2008)	Cinar & Ahiska (2010)	Shahbandarzadeh & Ghorbanpour (2011)	Chatterjee & Mukherjee (2013)	Ho et al. (2013)	Turhan et al. (2013)	Koç & Burhan (2015)
Foot / Vehicle Traffic	X		X	X			X				X		
Population Density	X		X						X	X		X	
Age Distribution	X		X									X	
Education Level Distribution								X		X		X	
Gender Distribution												X	
Number of Customers							X						
Income Level of Customers			X				X						
Customer/ Demand Potential													X
Competitor's Location/ Number of Competitors		X	X	X	X						X	X	X
Distance to Existing Competitors						X							
Competitors Sales Volume												X	
Number of Own Facilities		X											
Distance to Tourism Scenic Spots						X							
Return on Investment					X								
Expected Revenue of Location							X						
Recurring costs (rent, taxes, insurance etc.)				X	X		X				X	X	
Security/ Safety Issue	X						X				X		X

Moreover, not using any scientific method for location selection decision is the common characteristics of these banks. This was the difficulty of the study and also the proof of the need for a research in this area. Initial list of the criteria was formed as a result of literature survey and the list was finalized based on the interviews.

Based on the prominence in the available literature and opinions of the experts consulted, the criteria in the final list are split into five main categories namely financial, commercial, traffic, demographic and strategic, according to their similar characteristics as shown in Figure 4.6.

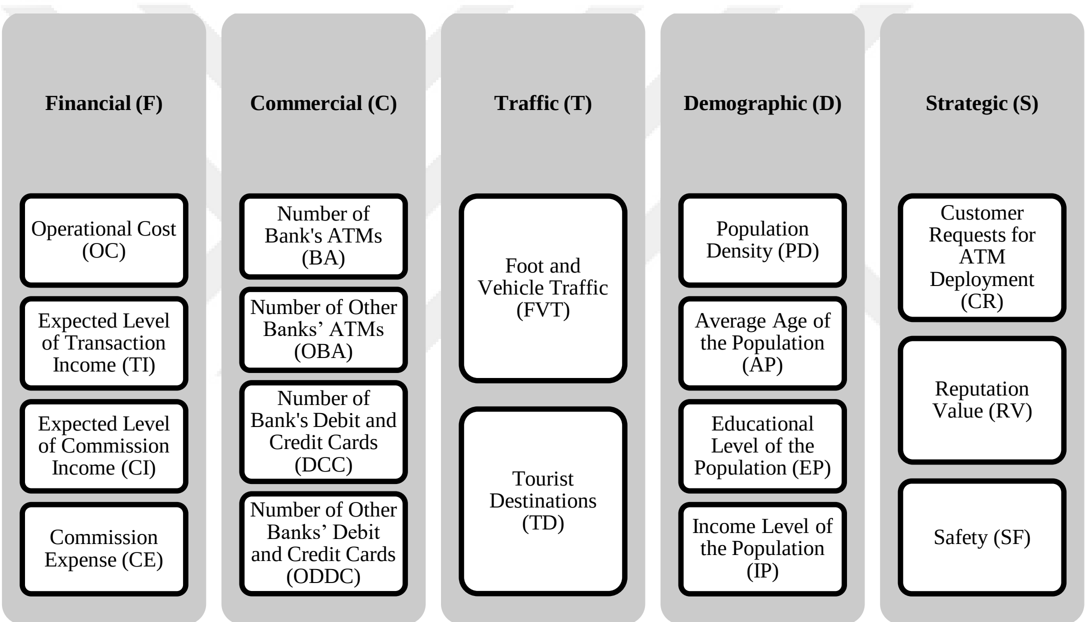

Figure 4.6: Criteria categorization for ATM deployment problem

In the problem, the majority of the criteria are quantitative however, while the experts evaluating these criteria there is no information about the value of each criterion as the problem is not handled for specific locations and a general problem is discussed during the study.

1. ***Financial (F) main category***

This main category is composed of operational cost (OC), and expected level of transaction income (TI), expected level of commission income (CI), and commission expense (CE).

(1) *Operational cost (OC):* After the deployment of the ATM, the bank bears these costs for carrying out the operations which are needed to keep ATM in service.

The operational cost includes the following costs:

(a) *Rent:* It is the money that is paid monthly to the property owner or municipality for the ATM location.
(b) *Insurance cost:* It is the money that is paid monthly to the insurance company for protecting ATM's hardware and its cash against natural disasters (e.g. flood, earthquake) and damaging incidents (e.g. fire, vandalism and theft).
(c) *CIT (Cash-in-transit) cost:* This item includes the cost of daily operations like cash handling and installation. Nowadays, banks generally prefer to get services from outsource carrier companies for performing these operations.
(d) *Funding cost:* It is the opportunity cost of holding cash in ATMs which causes the loss of the overnight interest that would be earned by depositing cash to the Central Bank.
(e) *Maintenance and repair cost:* It is the cost related to ATMs periodic maintenance (technical and physical appearance) and repairing services.
(f) *Other cost:* This item consists of monthly electricity and internet connection cost.

(2) *Expected level of transaction income (TI):* It is the income that is estimated to earn from the transactions carried out by the bank's own customers in the deployed ATMs.

(3) *Expected level of commission income (CI):* It is the income that is estimated to earn from other banks' customers in return to the provided service. The bank gets

commission fee per transaction from other banks and / or their customers when its ATMs are used by the other banks' customers.

(4) *Commission expense (CE):* It is the commission fee that is paid to the other banks in return for the provided service to its customers. The bank pays commission fee per transaction to other banks when its customers get service from other banks' ATMs.

2. Commercial (C) main category

This main category comprises number of bank's ATMs (BA), number of other banks' ATMs (OBA), number of bank's debit and credit cards (DDC), number of other banks' debit and credit cards (ODCC).

(1) *Number of bank's ATMs (BA):* Number of bank's own ATMs which are placed in the region of alternative location is one of the criteria that is considered while deciding the location for deployment.

(2) *Number of other banks' ATMs (OBA):* Number of other banks' ATMs which are placed in the region of an alternative location is one of the criteria that is considered while making a decision for the location selection.

(3) *Number of bank's debit and credit cards (DDC):* Number of debit and credit cards that is owned by the bank's customers in the region of an alternative location. This criterion affects ATM usage rate as the customers that have debit and credit cards will use ATMs more frequently.

(4) *Number of other banks' debit and credit cards (ODCC):* Number of debit and credit cards that is owned by other banks' customers in the region of an alternative location. This criterion has influence on ATM usage rate as other banks' customers that have debit and credit cards tend to use ATMs more frequently.

3. ***Traffic (T) main category***

This main category consists of foot and vehicle traffic (FVT) and tourist destination (TD).

(1) *Foot and vehicle traffic (FVT):* People use ATMs not just in the region that they live or they work but also on their way to home, work or another destination. As a result of this, the streets with high foot and vehicle traffic density are preferred for ATM placement.

(2) *Tourist destinations (TD):* The regions that tourists visit intensively are regarded as the potential locations for ATM placement as these ATMs are used frequently by the tourists and bank earn commission due to these transactions.

4. ***Demographic (D) main category***

This main category involves population density (PD), average age of the population (AP), educational level of the population (EP), and income level of the population (IP).

(1) *Population density (PD):* The population density in the region of an alternative location.

(2) *Average age of the population (AP):* It is the average age of the population in the region of an alternative location. This criterion has an effect on the ATM usage habit. For instance, people whose age is between 20 and 50 tend to use ATMs more often.

(3) *Educational level of the population (EP):* It is the educational level of the population in the region of alternative location which affects the ATM usage habit of the population. For example, it is expected that people who finished elementary school use ATMs more often than people who are illiterate.

(4) *Income level of the population (IP):* It is the income level of the population in the region of an alternative location. Generally, it is expected that ATMs are used more

frequently and the utilization rate of ATMs is higher in the regions where the income level of the population is high.

5. <u>Strategic (S) main category</u>

This main category is composed of customer requests for ATM deployment (CR), reputation value (RV) and safety (SF).

(1) *Customer requests for ATM deployment (CR):* Received customer requests regarding the absence of ATMs in a particular region are also taken into consideration while choosing the locations for ATM deployment.

(2) *Reputation value (RV):* ATMs are placed in some locations in order to establish reputation in the eyes of the customers. Big airports and upper-middle class shopping malls can be counted in this group.

(3) *Safety (SF):* People prefer using ATMs which are seemed to be placed in safe locations in case of robbery. This situation is also valid from the viewpoint of banks as they prefer safer locations to deploy ATMs.

4.5.2 Phase 2: Determining the Importance of Location Factors

ATM location selection decision requires considering several conflicting criteria that have interrelations among them. Accordingly, fuzzy set theory and ANP are combined to improve the efficiency of the model. The steps of Phase 2 are presented in Figure 4.6.

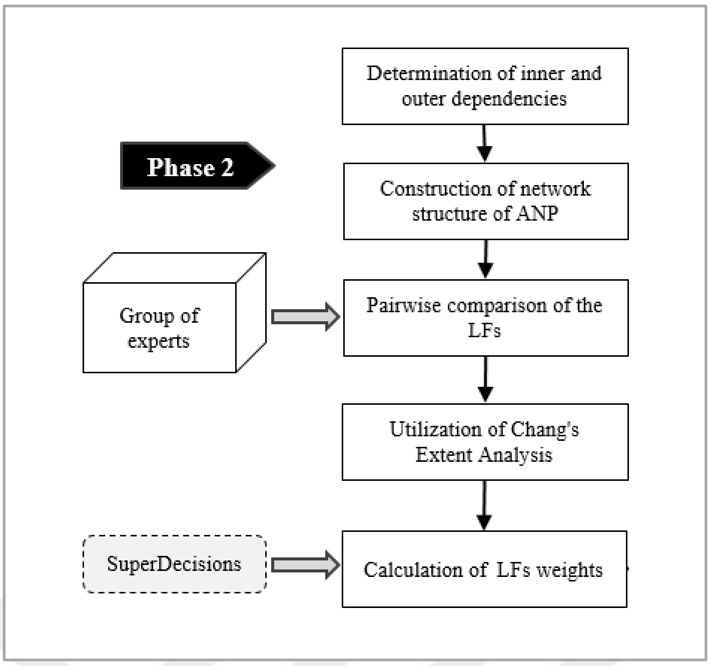

Figure 4.7: Steps of the Phase 2

4.5.2.1 Determination of Inner and Outer Dependencies

The interaction matrix which shows the dependencies and influences between the main categories and criteria was established based on the interviews (see Table 4.2).

In the interaction matrix, the criteria on the left-hand side influence the criteria on the upper row. For example, “Safety (SF)” criterion in “Strategic (S)” main category has influence on “Reputation Value (RV)” in its own category, “Operational Cost (OC)”, “Expected Level of Transaction Income (TI)” in “Financial (F)” main category, “Foot and Vehicle Traffic (FVT)” in “Traffic (T)” main category and “Number of Bank’s ATMs (BA)” and “Number of Other Banks’ ATMs (OBA)” in “Commercial (C)” main category.

Table 4.2: Criteria interaction matrix

		F				D				T		C				S		
		OC	CE	TI	CI	PD	AP	EP	IP	FVT	TD	BA	OBA	DCC	ODDC	CR	RV	SF
F	OC											*	*					
	CE			*								*	*			*		
	TI	*	*									*						
	CI	*										*						
D	PD	*	*	*	*					*		*	*	*	*	*	*	
	AP	*	*	*	*					*		*	*	*	*	*	*	
	EP	*	*	*	*	*						*	*	*	*	*	*	
	IP	*	*	*	*			*				*	*	*	*	*	*	*
T	FVT	*	*	*	*							*	*			*	*	*
	TD	*			*					*		*	*			*	*	*
C	BA		*	*	*								*	*		*		
	OBA		*		*							*			*	*	*	
	DCC	*	*	*								*	*			*		
	ODDC				*							*	*					
S	CR		*	*								*						
	RV	*										*	*					
	SF	*		*						*		*	*				*	

4.5.2.2 Construction of the Network Structure

ANP network model was constructed in SuperDecisions® software as it is considered to be "the best and up-to-date analytic network process program" (Guneri et al., 2009). Main categories were built as clusters and criteria were built as nodes in the related clusters. Then, the influence between the nodes was depicted by the links created according to the interaction matrix. The ANP network structure is shown in Figure 4.8, which displays the relations between all the main categories (clusters) and criteria (nodes).

4.5.2.3 Pairwise Comparison of Location Factors

A questionnaire was formed in order to perform the pairwise comparisons between the main categories and the criteria. The questions were formulated in terms of influence. 'Which of two elements being compared is influenced more with respect to the control element?' was the perspective used in the questionnaire. In our model, the influence is flowing from the control element to the elements being compared.

An example question from the questionnaire and answers of decision group for this question is presented in Table 4.3. In the given example; question is formulated as follows: Which one of the criteria is influenced more by the "Number of Bank Debit & Credit Cards" element? Control element in this question is "Number of Bank Debit & Credit Cards" criterion and the criteria of "Financial" cluster are analyzed. All the other questions were formulated using the same logic. Each question was formed based on the interaction matrix that is presented in Table 4.2.

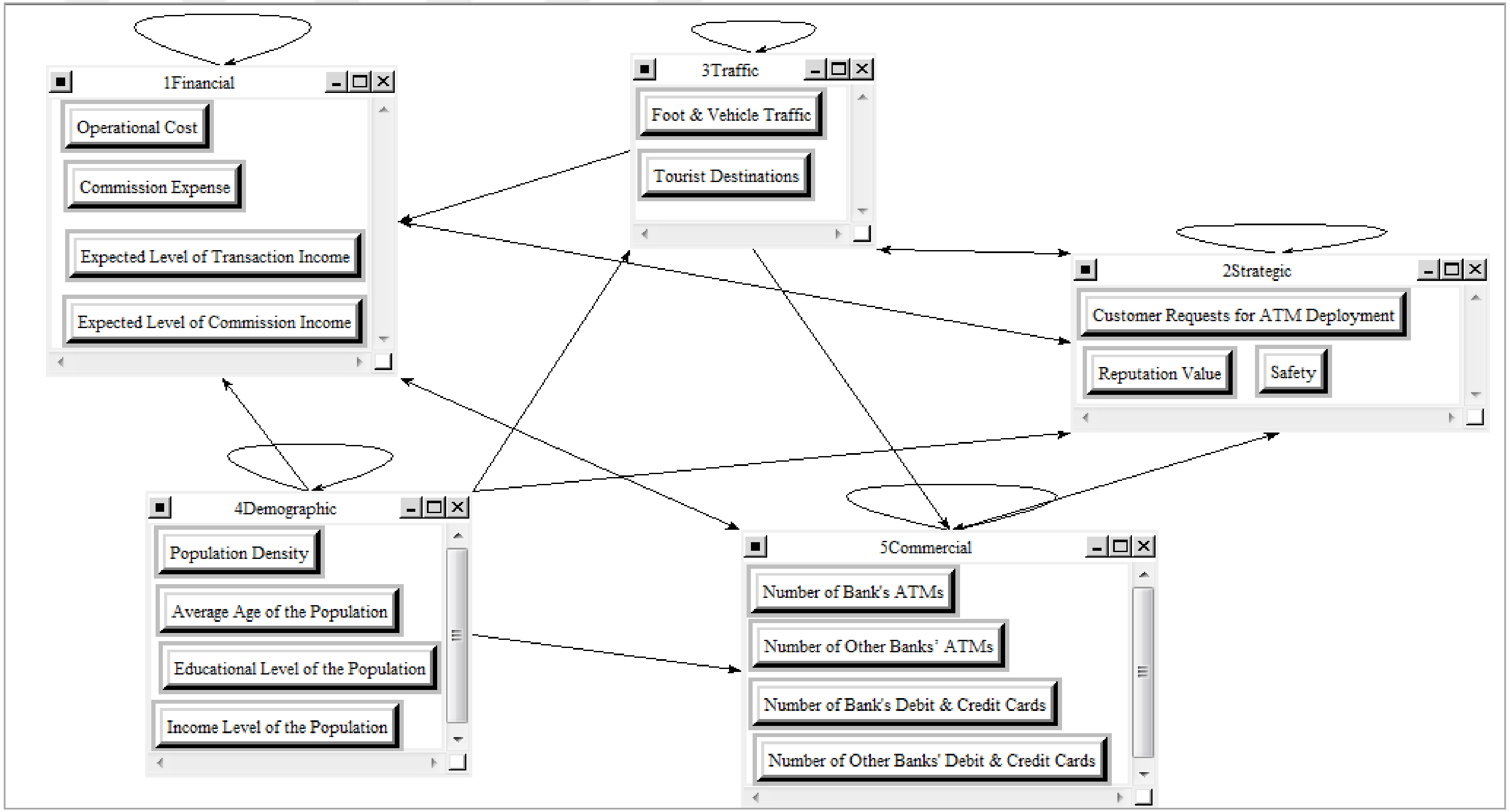

Figure 4.8: ANP network structure for ATM deployment problem

It can be easily seen that in the example question, “Expected Level of Commission Income” does not exist in the table. This is the natural outcome of interaction matrix, where we see that “Number of Bank Debit & Credit Cards (DCC)” does not influence the “Expected Level of Commission Income (CI)” criterion. Therefore, we do not expect to see this criterion in the question.

Table 4.3: Example question from the questionnaire

	Comparison of Criteria in Financial Cluster with respect to Number of Bank Debit & Credit Cards									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense								X		Expected Level of Transaction Income
Commission Expense							X			Operational Cost
Expected Level of Transaction Income						X				Operational Cost

In the next step, the questionnaire was shared with the decision group in a meeting where all the experts gathered together. The experts perform pairwise comparisons in a five-point scale linguistic terms based on the relative dominance of the two elements being considered. In the questionnaire five questions were answered for the main categories whilst thirty eight questions were answered for the criteria and the questionnaire was completed in consensus.

The responses in linguistic terms for each comparison were converted into triangular fuzzy numbers by using Table 4.4 and became ready for Chang’s extent analysis method. The utilized scale is adopted from Chang’s fuzzy AHP method (D.-Y. Chang, 1996).

Table 4.4: Membership functions of linguistic scales

Linguistic Scale	**Triangular Fuzzy Scale**	**Triangular Fuzzy Reciprocal Scale**
Equally affected	(1,1,1)	(1,1,1)
Weakly more affected	(2/3,1,3/2)	(2/3,1,3/2)
Strongly more affected	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more affected	(5/2,3,7/2)	(2/7,1/3,2/5)
Absolutely more affected	(7/2,4,9/2)	(2/9,1/4,2/7)

4.5.2.4 Utilization of Chang's Extent Analysis

Blurriness of the information was cleared by the extent analysis and computations were carried out in an Ms Excel worksheet as fuzzy data cannot be used in SuperDecisions® software directly. Initially, m extent analysis values for each object were calculated and then fuzzy synthetic extent values with respect to the i^{th} object, degrees of possibility and weight vectors were computed. Related calculations based on the fuzzy pairwise comparison matrix given in Table 4.5, are presented below to make the computation stage clear. Moreover, all the calculations for Chang's Extent Analysis are provided in detail in Appendix A.

Table 4.5: Pair-wise comparison matrix of the criteria in Financial cluster with respect to Number of Bank's Debit & Credit Cards

	Number of Bank's Debit &Credit Cards		
	Commission Expense	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)
Expected Level of Transaction Income	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

Equations 4.5 - 4.7 were utilized for the following calculations and results were obtained as follows:

$$\sum_{j=1}^{3} M_{g_1}^{j} = (1 + 2/7 + 2/5,\ 1 + 1/3 + 1/2,\ 1 + 2/5 + 2/3) = (1.69, 1.83, 2.07)$$

$$\sum_{j=1}^{3} M_{g_2}^{j} = (5/2 + 1 + 2/3,\ 3 + 1 + 1,\ 7/2 + 1 + 3/2) = (4.17, 5.00, 6.00)$$

$$\sum_{j=1}^{3} M_{g_3}^{j} = (3/2 + 2/3 + 1,\ 2 + 1 + 1,\ 5/2 + 3/2 + 1) = (3.17, 4.00, 5.00)$$

$$\sum_{i=1}^{3} \sum_{j=1}^{3} M_{g_i}^{j} = (1.69 + 4.17 + 3.17, 1.83 + 5.00 + 4.00, 2.07 + 6.00 + 5.00) = (9.02, 10.83, 13.07)$$

$$\left[\sum_{i=1}^{3} \sum_{j=1}^{3} M_{g_i}^{j}\right]^{-1} = (9.02, 10.83, 13.07)^{-1} = (1/13.07,\ 1/10.83,\ 1/9.02) = (0.08, 0.09, 0.11)$$

Equation 4.4 was used for the following computation:

$$S_{CE} = (1.69, 1.83, 2.07) \otimes (0.08, 0.09, 0.11) \approx (0.129, 0.169, 0.229)$$

Similarly, other calculations were also performed by using Equation 4.4 and results were obtained as follows:

$$S_{TI} = (4.17, 5.00, 6.00) \otimes (0.08, 0.09, 0.11) \approx (0.319, 0.462, 0.665)$$

$$S_{OC} = (3.17, 4.00, 5.00) \otimes (0.08, 0.09, 0.11) \approx (0.242, 0.369, 0.554)$$

Then Equations 4.8 - 4.11 were applied to express the degrees of possibility for the considered criteria as below:

$V(S_{CE} \geq S_{TI}) = 0$, $V(S_{CE} \geq S_{OC}) = 0$

$V(S_{TI} \geq S_{CE}) = 1$, $V(S_{TI} \geq S_{OC}) = 1$

$V(S_{OC} \geq S_{CE}) = 1$,

$$V(S_{OC} \geq S_{TI}) = \frac{(0.319 - 0.554)}{(0.369 - 0.554) - (0.462 - 0.319)} = 0.718$$

Equation 4.12 was used to obtain $d'(A_i)$.

$d'(S_{CE}) = \min(0, 0) = 0$, $d'(S_{TI}) = \min(1, 1) = 1$,

$d'(S_{OC}) = \min(1, 0.718) = 0.718$

Then the weight vector was obtained like in Equation 4.13:

$$W'_{DCC} = (0, 1, 0.718)^{T}$$

After the normalization, the normalized vector which is a crisp number was calculated by using Equation 4.14:

$$W_{DCC} = (0, 0.582, 0.418)^{T}$$

According to the solution of given example; it is seen that "Transaction Income (TI)" is the most influenced criterion in the financial main category with respect to the "Number of Bank's Debit & Credit Cards (DCC)" criterion. A similar procedure was applied for all comparison matrices to obtain the crisp results.

4.5.2.5 Calculation of LF's Weights

Crisp results for the fuzzy pairwise comparisons were achieved by Chang's extent analysis and weight vectors were entered directly into the ANP model which was constructed beforehand in SuperDecisions® software. The problem was solved quickly and the results were obtained easily with the help of the software. This makes the calculation process practicable by avoiding time consuming calculations.

In order to apply FANP, the interaction (inner and outer dependencies) between the factors was determined and network structure was constructed based on the interactions. Pairwise comparison matrices were built and experts used these matrices to evaluate the factors in linguistic terms. Chang's Extent Analysis (D.-Y. Chang, 1996) was adopted to clear the fuzziness of the information and SuperDecisions® was preferred to perform ANP computations. Limit matrix that was obtained from SuperDecisions® is presented in Table 4.6.

The results of the FANP that was conducted for ATM deployment problem which show the importance of criteria are presented in Table 4.7. In the table normalized by cluster column shows the weights of each criterion in their cluster (main category) and limiting column shows the weights of each criterion among the whole network.

Table 4.6: SuperDecisions Limit Matrix

		F				S			T		D				C			
		CE	CI	TI	OC	CR	RV	SF	FVT	TD	AP	EP	IP	PD	BA	DCC	ODCC	OBA
F	CE	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297	0.0297
	CI	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188	0.2188
	TI	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083	0.2083
	OC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
S	CR	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462	0.0462
	RV	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	SF	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
T	FVT	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	TD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
D	AP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	EP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	IP	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	PD	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
C	BA	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822	0.4822
	DCC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	ODCC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
	OBA	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149	0.0149

Table 4.7: Prioritization of the criteria

No	Name of the Criterion	Normalized By Cluster	Limiting
1	Number of Bank's ATMs (BA)	0.970110	0.482158
2	Expected Level of Commission Income (CI)	0.478960	0.218774
3	Expected Level of Transaction Income (TI)	0.456020	0.208296
4	Customer Requests for ATM Deployment (CR)	1.000000	0.046222
5	Commission Expense (CE)	0.065010	0.029693
6	Number of Other Banks' ATMs (OBA)	0.029880	0.014850
7	Operational Cost (OC)	0.000010	0.000004
8	Number of Bank's Debit & Credit Cards (DCC)	0.000010	0.000003

"Number of Bank's ATMs" was found as the most important criterion in the network with weight at the level of 48.22%. "Number of Bank's ATMs" also constitutes the biggest share of "Commercial" main category with 97.01%. "Number of Other Banks' ATMs" criterion follows "Number of Bank's ATMs" with weight of 2.99%. The last criterion which is considered in the "Commercial" main category is "Number of Bank's Debit & Credit Cards" criterion with a very small weight at the level of 0.0003%.

The next two most important criteria in the network are "Expected Level of Commission Income" and "Expected Level of Transaction Income" which belong to "Financial" category and their importance is almost equal with the level of 21.88% and 20.83% respectively. "Commission Expense" is another member of "Financial" category; however there is a big difference in the level of the importance as it is just at a level of 2.96%. Operational cost comes at fourth with the weight of 0.001% in "Financial" category while it has the weight of 0.0004% in the network.

"Customer Requests for ATM Deployment" is the only criterion that was considered in the "Strategic" main cluster and it has a weight of 4.62% in the network.

The rest of the nine criteria weights were found as "0," which is a natural result in Fuzzy Extent Analysis. However, these zero importance values demonstrate that the related criteria were considered at the beginning of the evaluations, but in fact they turned up unimportant when compared with other criteria. If evaluations were performed by crisp values, these criteria would not be zero. Therefore, it can be concluded that Extent Analysis eliminates the criteria which are not really important to decision makers. Moreover, none of the criteria in “Demographics” and “Traffic” were regarded as important in the deployment decision.

According to the results of the FANP, banks should consider number of their own ATMs as the most important location criterion. However, this criterion has negative effect on the location decision which means that banks should intend to place new ATMs where their existence is rare. Moreover, expected commission income and transaction income come with the second and third priority respectively. Commission and transaction income are the indicators of ATM usage as the mostly used ATMs will have the potential to bring largest income. In other words, banks should pay attention to these criteria since they should place their ATMs where they expect to earn the largest income. Nowadays, customer requests are given more importance as they directly affect customer satisfaction and loyalty. Unhappy customers whose requests are ignored will most probably choose to change her / his company. Consequently, this criterion should be seen as a key indicator of possible suitable ATM location. Commission expense is another important criterion as this incurred cost indicates that banks own customers use their competitors’ ATMs. Therefore, banks should consider these locations to deploy new ATMs. Operational cost and number of banks’ customers’ debit and credit cards criteria have very small impact in the location selection decision. On the other hand, these location criteria should be treated as a whole and all of them should be given its deserved importance in a deep analyze to make the location decision.

In practice, banks generally focus on the number of other banks’ ATMs and tend to place new ATMs close to their competitors’ locations. Moreover, they make location selection decisions based on some figures such as commission expense and income without following any scientific and systematic approach. Nonetheless, when we look in the literature it is seen that the ATM location models that are constructed in previous studies concentrate on customer utility (i.e. customer travelling distance to facility or / and waiting time at the facility) and service utility (i.e. the idle time of the machine). However, none of these approaches utilize the strengths of each other in a complementary way. Therefore, the experience of decision makers should be incorporated into the decision process to make sound location selection decisions. Decision makers may consider these criteria weights in order to give scores to their alternative locations and this would be an important step for them to get closer to right locations.

The following steps of the next three phases (Phase 3, Phase 4 and Phase 5) were performed by a decision group in a Turkish bank that is ranked in the top 10 according to the size of assets and number of ATMs. This decision group comprises experts who have different responsibilities on ATM management. The list of location factors, which is given in Table 4.7, was also validated by this decision group.

4.5.3 Phase 3: Scores of Subregions

The steps of Phase 3, which comprises determination of the regions and subregions, data collection and analysis, and calculation of the scores for each subregion are presented in Figure 4.9.

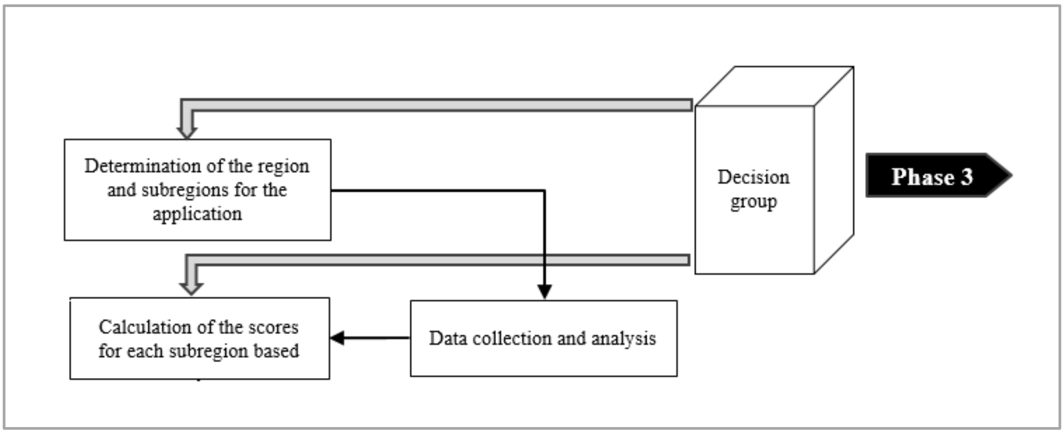

Figure 4.9: Steps of the Phase 3

4.5.3.1 Determination of the Region and Subregions for the Application

The decision group performed long discussions on selection of application region. Consequently, Beşiktaş is a municipality of Istanbul, which is located on the European side of the city, was chosen as the application region due to its strategic position. The location of Beşiktaş in Istanbul map is shown in Figure 4.10.

Figure 4.10: The location of Beşiktaş on Istanbul city map ("Location of Besiktas in Istanbul," 2009)

The population is 186,570 and the area is 21.33 km^2. Beşiktaş has a role as the entrance of the Bosporus Bridge on the European side and it is the feeder for the inner-city motorway on the bridge. Moreover, it hosts one of the most important public transportation hubs and several touristic places. Therefore, thousands of people commute everyday to or via Besiktaş. Additionally, Beşiktaş has 23 districts which are depicted on Google Earth in Figure 4.11. The visualization step is detailed in Phase 5.

Figure 4.11: Districts of Beşiktaş on Google Earth

4.5.3.2 Data Collection and Analysis

There are 22 ATMs of the bank where 434 ATMs of competitors located in these 23 districts of Beşiktaş. The locations of 456 ATMs are showed on Google Earth in Figure 4.12 in which L1 to L22 represent bank's ATMs whilst L23 to L456 stands for ATMs of other banks.

The competitors have the highest number of ATMs (i.e. 68) in District-14, whilst they have the smallest number of ATMs (i.e. 3) in District-11 and District-21. The bank has no ATM in 9 districts (1, 3, 7, 10, 12, 15, 16, 20, 21). District-16 is the only district in which neither the bank nor the competitors have an ATM. Furthermore, the bank has the highest number of ATMs, which is 3, in districts 18, 19 and 22.

The district and coordinates of each ATM are presented in Appendix B where the top 22 ATMs (L1-L22) are belong to the bank whilst the rest of the ATMs are belong to the competitors.

Great circle distance metric was used in order to calculate the distance between ATM locations.

Assume that there are two ATM locations which have Latitude and Longitude data in decimal degree as shown in Table 4.8.

Table 4.8: Latitude & Longitude data for two ATM locations

ATM Locations	Latitude	Longitude
Location1	Lat1	Long1
Location2	Lat2	Long2

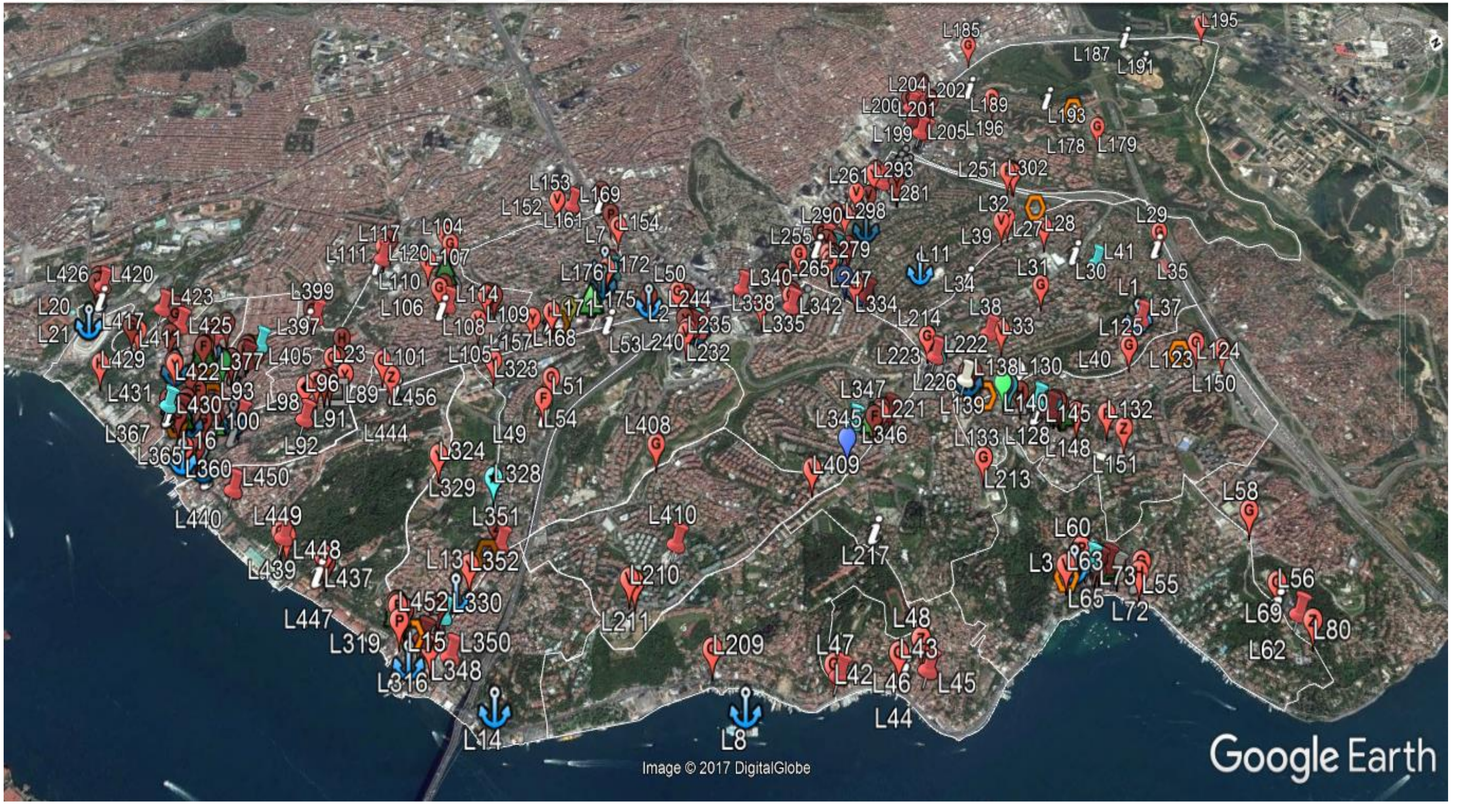

Figure 4.12: The locations of all ATMs

The distance between 456 ATM locations was calculated in kilometers in Ms Excel with the help of formula 4.17. The distance matrix is given in Appendix C.

$$\begin{aligned} Distance = \cos^{-1}\big(&\cos\big(Radians(90 - Lat1)\big) \\ &\times \cos\big(Radians(90 - Lat2)\big) \\ &+ \sin\big(Radians(90 - Lat1)\big) \\ &\times \sin\big(Radians(90 - Lat2)\big) \\ &\times \cos\big(Radians(Long1 - Long2)\big)\big) \times R \end{aligned} \tag{4.17}$$

where R = Earth's radius (mean radius) = 6,371 km.

Annual number of transactions that were performed on bank's ATMs by bank's own customers, commission expense and commission income data for all districts were gathered and analyzed for score computation. It should be mentioned that as the bank do not monitor the transaction income data for each ATM, we used number of transaction (transaction volume) that was performed by bank's own customers in order to estimate the transaction income and used this data in the score calculation.

The demand on bank's own ATM, was taken as total number of transactions that all customers performed on related ATM. On the other hand, the demand on competitors' ATMs was taken as the total number of transactions which the bank's own customers performed. In order to obtain the total number of transactions which were performed on competitors' ATMs, we utilized from commission expense that the bank paid to its competitors and divided it by an average commission fee per transaction.

Demand nodes and the potential ATM sites are the locations where the bank's and the other banks' ATMs reside.

Capacity of each ATM is regarded the same and it was calculated on time basis. Capacity is defined as the monthly number of transaction that customers can get service from the ATM.

The downtime for an open ATM is assumed as the 1% of its working time which is 24 hours a day.

ATMs give service for $24 \times 60 = 1.440\ min.$ for a day

The downtime is: $1.440 \times 0{,}01 = 14{,}4\ min.$ for a day
$14{,}4 \times 30 = 432\ min.$ for a month

Generally, CIT operation is performed twice in a week and one operation takes 45 min. on average. Therefore, for an ATM;

CIT time is: $45 \times 2 = 90\ min.$ for a week
$90 \times 4 = 360\ min.$ for a month

In total, ATM is not able to give service for $432 + 360 = 792\ min.$ for a month.

We assume that an ATM gives the service between the time 7:00 am and 12:00 pm. Therefore, the service time for an ATM,

Service time is: $17 \times 60 = 1.020\ min.$ for a day
$1.020 \times 30 = 30.600\ min.$ for a month

Net service time is calculated by subtracting total out of service time from service time.

Net service time is: $30.600 - 792 = 29.808\ min.$ for a month

We assume that each transaction lasts 1,5 min. on average.

The number of transactions that is performed on an open ATM:

Capacity (number of transactions) $= 29.808/1{,}5$
$= 19.872$ for a month

The setup cost for an ATM is considered as 100.000 TL where closing an open ATM is considered as 5.000 TL. Annual operational cost is estimated as 60.000 TL.

4.5.3.3 Calculation of the Scores for Each Subregion

The attractiveness, which is represented by scores of each subregion, was calculated by considering six LFs which we found the most important for location selection and constitute 99% of the weight of all factors. "Customer Requests for ATM Deployment" factor could not be included in the model as the bank does not record any data on this LF.

All the factors except "Number of Bank's ATMs" have a positive effect on attractiveness of the location since the eagerness of the bank to locate ATMs would be inversely proportional to the number of bank's own ATMs.

Table 4.9 shows the number of other banks' ATMs (OBA) for each district where there is not any ATM in District-16.

Table 4.9: Number of Other Banks' ATMs in each District

District	**Number of Other Banks' (OBA)**	**District**	**Number of Other Banks' (OBA)**
District-1	4	District-13	19
District-2	15	District-14	68
District-3	7	District-15	19
District-4	6	District-16	0
District-5	26	District-17	14
District-6	20	District-18	7
District-7	21	District-19	35
District-8	30	District-20	18
District-9	25	District-21	3
District-10	32	District-22	24
District-11	3	District-23	22
District-12	16		

Collected data for 23 districts was sorted in ascending order based on each LF. Then, frequency distribution was used for grouping the data.

2^m formula ($2^k > n, where\ k\ is\ the\ number\ of\ classes$) is considered to decide the number of classes. There are 23 observations (neighborhoods), therefore we choose "5" as *k*.

$2^k > n \quad 2^5 > 23 \quad k = 5$

Range = Largest data value-Smallest data value

Range = 68-0 = 68

Class width = Range/ k

Class width = 68/5 = 13,6 (13,6 is rounded up to 14)

The smallest data value is regarded as the lower limit of the first class. In order to find the lower limit of the remaining classes, the class width was added to the lower limit of each previous class.

The upper limit of the first class is one less than the lower limit of the second class. In order to find the upper limit of the other classes, the class width was added to the upper limit of the first class. The same operation was repeated until finding the upper limit of last class. It is important that the classes include all the data value.

The same operations that are given above are also performed for the remaining criteria.

Score was assigned in five point scale for each data group by the decision group according to the factor's positive or negative effect on attractiveness of the location.

Assigned scores, on a scale ranging from 1 to 5, for location factor OBA based on the frequency distribution are depicted in Table 4.10.

Table 4.10: Scores for Number of Other Banks' ATMs

Number of Other Banks' (OBA)	Score
0-13	1
14-27	2
28-41	3
42-55	4
56-69	5

The district that has other banks' ATMs in the range of 0-13 was given the score of "1", whilst the district that has other banks' ATM in the range of 56-69 was given the score of "5". Therefore, District-1 was assigned score "1" as it has 4 ATMs and District-2 was assigned score "2" as it has 15 ATMs. Consequently, the higher score denotes the stronger eagerness of the bank to locate ATMs in the related districts. The scores for each district are presented in Table 4.11.

Table 4.11: Scores of the Districts for OBA

District	Score	District	Score
District-1	1	District-13	2
District-2	2	District-14	5
District-3	1	District-15	2
District-4	1	District-16	1
District-5	2	District-17	2
District-6	2	District-18	1
District-7	2	District-19	3
District-8	3	District-20	2
District-9	2	District-21	1
District-10	3	District-22	2
District-11	1	District-23	2
District-12	2		

The formulation of weighted total score calculation for each district is given as follow:

$$S_t = \sum_{f \in F} w_f s_{ft} \;\; \forall t \in T, \tag{4.18}$$

Indices & Sets:

f : index for location factor,

t : index for district,

F : finite set of indices associated with LFs,

T : finite set of indices associated with districts,

Parameters:

w_f : the weight of location factor f, $\forall f \in F$,

s_{ft} : the score of district t according to the location factor f, $\forall t \in T$,

s_t : total score of district t, $\forall t \in T$,

We calculated the weighted total score (WTS) for each district based on the decision group's score and weights of LFs obtained from FANP. The score, weighted score and weighted total score of each district is provided in Table 4.12. Moreover, the scores, weighted scores, and weighted total scores for each ATM are given in Appendix D.

As we mentioned above, since District-1 was assigned score "1" for OBA and the weight of OBA is 1.49%, the weighted score of OBA was found 0.015. The same computation was performed for each LF and district. Then, the weighted total score of each LF based on each district was obtained by adding each LFs weighted score together.

Including weighted total score into the model strengthened the model's validity since the decision makers' experience and foresight was incorporated in the model.

In ATM location problem, subjectivity should be involved in the decision process. However, making decisions only based on subjectivity would cause that the selection process is lack of accuracy and consistency. Moreover, there are multiple objectives that decision maker should take into account while developing the deployment strategy. In order to overcome these limitations, we integrate FANP and global criterion method.

Table 4.12: Scores, Weighted Scores and Total Weighted Scores of Districts

	Score					Weighted Score					Weighted Total Score
Districts/ LFs	TV	CI	CE	BA	OBA	TV	CI	CE	BA	OBA	WTS
District-1	5	2	1	5	1	1.04148	0.43755	0.02969	2.41079	0.01485	3.93436
District-2	1	1	2	3	2	0.20830	0.21877	0.05939	1.44647	0.02970	1.96263
District-3	1	1	1	5	1	0.20830	0.21877	0.02969	2.41079	0.01485	2.88240
District-4	1	1	1	3	1	0.20830	0.21877	0.02969	1.44647	0.01485	1.91809
District-5	2	1	2	3	2	0.41659	0.21877	0.05939	1.44647	0.02970	2.17093
District-6	5	1	2	3	2	1.04148	0.21877	0.05939	1.44647	0.02970	2.79581
District-7	3	2	4	5	2	0.62489	0.43755	0.11877	2.41079	0.02970	3.62170
District-8	3	1	4	3	3	0.62489	0.21877	0.11877	1.44647	0.04455	2.45346
District-9	3	2	2	2	2	0.62489	0.43755	0.05939	0.96432	0.02970	2.11584
District-10	3	1	2	5	3	0.62489	0.21877	0.05939	2.41079	0.04455	3.35839
District-11	1	1	1	3	1	0.20830	0.21877	0.02969	1.44647	0.01485	1.91809
District-12	2	1	5	5	2	0.41659	0.21877	0.14847	2.41079	0.02970	3.22432
District-13	2	2	1	3	2	0.41659	0.43755	0.02969	1.44647	0.02970	2.36001
District-14	4	2	4	2	5	0.83318	0.43755	0.11877	0.96432	0.07425	2.42807
District-15	4	3	2	5	2	0.83318	0.65632	0.05939	2.41079	0.02970	3.98938
District-17	2	1	1	3	2	0.41659	0.21877	0.02969	1.44647	0.02970	2.14123
District-18	5	5	1	1	1	1.04148	1.09387	0.02969	0.48216	0.01485	2.66205
District-19	5	5	3	1	3	1.04148	1.09387	0.08908	0.48216	0.04455	2.75114
District-20	4	2	3	5	2	0.83318	0.43755	0.08908	2.41079	0.02970	3.80030
District-21	3	3	1	5	1	0.62489	0.65632	0.02969	2.41079	0.01485	3.73654
District-22	2	1	2	1	2	0.41659	0.21877	0.05939	0.48216	0.02970	1.20661
District-23	5	2	1	3	2	1.04148	0.43755	0.02969	1.44647	0.02970	2.98490

4.5.4 Phase 4: Finding ATM locations

4.5.4.1 Formulation of the MOO Model

The steps of Phase 4 is given in Figure 4.13. Global criterion method was applied to the problem in which there are three objectives. Moreover, weighted total score (WTS) is regarded as the first objective of the MOO model.

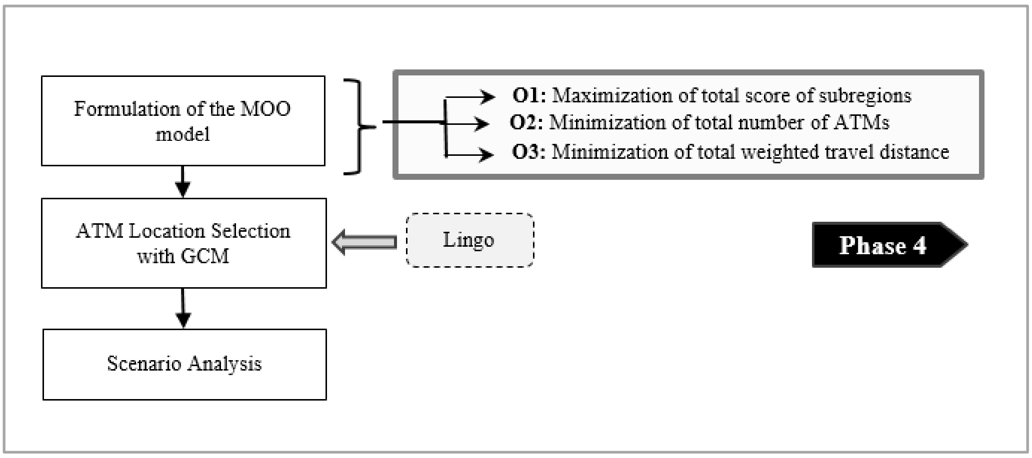

Figure 4.13: Steps of the Phase 4

Mathematical model formulation for the ATM location problem was constructed as follows:

$$Max\ f_1(x) = \sum_{j \epsilon M} S_j Y_j \tag{4.19}$$

$$Min\ f_2(x) = \sum_{j \epsilon M} Y_j \tag{4.20}$$

$$Min\ f_3(x) = \sum_{i \epsilon N} \sum_{j \epsilon M} a_i X_{ij} d_{ij} \tag{4.21}$$

Subject to:

$$\sum_{j \epsilon M} X_{ij} = 1, \quad \forall i \in N, \tag{4.22}$$

$$X_{ij} \leq Y_j, \quad \forall i \in N, j \in M, \tag{4.23}$$

$$d_{ij}X_{ij} \leq D, \quad \forall i \in N, j \in M, \tag{4.24}$$

$$\sum_{i \in N} X_{ij}a_i \leq C, \quad \forall j \in M, \tag{4.25}$$

$$\sum_{j \in M_1} (1 - Y_j)v_j + \sum_{j \in M_2} Y_j u_j \leq CB \tag{4.26}$$

$$\sum_{j \in M} Y_j o_j \leq OB \tag{4.27}$$

$$Y_j \in \{0,1\}, \quad \forall j \in M, \tag{4.28}$$

$$X_{ij} \in \{0,1\}, \ \forall i \in N, j \in M, \tag{4.29}$$

The model decides the locations for ATMs and accordingly, the total number of ATMs that is required to be deployed. As a result of the model, if there is any ATM that the bank needs to remove, it is also determined. Additionally, the model assigns the demand nodes to the deployed ATMs.

The following notation is used in the model:

Indices & Sets:

i	**:** index for demand nodes (sites of bank's ATMs and the competitors' ATMs),
j	**:** index for potential ATM sites (sites of bank's ATMs and the competitors' ATMs),
N	$= \{1, \dots, n\}$: the set of demand nodes where demand originates in,
M_1	$= \{j_1, \dots, j_q\}$: the set of nodes where existing ATMs are located,
M_2	$= \{j_{q+1}, \dots, j_m\}$: the set of nodes where new ATMs can be located,

M $= \{1, \dots, m\} = M_1 \cup M_2$: the set of all facility nodes where existing facilities located and new ATMs can be located,

q $= |M_1|$: the number of existing ATMs,

m $= |M|$: the total number of existing and potential ATMs

Parameters:

v_j : the cost of removing an existing ATM at node $j \in M_1$,

u_j : the cost of deploying a new ATM (set-up cost) at node $j \in M_2$,

o_j : operational cost for a deployed ATM at node $j \in M$,

a_i : demand amount (transaction volume) at node i,

d_{ij} : distance between demand node i and potential ATM site j,

OB : the total annual budget available for operational expenses (opex),

CB : the total budget available for capital expenses (capex),

S_j : total weighted preference score for potential ATM site j (higher values denote higher preference and the score of related district will be assigned to each site),

C : capacity of ATM which is equal for all ATMs,

D : maximum distance that customers are allowed to travel.

Decision variables:

Y_j : a binary indicator for potential ATM deployment,

$$Y_j = \begin{cases} 1, & \text{if ATM is located at node } j \in M \\ 0, & \text{otherwise} \end{cases}$$

X_{ij} : a binary indicator for demand assignment to ATM site,

$$X_{ij} = \begin{cases} 1, & \text{if demand at node } i \in N \text{ is served by a potential ATM at node } j \in M \\ 0, & \text{otherwise} \end{cases}$$

Objectives and Constraints:

Objective function $f_1(x)$ maximizes the weighted total score of locations; objective function $f_2(x)$ minimizes the total number of ATMs whilst objective function $f_3(x)$ minimizes the total weighted travel distance of customers.

Constraint 4.22 ensures that total demand in each node will be satisfied which means there will not be any demand node whose demand cannot be met. Constraint 4.23 states that demand can be only satisfied by the deployed ATMs. If an ATM is not deployed at a node, then no demand is assigned to that alternative location node. Constraint 4.24 limits the distance that customers will tolerate to travel and this distance is called "distance threshold". Constraint 4.25 indicates that satisfied demand cannot exceed the capacity of each located ATM. Therefore, total demand that is assigned to an alternative location is limited with the ATM capacity. Constraint 4.26 guarantees that set-up and removing cost cannot exceed the budget limit which is determined for capital expenses. If a deployed ATM is removed, the removing cost of an ATM is considered; where the deployment cost is taken into consideration if a new ATM is located. If $\mathrm{Y_j} = 0$ for $\mathrm{j} \in \mathrm{M_1}$, then the existing ATM $\mathrm{j} \in \mathrm{M_1}$ is going to be removed with the cost of $(1 - Y_j)v_j$; if $Y_j = 1$ for $j \in M_2$, then a new ATM is going to be deployed at the potential facility site j with a cost of $Y_j u_j$. Constraint 4.27 defines the total annual budget limit for operational expenses which includes operational cost for ATM placements. Moreover, if $Y_j = 1$ for $j \in M$, then open facility j is going to give service with cost of $Y_j o_j$. Constraints 4.28 and 4.29 are integrality constraints for the problem variables that ensure the decision variables are zero-one variables.

The characteristics and assumptions of the model are presented below:

- The problem is endogenous, i.e., the number of facilities to be located is found as a result of the model,
- There are multiple ATMs that are intended to be located,
- There is only one type of ATM, i.e. single facility type is considered,
- Only one ATM can be located at each node (alternative location),

- Weighted score for each potential location is pre-calculated based on related district according to Fuzzy ANP weights,
- Demand at each node is satisfied by only one ATM,
- Demand is served by the ATM which is closest to the demand node,
- The problem is capacitated since each ATM has limited capacity and all the ATMs have the same capacity,
- The decision space is discrete,
- Distance between demand node and potential ATM site is pre-calculated based on the great circle distance,
- There is a distance limit (threshold) that customers are allowed to travel,
- Alternative locations are regarded as the bank's own and its competitors' ATM locations,
- All relevant data is deterministic, i.e. are fully known in advance,
- There is one planning period, i.e. static location problem,
- The problem has multiple objectives,
- Competition exists as the locations of competitors are taken into account,
- During the decision process, the competitors make no change in locations of their ATMs.

4.5.4.2 ATM Location Selection with CGM

In order to aply Global Criterion Method, we transformed three objectives (Equations 4.19, 4.20 and 4.21) into one objective by using Equation 4.30. We used $|z^{nad} - z_i^*|$ in the denominator to normalize objective functions which are in different units.

$$Minimize \sum_{i=1}^{3} \left| \frac{f_i(x) - z_i^*}{z^{nad} - z_i^*} \right| \tag{4.30}$$

The CGM model which consists of Equation 4.30 and constraints 4.22 to 4.29 and single-objective optimization models which are also subject to constraints 4.22 – 4.29 are solved by using Lingo software on Intel i7 2.2 GHz personal computer with 6.0 GB of memory.

4.5.4.3 Scenario Analysis

Different scenarios were analyzed to provide solution alternatives to the bank, so that the bank management may decide the most appropriate solution. The distance threshold was modified in each scenario to produce different solutions since they are the only parameters that are in control of the bank. The distance threshold was changed between 0.5 and 1.5 in each scenario. However, when the models run for distance threshold whose values are 0.5, 0.6, 0.7 and 0.8, it ends up infeasible where any solution that satisfies all the constraints cannot be found. Therefore, four scenarios were considered as in Table 4.13.

Table 4.13: Distance Threshold for Each Scenario

	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**
Distance threshold (km)	0.9	1.0	1.2	1.5

We solved three single-objective optimization models seperately for each scenario and recorded their ideal and nadir values before running the GCM model. Then ideal and nadir values are used in the GCM model.

Payoff tables are formed to estimate the ideal and nadir values which are presented in Table 4.14. The 1st row of each scenario in the given table displays the values of all the objective functions that are calculated at the point where $f_1(x)$ obtains its best value. 2nd and 3rd rows also show the values of all the objective functions that are computed at the point where $f_2(x)$ and $f_3(x)$ obtain their best values respectively.

Table 4.14: Payoff Table for each Scenario

Scenario	$f_i(x)$	$f_1(x)$	$f_2(x)$	$f_3(x)$
I	**max $f_1(x)$**	89.64	33	12,632.81
	min $f_2(x)$	30.10	11	21,439.30
	min $f_3(x)$	82.42	33	532.94
II	**max $f_1(x)$**	90.15	33	11,568.50
	min $f_2(x)$	29.97	10	22,581.60
	min $f_3(x)$	82.42	33	532.94
III	**max $f_1(x)$**	90.46	33	19,284.68
	min $f_2(x)$	19.57	7	29,123.02
	min $f_3(x)$	81.12	33	518.07
IV	**max f1(x)**	92.90	33	22,301.70
	min f2(x)	15.71	5	37,012.70
	min f3(x)	82.75	33	502.53

In each scenario, budget for capex which includes set-up and closing cost and budget for opex are set to 1.1 million TL and 2 million TL respectively. The models in Lingo for solving each objective and GCM model are provided in Appendix E with their solutions. The solutions of the CGM models are given in terms of ATM locations for each scenario in Table 4.15. The cost of applying each scenario was also found the same since all the scenarios remove 2 ATM and locate 11 ATMs. In other words, removing cost, set-up cost and operational cost are 1.1 million TL, 10,000 TL and 1.860 million TL respectively for each scenario.

L19 and L20 or L21 are the ATMs that are decided to be removed in all the scenarios since L20 and L21 are located next to each other. Moreover, L26, L317 or L318 and L326 or L327 (these ATMs are also deployed next to each other) are the common selected locations in all scenarios.

Table 4.15: The solutions of the GCM model in terms of ATM locations

Scenarios	Removed ATMs	Located ATMs	Solution
Scenario I	L19, L21	L26, L58, L191, L199, L217, L315, L317, L322, L323, L326, L332	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18, L20, L22, L26, L58, L191, L199, L217, L315, L317, L322, L323, L326, L332
Scenario II	L19, L21	L26, L58, L186, L187, L315, L318, L322, L323, L326, L332, L409	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18, L20, L22, L26, L58, L186, L187, L315, L318, L322, L323, L326, L332, L409
Scenario III	L19, L20	L26, L58, L186, L187, L315, L317, L321, L322, L323, L327, L332	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18, L21, L22, L26, L58, L186, L187, L315, L317, L321, L322, L323, L327, L332
Scenario IV	L19, L20	L26, L193, L315, L316, L317, L321, L323, L325, L326, L329, L332	L1, L2, L3, L4, L5, L6, L7, L8, L9, L10, L11, L12, L13, L14, L15, L16, L17, L18, L21, L22, L26, L193, L315, L316, L317, L321, L323, L325, L326, L329, L332

4.5.5 Phase 5: Visualizing the Results and Evaluation of the Scenarios

The steps of Phase 5 are depicted in Figure 4.14.

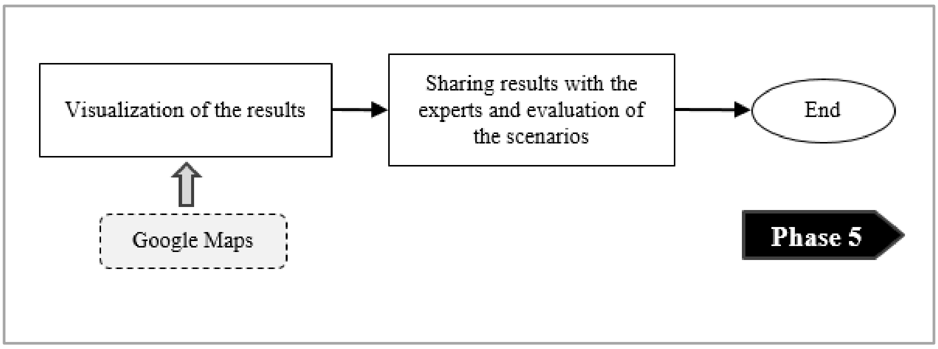

Figure 4.14: Steps of the Phase 5

4.5.5.1 Visualizing the Results

We utilized Google Earth Pro software to visualize the solutions of the problem, since it lets users to import complete dataset and view it in satellite projection (Leydesdorff & Persson, 2010).

In the model, since the application region is Besiktaş and subregions are its districts; it is helpful for DM to see the borders of each district and locations of ATMs.

Wikimapia.org is a free mapping tool that enables users explicitly mark polygons on a map to indicate places of interest (Mummidi & Krumm, 2008). Therefore, “Ge.kml”, a free add-on was used to obtain the borders of each district and display these borders on Google Earth. The borders of districts are presented in Figure 4.11 and they were validated by the data which is provided by Istanbul metropolitan municipality website.

Moreover, the coordinates of ATM locations that is given in Appendix B, were converted into the kml (Keyhole Markup Language) format since they were in Ms Office Excel format and Google Earth only accepts the data in kml format.

4.5.5.2 Evaluation of the Scenarios

The results of each scenario is presented in Table 4.16 based on the values of each objective function.

Table 4.16: Results for each Scenario

	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**
Objective value	0.979	0.981	0.980	0.982
$f_1(x)$	87.22	87.73	87.99	90.44
$f_2(x)$	31	31	31	31
$f_3(x)$	1,151.14	1,147.79	1,153.33	1,291.50

From Table 4.16, it is seen that Scenario II performs better than Scenario I for all objective functions even though the objective value of Scenario I is smaller than Scenario II. Therefore, Scenario I was eliminated from the solution set. Furthermore, all scenarios perform the same for the second objective function. On the other hand, it can not be concluded that one of Scenario II, III and IV is better than another for both the first and third objective. Hence, we examined the results of these three scenarios in detail.

Initially, an assignment model was built in Lingo to compare the results of these scenarios with the existing situation. The Lingo script for assignment model and its solution are provided in Appendix E.

Mathematical model formulation for the assignment problem, which assigns the demand on the demand nodes to the existing ATM locations, is constructed as follows:

$$Minimize \sum_{i \epsilon N} \sum_{j \epsilon M} a_i X_{ij} d_{ij} \qquad (4.31)$$

Subject to:

$$\sum_{j \epsilon M} X_{ij} = 1, \quad \forall i \in N, \qquad (4.32)$$

$$\sum_{i \epsilon N} X_{ij} a_i \leq C, \quad \forall j \in M, \qquad (4.33)$$

$$X_{ij} \in \{0,1\}, \quad \forall i \in N, j \in M, \qquad (4.344)$$

The following notation is used in the model:

Indices & Sets:

i **:** index for demand nodes (sites of bank's ATMs and the competitors' ATMs),

j **:** index for existing ATM sites of the bank,

N $= \{1, \ldots, n\}$: the set of demand nodes where demand originates in,

M $= \{1, \ldots, m\}$ the set of facility nodes where existing facilities located,

m $= |M|$: the number of existing ATMs.

Parameters:

a_i : demand amount (transaction volume) at node i,

d_{ij} : distance between demand node i and potential ATM site j,

C : capacity of ATM which is equal for all ATMs.

Decision variables:

X_{ij} : a binary indicator for demand assignment to ATM site,

$$X_{ij} = \begin{cases} 1, & \textit{if demand at node } i \in \text{N} \textit{ is served by a potential ATM at node } j \in \text{M} \\ 0, & \textit{otherwise} \end{cases}$$

Objectives and Constraints:

Objective function 4.31 minimizes the total weighted travel distance of customers. Constraint 4.32 ensures that total demand in each node will be satisfied which means there will not be any demand node whose demand cannot be met. Constraint 4.33 indicates that satisfied demand cannot exceed the capacity of each located ATM. Therefore, total demand that is assigned to an existing ATM location is limited with the ATM capacity. Moreover, constraint 4.34 is an integrality constraint that ensures the decision variable is a zero-one variable.

Assignment model that was built in Lingo and its Lingo solution are provided in Appendix F, respectively. The total distance that the customers travelled was calculated based on the assignment model under the assumptions of that each customer uses the closest ATMs and even the customers that use the competitors' ATMs would use the bank's own ATMs.

Table 4.17 presents the values of each objective functions for the existing situation.

Table 4.17: Results for Existing Situation

	Value
$f_1(x)$	49.65
$f_2(x)$	22
$f_3(x)$	1,338.07

Additionally, as it is seen from Table 4.17, all the scenarios perform much better than the existing situation for the first and third objectives. Since, additional ATMs are deployed in all the scenarios, second objective value of the existing situation is better than all scenarios. Moreover, the distance threshold for the existing situation was found as 2.45 km. In other words, the customer satisfaction is increased by reducing the travel distance limit (distance threshold) of the customers. Moreover, the operational cost is 1.32 million TL for the existing ATM locations since there are 22 ATMs placed and there is not any set-up and removing cost that is met.

Furthermore, the locations of ATMs found as a result of each scenario are presented on the maps in Figure 4.15, 4.16, 4.17 and 4.18 respectively. Additionally, the locations of existing ATMs were showed on the map in Figure 4.19.

After analyzing the scenario results and the locations of ATMs on the map, Scenario II, in which the distance threshold is 1.0 km, was suggested to the bank among Scenario II, III and IV since the Scenario I is dominated by the other scenarios.

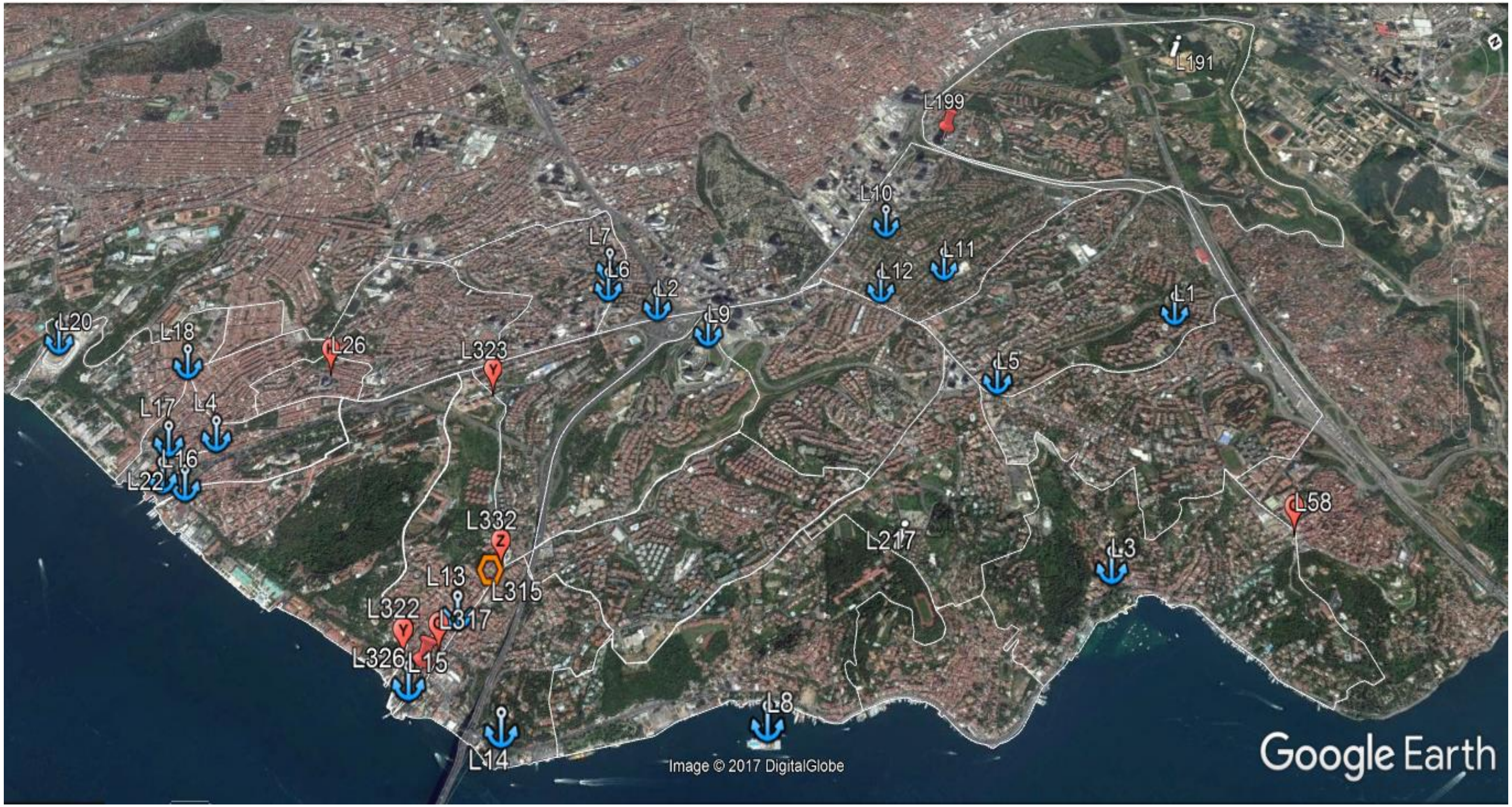

Figure 4.15: ATM Locations for Scenario I

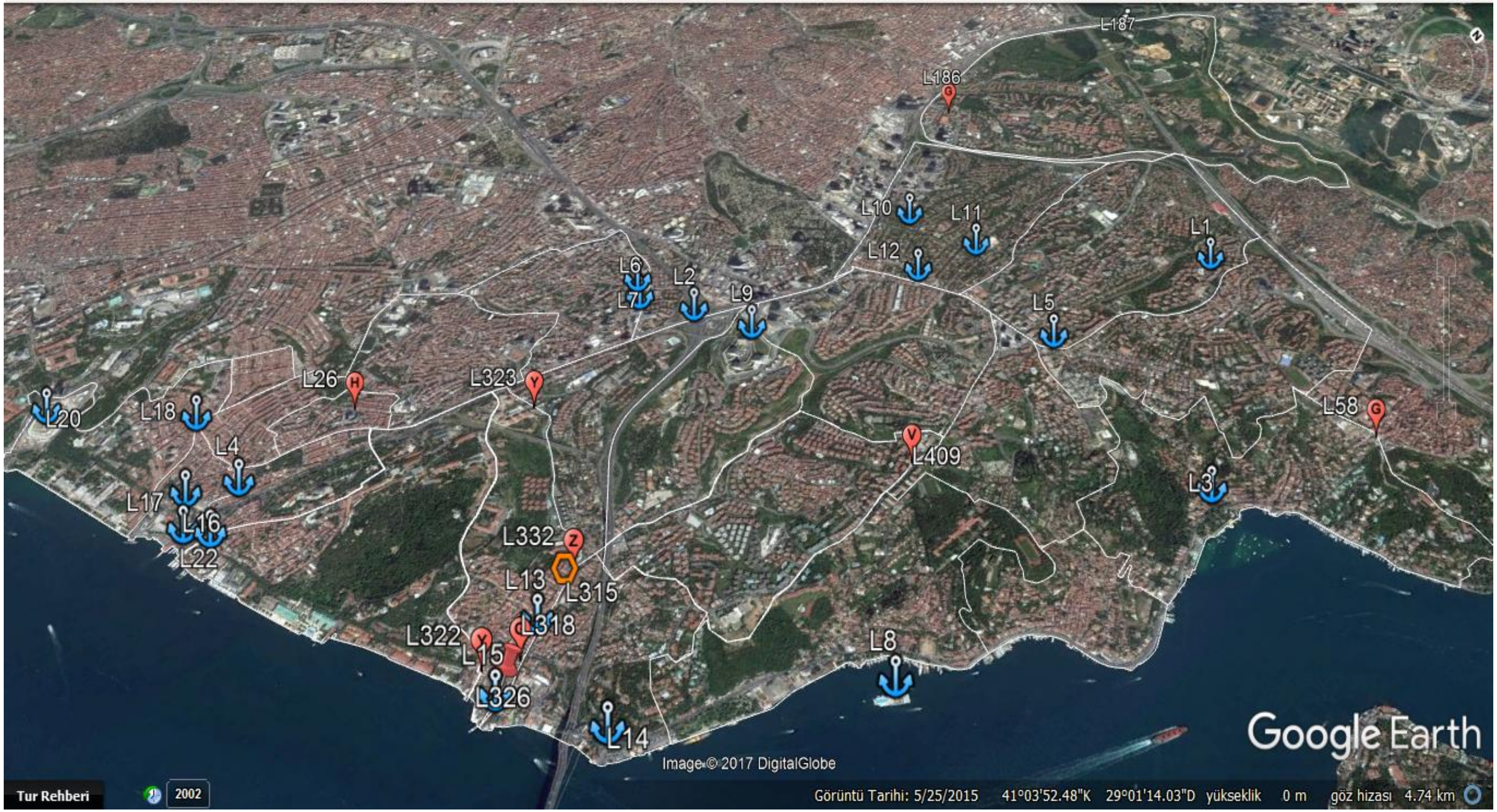

Figure 4.16: ATM Locations for Scenario II

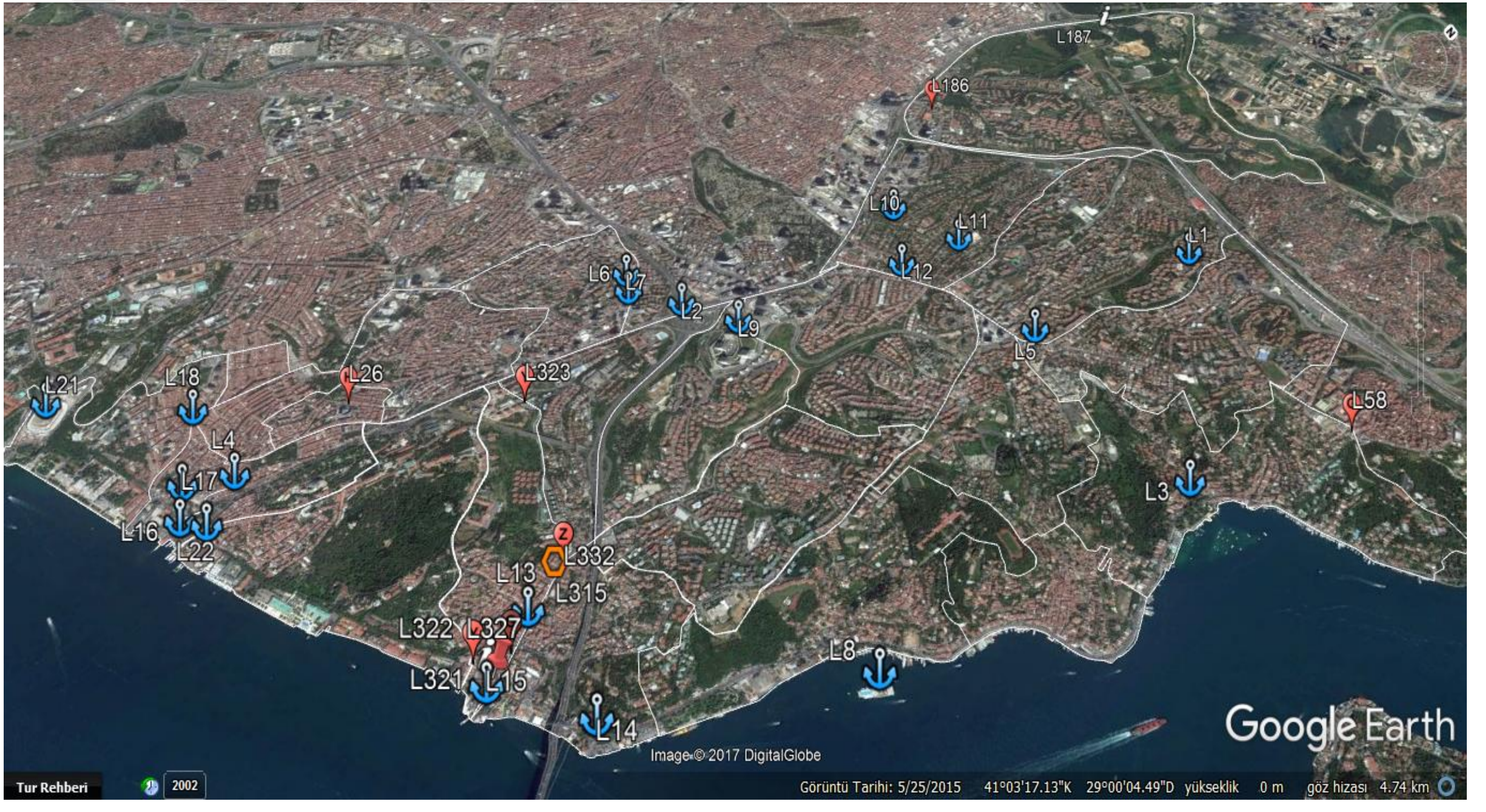

Figure 4.17: ATM Locations for Scenario III

Figure 4.18: ATM Locations for Scenario IV

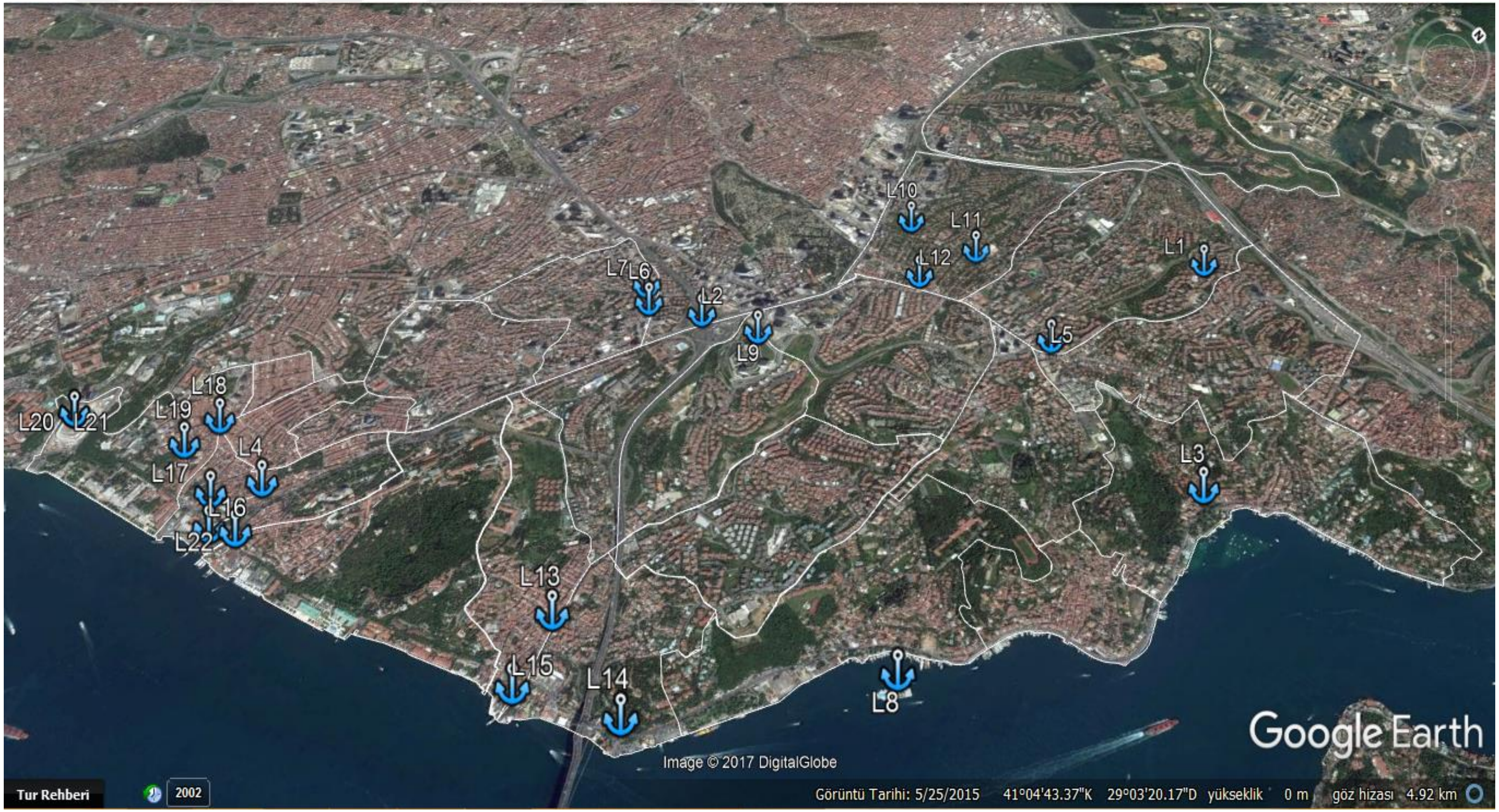

Figure 4.19: Existing ATM Locations

4.6 Application Results

As a result of the first stage of the study, it is concluded that “Number of Bank’s ATMs”, “Expected Level of Commission Income” and “Expected Level of Transaction Income” criteria play a vital role in the evaluation of potential locations for ATMs with the priority weights of 48.22%, 21.88% and 20.83% in percentage correspondingly. The weights of three criteria constitute the 91% of the whole network. “Demographics” and “Traffic” main categories are found as zero and this shows that decision group did not really care about these categories compared to others. This result found reasonable by the experts as the criteria that are in Demographics and Traffic main categories were taken into account to include potential customers, however this potential had been considered in the “Expected Level of Commission Income” and “Expected Level of Transaction Income” criteria.

Moreover, in the second stage, we proposed the 2nd Scenario to the bank which is depicted in Figure 4.16. In 2nd Scenario, one ATM is located in District 1, two ATMs are deployed in District-10, six ATMs are located in District 15 and one ATM is placed in District-21, where the bank has no ATMs in the existing situation. Additionally, one more ATM is deployed in District-5 in which there is only one ATM of the bank. This is an interesting finding of the solution that the methodology suggests deploying ATMs where there is not any ATM of the bank in the existing case. However, this is a rational argument since there are several ATMs of other banks in these districts. The results can be interpreted as the model can also recognize the potential of the subregions. Furthermore, the model removes two ATMs which are in District-22.

Application results indicate that the proposed methodology intends to spread the bank’s ATM based on the distance threshold. In addition to this, ATMs are generally located close to borders of the districts, especially where there are not any ATMs of the bank on the related districts or its neighbors. Moreover, the produced solutions give better results than the current situation in terms of customer satisfaction which we measure with distance threshold and total weighted travel distance and the total score which is regarded as location attractiveness indicator.

This chapter presents the proposed methodology, which we consider essentially in two main stages, in five phases in detail. In the first stage of the study the most important location factors and their importance weights were calculated by Fuzzy ANP. Moreover, in the second stage, the weights of location factors were used to compute the scores for each subregion. Score maximization is included in the multiobjective model as one of the objectives which was considered to build a new location strategy. Global Criterion Method was used to find the optimum solution of the multiobjective model. Then, different scenarios were analyzed which suggest different solution alternatives. In order to validate the proposed methodology the scenarios were compared with the existing case and visualized on Google maps.

Chapter 5 concludes the study and introduces the future research areas for the thesis.

5. CONCLUSION

Accessibility of the service is a significant factor that customers value while choosing their service provider. Moreover, ATMs are one of the main distribution channels with a promising future that are used to provide service to customers in the banking industry. Therefore, banks have been constantly striving to expand their ATM network in order to meet customer demand and enhance customer satisfaction. Nevertheless, locating ATMs at every corner is certainly not the right decision as it would boost costs while increasing customer satisfaction. Additionally, good location can bring substantial benefit to the performance of the facility and accordingly performance of the bank as it can increase market share and profitability.

On the other hand, choosing the most suitable ATM location is not an easy task as it requires considering several conflicting criteria which affect location decision. Moreover, it is a strategic and long-term decision for the banks as it affects the competitiveness and ATMs are expected to be operable and profitable for a long period of time. Hence, banks have to make the deployment decisions by thinking it thoroughly and conduct in-depth analyses.

Although facility location problems have been arousing interest growingly, ATM deployment problem has not been received enough attention in the existing literature that has been looked into. In addition to this, banks have been undervalued the ATM location problem and its potential benefits. In practice, banks generally follow the lead of the industry and observe where they locate their ATMs or they prefer locations where most of the banks' ATMs are situated. These locations are analyzed and supported by some numerical data but in the end location decisions are made instinctively without any scientific method. Moreover, appropriate location selection requires time and money; therefore most of the banks decide not to attempt it. Banks tend to apply classical methods while making decisions even these wrong decisions cause substantial increase in operational expenses and decrease in customer satisfaction and reputation value. Therefore, an analytical and systematic method is required in the field that aids decision makers who work in this challenging area. Addressing this important problem and the intention of filling the gap in the literature and practice by proposing a methodology which enables making solid ATM location decisions is the motivation of our study.

A variety of different methods are utilized for decision-making processes in location management. However, an integrated methodology which combines Fuzzy ANP and Global Criterion Method is presented in the study.

ANP is one of the best methods in deciding complex structures that comprises many conflicting tangible and intangible factors holding interactions. Classical ANP requires deterministic evaluations, however in most cases decisions are made within uncertain environment. This issue leads to the employment of Fuzzy ANP in the real life in order to deal with uncertain human judgments including internal inconsistency. ATM deployment problem also embodies this complexity as it consists of several criteria. In the proposed method, ANP and fuzzy logic is integrated successfully by the use of triangular fuzzy numbers and Chang's Extent Analysis. It is seemed that fuzzy ANP approach simplifies the evaluation process as the pairwise comparisons are performed in a more reliable way. Nonetheless, the decisions that are only based on MCDM techniques would not provide the optimal results. Accordingly, mathematical model that considers resource limitations is embedded to the solution approach. In addition to this, decision makers cannot efficiently evaluate many alternative locations simultaneously by using MCDM techniques such as AHP, ANP, Electre, TOPSIS and etc. In real world problems, decision makers can face complex problems that require evaluating hundreds of candidates. Therefore, we employed Global Criterion Method which is a non-priori multiobjective optimization technique and can produce Pareto optimal solutions. This method is more applicable than other multiobjective optimization methods as it does not require any reference value from the decision maker and the method produces these values by itself. In this way, selection of appropriate locations from many alternatives becomes achievable. Furthermore, applying the proposed methodology into real life case studies strengthened the validity of the results and the applicability of the methodology.

Examining and understanding the location criteria is the primary condition for making any location selection decision. We perceived the absence of this perspective in the interviews that were conducted with different experts who work on ATM management in Turkey. Therefore, ATM deployment problem criteria are analyzed in detail. Then, a mathematical optimization method is used by including the importance of location factors into the model. The locations and number of ATMs were determined as a result of the model.

The most beneficial aspects of the presented approach can be stated as follows:

a. The model considers both the multiobjectivity nature of the problem, and includes subjectivity of the decision maker by assessing the attractiveness of locations.
b. The model enables the DM to make tradeoffs between conflicting objectives and evaluating different solutions.
c. The model is capable of performing what-if scenarios related to ATM location strategy. Accordingly, the model can be simply adjusted to varying resource commitments and service policies.
d. The proposed approach can be easily employed and give satisfactory solutions not only for ATM location problem, but it may be also applied for other service facility location problems.

Nevertheless, to the best of our knowledge MADM and MODM methods has not been applied to ATM deployment problem together in the literature. Another major contribution is the introduction of a new perspective that incorporates the experience and knowledge of the decision makers into a scientific approach while considering resource limitations and we believe this is very critical to make feasible and reliable decisions in ATM location selection.

Consequently, this study could be regarded as successful application of the integrated methodology for ATM location selection problem and it is hoped to take a part as a decision aid tool for reserchers and practitioners who work and struggle in ATM deployment management.

As aforementioned this study intends to find a sound solution for ATM location problem which was applied for a Turkish bank. The proposed methodology evaluates the existing ATMs of the bank and suggests new location alternatives in Beşiktaş since only this municapility of İstanbul was considered. Therefore, expanding the geographic boundaries and solving the problem for a larger geographic area can be regarded as a future research. Even though it is mentioned that this model can be utilized by the banks who are at the initial stage of the ATM deployment, investigating this problem as a separate issue can be a future direction. Moreover, we calculate the demand by considering the number of transactions that are performed by the bank's customers on the banks' own ATMs and other banks' ATMs. However, demographic information and GSM operator data, which provides foot traffic on the streets, can also be used to project the future demand data despite the cost of obtaining this data. Computation of demand data differently can be another future research direction. Furthermore, all the model parameters are assumed deterministic and it is assumed that demand of customers which occurs on the same node, could be satisfied only from one ATM. Hence by the taking probabilistic parameters into account, the demand of the customers can be met by different ATMs and this issue can be considered a future research. In other words, the customers whose demands occur on the same node, would be allowed to use different ATMs. Additionally, we adopted fuzzy scale of Chang's fuzzy AHP method (D.-Y. Chang, 1996) to our research in order to convert linguistic terms to triangular fuzzy numbers. However, deciding the fuzzy scale based on the problem can be another future research area. Nonetheless, since the ranges for the scores are delicate, in the future research the scores can be dealt with fuzzy set theory. Weigting the each objective and using weighted metrics method instead of global criterion method can also be regarded as a future study. On the other hand, utilizing another MADM technique and comparing the results with FANP can be considered as a future research direction. Lastly, the most important future research area would be developing a generic and user friendly tool that enables performing whole methodology in one software. This tool would make the methodology more attractive and applicable for the financial institutions and other researches who work on ATM location management.

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APPENDICES

Appendix A- Computations for Chang's Extent Analysis

A.1 Calculations of Comparison Matrices between Main Categories

Control element: Financial

	Financial									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Financial			X							Strategic
Financial								X		Commercial
Strategic								X		Commercial

	Financial		
	Financial	Strategic	Commercial
Financial	(1,1,1)	(3/2,2,5/2)	(2/7,1/3,2/5)
Strategic	(2/5,1/2,2/3)	(1,1,1)	(2/7,1/3,2/5)
Commercial	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)

	Financial			Strategic			Commercial		
	l	m	u	l	m	u	l	m	u
Financial	1	1	1	1 1/2	2	2 1/2	2/7	1/3	2/5
Strategic	2/5	1/2	2/3	1	1	1	2/7	1/3	2/5
Commercial	2 1/2	3	3 1/2	2 1/2	3	3 1/2	1	1	1

	l	m	u
Financial	2,79	3,33	3,90
Strategic	1,69	1,83	2,07
Commercial	6,00	7,00	8,00
Sum	10,47	12,17	13,97
Inverse	0,07	0,08	0,10

	l	m	u
Sfinancial =	0,199	0,274	0,372
Sstrategic =	0,121	0,151	0,197
Scommercial =	0,430	0,575	0,764

		Min
V (Sfinacial ≥ Sstrategic) =	1	0
V (Sfinacial ≥ Scommercial) =	0	
V (Sstrategic ≥ Sfinacial) =	0	0
V (Sstrategic ≥ Sc) =	0	
V (Scommercial ≥ Sfinacial) =	1	1
V (Scommercial ≥ Sstrategic)=	1	

	W'	W
Financial =	0	0,000
Strategic =	0	0,000
Commercial =	1	1,000
Sum=	**1,000**	**1,000**

Control element: Strategic

	Strategic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Financial	X									Strategic
Financial			X							Traffic
Financial							X			Commercial
Strategic								X		Traffic
Strategic									X	Commercial
Traffic							X			Commercial

	Strategic			
	Financial	Strategic	Commercial	Traffic
Financial	(1,1,1)	(7/2,4,9/2)	(2/5,1/2,2/3)	(3/2,2,5/2)
Strategic	(2/9,1/4,2/7)	(1,1,1)	(2/9,1/4,2/7)	(2/7,1/3,2/5)
Commercial	(3/2,2,5/2)	(7/2,4,9/2)	(1,1,1)	(3/2,2,5/2)
Traffic	(2/5,1/2,2/3)	(5/2,3,7/2)	(2/5,1/2,2/3)	(1,1,1)

	Financial			Strategic			Commercial			Traffic		
	l	m	u	l	m	u	l	m	u	l	m	u
Financial	1	1	1	3 1/2	4	4 1/2	2/5	1/2	2/3	1 1/2	2	2 1/2
Strategic	2/9	1/4	2/7	1	1	1	2/9	1/4	2/7	2/7	1/3	2/5
Commercial	1 1/2	2	2 1/2	3 1/2	4	4 1/2	1	1	1	1 1/2	2	2 1/2
Traffic	2/5	1/2	2/3	2 1/2	3	3 1/2	2/5	1/2	2/3	1	1	1

	l	m	u
Financial	6,40	7,50	8,67
Strategic	1,73	1,83	1,97
Commercial	7,50	9,00	10,50
Traffic	4,30	5,00	5,83
Sum	19,93	23,33	26,97
Inverse	0,04	0,04	0,05

	l	m	u
Sfinancial =	0,237	0,321	0,435
Sstrategic =	0,064	0,079	0,099
Scommercial =	0,278	0,386	0,527
Straffic =	0,159	0,214	0,293

		Min
V (Sf ≥ Ss)=	1	
V (Sf ≥ Sc)=	0,149	0,149
V (Sf ≥ St)=	1	
V (Ss ≥ Sf)=	0	
V (Ss ≥ Sc)=	0	0
V (Ss ≥ St)=	0	
V (Sc ≥ Sf)=	1	
V (Sc ≥ Ss)=	1	1
V (Sc ≥ St)=	1	
V (St≥ Sf)=	0,059	
V (St≥ Ss)=	1	0,059
V (St≥ Sc)=	0,079	

	W'	W
Financial =	0,149	0,123
Strategic =	0	0,000
Commercial =	1	0,828
Traffic =	0,059	0,049
Sum=	**1,208**	**1,000**

Control element: Traffic

	Traffic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Financial			X							Strategic
Financial		X								Traffic
Financial			X							Commercial
Strategic				X						Traffic
Strategic							X			Commercial
Traffic							X			Commercial

	Traffic			
	Financial	Strategic	Commercial	Traffic
Financial	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(5/2,3,7/2)
Strategic	(2/5,1/2,2/3)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Commercial	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
Traffic	(2/7,1/3,2/5)	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)

	Financial			Strategic			Commercial			Traffic		
	l	m	u	l	m	u	l	m	u	l	m	u
Financial	1	1	1	1 1/2	2	2 1/2	1 1/2	2	2 1/2	2 1/2	3	3 1/2
Strategic	2/5	1/2	2/3	1	1	1	2/5	1/2	2/3	2/3	1	1 1/2
Commercial	2/5	1/2	2/3	1 1/2	2	2 1/2	1	1	1	1 1/2	2	2 1/2
Traffic	2/7	1/3	2/5	2/3	1	1 1/2	2/5	1/2	2/3	1	1	1

	l	m	u
Financial	6,50	8,00	9,50
Strategic	2,47	3,00	3,83
Commercial	4,40	5,50	6,67
Traffic	2,35	2,83	3,57
Sum	15,72	19,33	23,57
Inverse	0,04	0,05	0,06

	l	m	u
Sfinancial =	0,276	0,414	0,604
Sstrategic =	0,105	0,155	0,244
Scommercial =	0,187	0,284	0,424
Straffic =	0,100	0,147	0,227

		Min
V (Sf ≥ Ss)=	1	1
V (Sf ≥ Sc)=	1	
V (Sf ≥ St)=	1	
V (Ss ≥ Sf)=	0	0,307
V (Ss ≥ Sc)=	0,307	
V (Ss ≥ St)=	1	
V (Sc ≥ Sf)=	0,534	0,534
V (Sc ≥ Ss)=	1	
V (Sc ≥ St)=	1	
V (St≥ Sf)=	0	0,226
V (St≥ Ss)=	0,934	
V (St≥ Sc)=	0,226	

	W'	W
Financial =	1	0,484
Strategic =	0,307	0,148
Commercial =	0,534	0,259
Traffic =	0,226	0,109
Sum=	**2,066**	**1,000**

Control element: Demographic

	Demographic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Financial		X								Strategic
Financial		X								Traffic
Financial	X									Demographic
Financial			X							Commercial
Strategic							X			Traffic
Strategic				X						Demographic
Strategic							X			Commercial
Traffic			X							Demographic
Traffic						X				Commercial
Demographic		X								Commercial

	Demographic				
	Financial	Strategic	Commercial	Traffic	Demographic
Financial	(1,1,1)	(5/2,3,7/2)	(3/2,2,5/2)	(5/2,3,7/2)	(7/2,4,9/2)
Strategic	(2/7,1/3,2/5)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(2/3,1,3/2)
Commercial	(2/5,1/2,2/3)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)	(2/7,1/3,2/5)
Traffic	(2/7,1/3,2/5)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)	(3/2,2,5/2)
Demographic	(2/9,1/4,2/7)	(2/3,1,3/2)	(5/2,3,7/2)	(2/5,1/2,2/3)	(1,1,1)

	Financial			Strategic			Commercial			Traffic			Demographic		
	l	m	u	l	m	u	l	m	u	l	m	u	l	m	u
Financial	1	1	1	2 1/2	3	3 1/2	1 1/2	2	2 1/2	2 1/2	3	3 1/2	3 1/2	4	4 1/2
Strategic	2/7	1/3	2/5	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	2/3	1	1 1/2
Commercial	2/5	1/2	2/3	1 1/2	2	2 1/2	1	1	1	2/3	1	1 1/2	2/7	1/3	2/5
Traffic	2/7	1/3	2/5	1 1/2	2	2 1/2	2/3	1	1 1/2	1	1	1	1 1/2	2	2 1/2
Demographic	2/9	1/4	2/7	2/3	1	1 1/2	2 1/2	3	3 1/2	2/5	1/2	2/3	1	1	1

	l	m	u
Financial	11,00	13,00	15,00
Strategic	2,75	3,33	4,23
Commercial	3,85	4,83	6,07
Traffic	4,95	6,33	7,90
Demographic	4,79	5,75	6,95
Sum	27,35	33,25	40,15
Inverse	0,02	0,03	0,04

	l	m	u
Sfinancial =	0,274	0,391	0,549
Sstrategic =	0,069	0,100	0,155
Scommercial =	0,096	0,145	0,222
Straffic =	0,123	0,190	0,289
Sdemographic =	0,119	0,173	0,254

		Min
V (Sf ≥ Ss)=	1	1
V (Sf ≥ Sc)=	1	
V (Sf ≥ St)=	1	
V (Sf ≥ Sd)=	1	
V (Ss ≥ Sf)=	0	0
V (Ss ≥ Sc)=	0,566	
V (Ss ≥ St)=	0,259	
V (Ss ≥ Sd)=	0,328	
V (Sc ≥ Sf)=	0	0
V (Sc ≥ Ss)=	1	
V (Sc ≥ St)=	0,686	
V (Sc ≥ Sd)=	0,788	
V (St≥ Sf)=	0,069	0,069
V (St≥ Ss)=	1	
V (St≥ Sc)=	1	
V (St≥ Sd)=	1	
V (Sd≥ Sf)=	0	0
V (Sd≥ Ss)=	1	
V (Sd≥ Sc)=	1	
V (Sd≥ St)=	0,882	

	W'	W
Financial =	1	0,935
Strategic =	0	0
Commercial =	0	0
Traffic =	0,069	0,065
Demographic =	0	0
Sum=	**1,069**	**1,000**

Control element: Commercial

	Commercial									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Financial		X								Strategic
Financial		X								Commercial
Strategic		X								Commercial

	Commercial		
	Financial	Strategic	Commercial
Financial	(1,1,1)	(5/2,3,7/2)	(5/2,3,7/2)
Strategic	(2/7,1/3,2/5)	(1,1,1)	(5/2,3,7/2)
Commercial	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)

	Financial			Strategic			Commercial		
	l	m	u	l	m	u	l	m	u
Financial	1	1	1	2 1/2	3	3 1/2	2 1/2	3	3 1/2
Strategic	2/7	1/3	2/5	1	1	1	2 1/2	3	3 1/2
Commercial	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

	l	m	u
Financial	6,00	7,00	8,00
Strategic	3,79	4,33	4,90
Commercial	1,57	1,67	1,80
Sum	11,36	13,00	14,70
Inverse	0,07	0,08	0,09

	l	m	u
Sfinancial =	0,408	0,538	0,704
Sstrategic =	0,258	0,333	0,431
Scommercial =	0,107	0,128	0,158

		Min
V (Sf ≥ Ss)=	1	1
V (Sf ≥ Sc)=	1	
V (Ss ≥ Sf)=	0,102	0,102
V (Ss ≥ Sc)=	1	
V (Sc ≥ Sf)=	0	0
V (Sc ≥ Ss)=	0	

	W'	W
Financial =	1	0,907
Strategic =	0,102	0,093
Commercial =	0	0,000
Sum=	**1,102**	**1,000**

A.2 Calculations of Comparison Matrices between Criteria

Control element: Operational Cost

Comparison with: Elements in Commercial cluster

	Operational Cost									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs					X					Number of Other Banks' ATMs

	Operational Cost	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(1,1,1)
Number of Other Banks' ATMs	(1,1,1)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1	1	1
Number of Other Banks' ATMs	1	1	1	1	1	1

	l	m	u
Number of Bank's ATMs	2,00	2,00	2,00
Number of Other Banks' ATMs	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
SBA =	0,500	0,500	0,500
SOBA =	0,500	0,500	0,500

V (SBA ≥ SOBA)=	1
V (SOBA ≥ SBA)=	1

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Customer Requests for ATM Deployment

Comparison with: Elements in Financial cluster

	Customer Requests for ATM Deployment									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense					X					Expected Level of Transaction Income

	Customer Requests for ATM Deployment	
	Commission Expense	Expected Level of Transaction Income
Commission Expense	(1,1,1)	(1,1,1)
Expected Level of Transaction Income	(1,1,1)	(1,1,1)

	Commission Expense			Expected Level of Transaction Income		
	l	m	u	l	m	u
Commission Expense	1	1	1	1	1	1
Expected Level of Transaction Income	1	1	1	1	1	1

	l	m	u
Commission Expense	2,00	2,00	2,00
Expected Level of Transaction Income	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
STI =	0,500	0,500	0,500
SOC=	0,500	0,500	0,500

V (STI ≥ SOC)=	1,00
V (SOC ≥ STI)=	1,00

	W'	W
TI	1,000	0,500
OC	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Reputation Value

Comparison with: Elements in Commercial cluster

	Reputation Value									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs					X					Number of Other Banks' ATMs

	Reputation Value	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(1,1,1)
Number of Other Banks' ATMs	(1,1,1)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1	1	1
Number of Other Banks' ATMs	1	1	1	1	1	1

	l	m	u
Number of Bank's ATMs	2,00	2,00	2,00
Number of Other Banks' ATMs	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
SBA =	0,500	0,500	0,500
SOBA =	0,500	0,500	0,500

V (SBA ≥ SOBA)=	1,00
V (SOBA ≥ SBA)=	1,00

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Safety

Comparison with: Elements in Financial cluster

	Safety									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Expected Level of Transaction Income				X						Operational Cost

	Safety	
	Expected Level of Transaction Income	Operational Cost
Expected Level of Transaction Income	(1,1,1)	(2/3,1,3/2)
Operational Cost	(2/3,1,3/2)	(1,1,1)

	Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u
Expected Level of Transaction Income	1	1	1	2/3	1	1 1/2
Operational Cost	2/3	1	1 1/2	1	1	1

	l	m	u
Expected Level of Transaction Income	1,67	2,00	2,50
Operational Cost	1,67	2,00	2,50
Sum	3,33	4,00	5,00
Inverse	0,20	0,25	0,30

	l	m	u
STI =	0,333	0,500	0,750
SOC=	0,333	0,500	0,750

V (STI ≥ SOC)=	1,00
V (SOC ≥ STI)=	1,00

	W'	W
TI	1,000	0,500
OC	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Safety

Comparison with: Elements in Commercial cluster

	Safety									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs					X					Number of Other Banks' ATMs

	Safety	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(1,1,1)
Number of Other Banks' ATMs	(1,1,1)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1	1	1
Number of Other Banks' ATMs	1	1	1	1	1	1

	l	m	u
Number of Bank's ATMs	2,00	2,00	2,00
Number of Other Banks' ATMs	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
SBA =	0,500	0,500	0,500
SOBA =	0,500	0,500	0,500

V (SBA ≥ SOBA)=	1,00
V (SOBA ≥ SBA)=	1,00

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Foot & Vehicle Traffic

Comparison with: Elements in Financial cluster

	Foot & Vehicle Traffic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense					X					Expected Level of Commission Income
Commission Expense							X			Expected Level of Transaction Income
Commission Expense						X				Operational Cost
Expected Level of Commission Income							X			Expected Level of Transaction Income
Expected Level of Commission Income							X			Operational Cost
Expected Level of Transaction Income				X						Operational Cost

	Foot & Vehicle Traffic			
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Expected Level of Commission Income	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(2/5,1/2,2/3)
Expected Level of Transaction Income	(3/2,2,5/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(2/3,1,3/2)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	1	1	1	2/5	1/2	2/3	2/3	1	1 1/2
Expected Level of Commission Income	1	1	1	1	1	1	2/3	1	1 1/2	2/5	1/2	2/3
Expected Level of Transaction Income	1 1/2	2	2 1/2	1 1/2	2	2 1/2	1	1	1	2/3	1	1 1/2
Operational Cost	2/3	1	1 1/2	1 1/2	2	2 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	3,07	3,50	4,17
Expected Level of Commission Income	3,07	3,50	4,17
Expected Level of Transaction Income	4,67	6,00	7,50
Operational Cost	3,83	5,00	6,50
Sum	14,63	18,00	22,33
Inverse	0,04	0,06	0,07

	l	m	u
SCE =	0,137	0,194	0,285
SCI =	0,137	0,194	0,285
STI =	0,209	0,333	0,513
SOC =	0,172	0,278	0,444

		Min
V (SCE = ≥ SCI)=	1	0,353
V (SCE = ≥ STI)=	0,353	
V (SCE = ≥ SOC)=	0,576	
V (SCI ≥ SCE =)=	1	0,353
V (SCI ≥ STI)=	0,353	
V (SCI ≥ SOC=)=	0,576	
V (STI ≥ SCE =)=	1	1
V (STI ≥ SCI)=	1	
V (STI ≥ SOC)=	1	
V (SOC ≥ SCE =)=	1	0,809
V (SOC ≥ SCI)=	1	
V (SOC ≥ STI)=	0,809	

	W'	W
CE =	0,353	0,140
CI=	0,353	0,140
TI=	1	0,398
OC=	0,809	0,322
Sum=	**2,515**	**1,000**

Control element: Foot & Vehicle Traffic

Comparison with: Elements in Strategic cluster

	Foot & Vehicle Traffic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment								X		Reputation Value
Customer Requests for ATM Deployment								X		Safety
Reputation Value						X				Safety

	Foot & Vehicle Traffic		
	Customer Requests for ATM Deployment	Reputation Value	Safety
Customer Requests for ATM Deployment	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)
Reputation Value	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)
Safety	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value			Safety		
	l	m	u	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5
Reputation Value	2 1/2	3	3 1/2	1	1	1	2/3	1	1 1/2
Safety	2 1/2	3	3 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Customer Requests for ATM Deployment	1,57	1,67	1,80
Reputation Value	4,17	5,00	6,00
Safety	4,17	5,00	6,00
Sum	9,90	11,67	13,80
Inverse	0,07	0,09	0,10

	l	m	u
SCR=	0,114	0,143	0,182
SRV=	0,302	0,429	0,606
SSF=	0,302	0,429	0,606

		Min
V (SCR ≥ SRV)=	0	0
V (SCR ≥ SSF)=	0	
V (SRV≥ SCR)=	1	1
V (SRV ≥ SSF)=	1	
V (SSF ≥ SCR)=	1	1
V (SSF ≥ SRV)=	1	

	W'	W
CR=	0	0
RV	1	0,500
SF=	1	0,500
Sum=	**2,000**	**1,000**

Control element: Foot & Vehicle Traffic

Comparison with: Elements in Commercial cluster

	Foot & Vehicle Traffic									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs					X					Number of Other Banks' ATMs

	Foot & Vehicle Traffic Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(1,1,1)
Number of Other Banks' ATMs	(1,1,1)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1	1	1
Number of Other Banks' ATMs	1	1	1	1	1	1

	l	m	u
Number of Bank's ATMs	2,00	2,00	2,00
Number of Other Banks' ATMs	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
SBA =	0,500	0,500	0,500
SOBA =	0,500	0,500	0,500

V (SBA ≥ SOBA)=	1,00
V (SOBA ≥ SBA)=	1,00

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Tourist Destinations

Comparison with: Elements in Financial cluster

	Tourist Destinations									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Expected Level of Commission Income			X							Operational Cost

	Tourist Destinations	
	Expected Level of Transaction Income	Operational Cost
Expected Level of Commission Income	(1,1,1)	(3/2,2,5/2)
Operational Cost	(2/5,1/2,2/3)	(1,1,1)

	Expected Level of Commission Income			Operational Cost		
	l	m	u	l	m	u
Expected Level of Commission Income	1	1	1	1 1/2	2	2 1/2
Operational Cost	2/5	1/2	2/3	1	1	1

	l	m	u
Expected Level of Commission Income	2,50	3,00	3,50
Operational Cost	1,40	1,50	1,67
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SCI =	0,484	0,667	0,897
SOC=	0,271	0,333	0,427

V (SCI ≥ SOC)=	1,000
V (SOC ≥ SCI)=	0,000

	W'	W
CI	1,000	1,000
OC	0,000	0,000
Sum=	**1,000**	**1,000**

Control element: Tourist Destinations

Comparison with: Elements in Strategic cluster

	Tourist Destinations									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment									X	Reputation Value
Customer Requests for ATM Deployment								X		Safety
Reputation Value				X						Safety

	Tourist Destinations		
	Customer Requests for ATM Deployment	Reputation Value	Safety
Customer Requests for ATM Deployment	(1,1,1)	(2/9,1/4,2/7)	(2/7,1/3,2/5)
Reputation Value	(7/2,4,9/2)	(1,1,1)	(2/3,1,3/2)
Safety	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value			Safety		
	l	m	u	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	2/9	1/4	2/7	2/7	1/3	2/5
Reputation Value	3 1/2	4	4 1/2	1	1	1	2/3	1	1 1/2
Safety	2 1/2	3	3 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Customer Requests for ATM Deployment	1,51	1,58	1,69
Reputation Value	5,17	6,00	7,00
Safety	4,17	5,00	6,00
Sum	10,84	12,58	14,69
Inverse	0,07	0,08	0,09

	l	m	u
SCR=	0,103	0,126	0,155
SRV=	0,352	0,477	0,646
SSF=	0,284	0,397	0,553

		Min
V (SCR ≥ SRV)=	0	0
V (SCR ≥ SSF)=	0	
V (SRV≥ SCR)=	1	1
V (SRV ≥ SSF)=	1	
V (SSF ≥ SCR)=	1	0,717
V (SSF ≥ SRV)=	0,717	

	W'	W
CR=	0	0,000
RV	1	0,582
Safety=	0,717	0,418
Sum=	**1,717**	**1,000**

Control element: Tourist Destinations

Comparison with: Elements in Commercial cluster

	Tourist Destinations									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs					X					Number of Other Banks' ATMs

	Tourist Destinations	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(1,1,1)
Number of Other Banks' ATMs	(1,1,1)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1	1	1
Number of Other Banks' ATMs	1	1	1	1	1	1

	l	m	u
Number of Bank's ATMs	2,00	2,00	2,00
Number of Other Banks' ATMs	2,00	2,00	2,00
Sum	4,00	4,00	4,00
Inverse	0,25	0,25	0,25

	l	m	u
SBA =	0,500	0,500	0,500
SOBA =	0,500	0,500	0,500

V (SBA ≥ SOBA)=	1,00
V (SOBA ≥ SBA)=	1,00

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Average Age of the Population

Comparison with: Elements in Financial cluster

	Average Age of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense							X			Expected Level of Commission Income
Commission Expense									X	Expected Level of Transaction Income
Commission Expense							X			Operational Cost
Expected Level of Commission Income							X			Expected Level of Transaction Income
Expected Level of Commission Income						X				Operational Cost
Expected Level of Transaction Income				X						Operational Cost

	Average Age of the Population			
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(2/5,1/2,2/3)	(2/9,1/4,2/7)	(2/5,1/2,2/3)
Expected Level of Commission Income	(3/2,2,5/2)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Expected Level of Transaction Income	(7/2,4,9/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(3/2,2,5/2)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	2/5	1/2	2/3	2/9	1/4	2/7	2/5	1/2	2/3
Expected Level of Commission Income	1 1/2	2	2 1/2	1	1	1	2/5	1/2	2/3	2/3	1	1 1/2
Expected Level of Transaction Income	3 1/2	4	4 1/2	1 1/2	2	2 1/2	1	1	1	2/3	1	1 1/2
Operational Cost	1 1/2	2	2 1/2	2/3	1	1 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	2,02	2,25	2,62
Expected Level of Commission Income	3,57	4,50	5,67
Expected Level of Transaction Income	6,67	8,00	9,50
Operational Cost	3,83	5,00	6,50
Sum	16,09	19,75	24,29
Inverse	0,04	0,05	0,06

	l	m	u
SCE =	0,083	0,114	0,163
SCI =	0,147	0,228	0,352
STI =	0,275	0,405	0,590
SOC =	0,158	0,253	0,404

		Min
V (SCE = ≥ SCI)=	0,123	0,000
V (SCE = ≥ STI)=	0,000	
V (SCE = ≥ SOC)=	0,034	
V (SCI ≥ SCE =)=	1,000	0,305
V (SCI ≥ STI)=	0,305	
V (SCI ≥ SOC=)=	0,885	
V (STI ≥ SCE =)=	1,000	1,000
V (STI ≥ SCI)=	1,000	
V (STI ≥ SOC)=	1,000	
V (SOC ≥ SCE =)=	1,000	0,460
V (SOC ≥ SCI)=	1,000	
V (SOC ≥ STI)=	0,460	

	W'	W
CE =	0,000	0,000
CI=	0,305	0,173
TI=	1	0,567
OC=	0,460	0,261
Sum=	**1,765**	**1,000**

Control element: Average Age of the Population

Comparison with: Elements in Strategic cluster

	Average Age of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment				X						Reputation Value

	Average Age of the Population	
	Customer Requests for ATM Deployment	Reputation Value
Customer Requests for ATM Deployment	(1,1,1)	(2/3,1,3/2)
Reputation Value	(2/3,1,3/2)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value		
	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	2/3	1	1 1/2
Reputation Value	2/3	1	1 1/2	1	1	1

	l	m	u
Customer Requests for ATM Deployment	1,67	2,00	2,50
Reputation Value	1,67	2,00	2,50
Sum	3,33	4,00	5,00
Inverse	0,20	0,25	0,30

	l	m	u
SCR=	0,333	0,500	0,750
SRV=	0,333	0,500	0,750

V (SCR ≥ SRV)=	1,000
V (SRV≥ SCR)=	1,000

	W'	W
CR=	1	0,500
RV	1	0,500
Sum=	**2,000**	**1,000**

Control element: Average Age of the Population

Comparison with: Elements in Strategic cluster

	Average Age of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs								X		Number of Bank's Debit & Credit Cards
Number of Bank's ATMs								X		Number of Other Banks' Debit & Credit Cards
Number of Bank's ATMs					X					Number of Other Banks' ATMs
Number of Bank's Debit & Credit Cards					X					Number of Other Banks' Debit & Credit Cards
Number of Bank's Debit & Credit Cards		X								Number of Other Banks' ATMs
Number of Other Banks' Debit & Credit Cards		X								Number of Other Banks' ATMs

	Average Age of the Population			
	Number of Bank's ATMs	Number of Bank's Debit & Credit Cards	Number of Other Banks' Debit & Credit Cards	Number of Other Banks’ ATMs
Number of Bank's ATMs	(1,1,1)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)
Number of Bank's Debit & Credit Cards	(5/2,3,7/2)	(1,1,1)	(1,1,1)	(5/2,3,7/2)
Number of Other Banks' Debit & Credit Cards	(5/2,3,7/2)	(2/7,1/3,2/5)	(1,1,1)	(5/2,3,7/2)
Number of Other Banks’ ATMs	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(2/7,1/3,2/5)	(1,1,1)

	Number of Bank's ATMs			Number of Bank's Debit & Credit Cards			Number of Other Banks' Debit & Credit Cards			Number of Other Banks’ ATMs		
	l	m	u	l	m	u	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1
Number of Bank's Debit & Credit Cards	2 1/2	3	3 1/2	1	1	1	1	1	1	2 1/2	3	3 1/2
Number of Other Banks' Debit & Credit Cards	2 1/2	3	3 1/2	2/7	1/3	2/5	1	1	1	2 1/2	3	3 1/2
Number of Other Banks’ ATMs	2/7	1/3	2/5	2/7	1/3	2/5	2/7	1/3	2/5	1	1	1

	l	m	u
Number of Bank's ATMs	2,57	2,67	2,80
Number of Bank's Debit & Credit Cards	7,00	8,00	9,00
Number of Other Banks' Debit & Credit Cards	6,29	7,33	8,40
Number of Other Banks’ ATMs	1,86	2,00	2,20
Sum	17,71	20,00	22,40
Inverse	0,04	0,05	0,06

	l	m	u
SBA =	0,115	0,133	0,158
SDCC =	0,313	0,400	0,508
SODCC =	0,281	0,367	0,474
SOBA =	0,083	0,100	0,124

		Min
V (SBA ≥ SDCC)=	0	0,000
V (SBA ≥ SODCC)=	0	
V (SBA ≥ SOBA)=	1,000	
V (SDCC ≥ SBA)=	1,000	1,000
V (SDCC ≥ SODCC)=	1,000	
V (SDCC ≥ SOBA)=	1,000	
V (SODCC ≥ SBA)=	1,000	0,829
V (SODCC ≥ SDCC)=	0,829	
V (SODCC ≥ SOBA)=	1,000	
V (SOBA ≥ SBA)=	0,220	0,000
V (SOBA ≥ SDCC)=	0	
V (SOBA ≥ SODCC)=	0	

	W'	W
BA=	0,000	0,000
DCC=	1,000	0,547
ODCC=	0,829	0,453
OBA=	0,000	0,000
Sum=	**1,829**	**1,000**

Control element: Educational Level of the Population

Comparison with: Elements in Financial cluster

	Educational Level of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense					X					Expected Level of Commission Income
Commission Expense								X		Expected Level of Transaction Income
Commission Expense							X			Operational Cost
Expected Level of Commission Income							X			Expected Level of Transaction Income
Expected Level of Commission Income						X				Operational Cost
Expected Level of Transaction Income			X							Operational Cost

	Educational Level of the Population			
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)
Expected Level of Commission Income	(1,1,1)	(1,1,1)	(2/5,1/2,2/3)	(2/3,1,3/2)
Expected Level of Transaction Income	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(3/2,2,5/2)
Operational Cost	(3/2,2,5/2)	(2/3,1,3/2)	(2/5,1/2,2/3)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	1	1	1	2/7	1/3	2/5	2/5	1/2	2/3
Expected Level of Commission Income	1	1	1	1	1	1	2/5	1/2	2/3	2/3	1	1 1/2
Expected Level of Transaction Income	2 1/2	3	3 1/2	1 1/2	2	2 1/2	1	1	1	1 1/2	2	2 1/2
Operational Cost	1 1/2	2	2 1/2	2/3	1	1 1/2	2/5	1/2	2/3	1	1	1

	l	m	u
Commission Expense	2,69	2,83	3,07
Expected Level of Commission Income	3,07	3,50	4,17
Expected Level of Transaction Income	6,50	8,00	9,50
Operational Cost	3,57	4,50	5,67
Sum	15,82	18,83	22,40
Inverse	0,04	0,05	0,06

	l	m	u
SCE =	0,120	0,150	0,194
SCI =	0,137	0,186	0,263
STI =	0,290	0,425	0,601
SOC =	0,159	0,239	0,358

		Min
V (SCE = ≥ SCI)=	0,617	0,000
V (SCE = ≥ STI)=	0,000	
V (SCE = ≥ SOC)=	0,281	
V (SCI ≥ SCE =)=	1,000	0,000
V (SCI ≥ STI)=	0,000	
V (SCI ≥ SOC=)=	0,662	
V (STI ≥ SCE =)=	1,000	1
V (STI ≥ SCI)=	1,000	
V (STI ≥ SOC)=	1,000	
V (SOC ≥ SCE =)=	1,000	0,268
V (SOC ≥ SCI)=	1,000	
V (SOC ≥ STI)=	0,268	

	W'	W
CE =	0,000	0,000
CI=	0,000	0,000
TI=	1	0,789
OC=	0,268	0,211
Sum=	**1,268**	**1,000**

Control element: Educational Level of the Population

Comparison with: Elements in Commercial cluster

	Educational Level of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs							X			Number of Bank's Debit & Credit Cards
Number of Bank's ATMs							X			Number of Other Banks' Debit & Credit Cards
Number of Bank's ATMs					X					Number of Other Banks' ATMs
Number of Bank's Debit & Credit Cards					X					Number of Other Banks' Debit & Credit Cards
Number of Bank's Debit & Credit Cards			X							Number of Other Banks' ATMs
Number of Other Banks' Debit & Credit Cards			X							Number of Other Banks' ATMs

	Educational Level of the Population			
	Number of Bank's ATMs	Number of Bank's Debit & Credit Cards	Number of Other Banks' Debit & Credit Cards	Number of Other Banks’ ATMs
Number of Bank's ATMs	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
Number of Bank's Debit & Credit Cards	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' Debit & Credit Cards	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks’ ATMs	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)

	Number of Bank's ATMs			Number of Bank's Debit & Credit Cards			Number of Other Banks' Debit & Credit Cards			Number of Other Banks’ ATMs		
	l	m	u	l	m	u	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	1	1	1
Number of Bank's Debit & Credit Cards	1 1/2	2	2 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' Debit & Credit Cards	1 1/2	2	2 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks’ ATMs	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	1	1	1

	l	m	u
Number of Bank's ATMs	2,80	3,00	3,33
Number of Bank's Debit & Credit Cards	5,00	6,00	7,00
Number of Other Banks' Debit & Credit Cards	5,00	6,00	7,00
Number of Other Banks’ ATMs	2,80	3,00	3,33
Sum	15,60	18,00	20,67
Inverse	0,05	0,06	0,06

	l	m	u
SBA =	0,135	0,167	0,214
SDCC =	0,242	0,333	0,449
SODCC =	0,242	0,333	0,449
SOBA =	0,135	0,167	0,214

		Min
V (SBA ≥ SDCC)=	0	0,000
V (SBA ≥ SODCC)=	0	
V (SBA ≥ SOBA)=	1,000	
V (SDCC ≥ SBA)=	1,000	1,000
V (SDCC ≥ SODCC)=	1,000	
V (SDCC ≥ SOBA)=	1,000	
V (SODCC ≥ SBA)=	1,000	1,000
V (SODCC ≥ SDCC)=	1,000	
V (SODCC ≥ SOBA)=	1,000	
V (SOBA ≥ SBA)=	1,000	0,000
V (SOBA ≥ SDCC)=	0	
V (SOBA ≥ SODCC)=	0	

	W'	W
BA=	0,000	0,000
DCC=	1,000	0,500
ODCC=	1,000	0,500
OBA=	0,000	0,000
Sum=	**2,000**	**1,000**

Control element: Income Level of the Population

Comparison with: Elements in Financial cluster

	Income Level of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense					X					Expected Level of Commission Income
Commission Expense						X				Expected Level of Transaction Income
Commission Expense						X				Operational Cost
Expected Level of Commission Income					X					Expected Level of Transaction Income
Expected Level of Commission Income						X				Operational Cost
Expected Level of Transaction Income				X						Operational Cost

	Income Level of the Population			
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)
Expected Level of Commission Income	(1,1,1)	(1,1,1)	(1,1,1)	(2/3,1,3/2)
Expected Level of Transaction Income	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(2/3,1,3/2)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	1	1	1	2/3	1	1 1/2	2/3	1	1 1/2
Expected Level of Commission Income	1	1	1	1	1	1	1	1	1	2/3	1	1 1/2
Expected Level of Transaction Income	2/3	1	1 1/2	1	1	1	1	1	1	2/3	1	1 1/2
Operational Cost	2/3	1	1 1/2	2/3	1	1 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	3,33	4,00	5,00
Expected Level of Commission Income	3,67	4,00	4,50
Expected Level of Transaction Income	3,33	4,00	5,00
Operational Cost	3,00	4,00	5,50
Sum	13,33	16,00	20,00
Inverse	0,05	0,06	0,08

	l	m	u
SCE =	0,167	0,250	0,375
SCI =	0,183	0,250	0,338
STI =	0,167	0,250	0,375
SOC =	0,150	0,250	0,413

		Min
V (SCE = ≥ SCI)=	1	1,000
V (SCE = ≥ STI)=	1	
V (SCE = ≥ SOC)=	1	
V (SCI ≥ SCE =)=	1	1,000
V (SCI ≥ STI)=	1	
V (SCI ≥ SOC=)=	1	
V (STI ≥ SCE =)=	1	1
V (STI ≥ SCI)=	1	
V (STI ≥ SOC)=	1	
V (SOC ≥ SCE =)=	1	1,000
V (SOC ≥ SCI)=	1	
V (SOC ≥ STI)=	1	

	W'	W
CE =	1,000	0,250
CI=	1,000	0,250
TI=	1,000	0,250
OC=	1,000	0,250
Sum=	**4,000**	**1,000**

Control element: Income Level of the Population

Comparison with: Elements in Strategic cluster

	Income Level of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment									X	Reputation Value
Customer Requests for ATM Deployment								X		Safety
Reputation Value				X						Safety

	Income Level of the Population		
	Customer Requests for ATM Deployment	Reputation Value	Safety
Customer Requests for ATM Deployment	(1,1,1)	(2/9,1/4,2/7)	(2/7,1/3,2/5)
Reputation Value	(7/2,4,9/2)	(1,1,1)	(2/3,1,3/2)
Safety	(5/2,3,7/2)	(2/3,1,3/2)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value			Safety		
	l	m	u	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	2/9	1/4	2/7	2/7	1/3	2/5
Reputation Value	3 1/2	4	4 1/2	1	1	1	2/3	1	1 1/2
Safety	2 1/2	3	3 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Customer Requests for ATM Deployment	1,51	1,58	1,69
Reputation Value	5,17	6,00	7,00
Safety	4,17	5,00	6,00
Sum	10,84	12,58	14,69
Inverse	0,07	0,08	0,09

	l	m	u
SCR=	0,103	0,126	0,155
SRV=	0,352	0,477	0,646
SSF=	0,284	0,397	0,553

		Min
V (SCR ≥ SRV)=	0	0
V (SCR ≥ SSF)=	0	
V (SRV≥ SCR)=	1	0
V (SRV ≥ SSF)=	0	
V (SSF ≥ SCR)=	1	0,717
V (SSF ≥ SRV)=	0,717	

	W'	W
CR=	0	0,000
RV	0	0,000
Safety=	0,717	1,000
Sum=	**0,717**	**1,000**

Control element: Income Level of the Population

Comparison with: Elements in Commercial cluster

	Income Level of the Population									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs							X			Number of Bank's Debit & Credit Cards
Number of Bank's ATMs							X			Number of Other Banks' Debit & Credit Cards
Number of Bank's ATMs					X					Number of Other Banks’ ATMs
Number of Bank's Debit & Credit Cards					X					Number of Other Banks' Debit & Credit Cards
Number of Bank's Debit & Credit Cards			X							Number of Other Banks’ ATMs
Number of Other Banks' Debit & Credit Cards			X							Number of Other Banks’ ATMs

	Income Level of the Population			
	Number of Bank's ATMs	Number of Bank's Debit & Credit Cards	Number of Other Banks' Debit & Credit Cards	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)
Number of Bank's Debit & Credit Cards	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' Debit & Credit Cards	(3/2,2,5/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' ATMs	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)

	Number of Bank's ATMs			Number of Bank's Debit & Credit Cards			Number of Other Banks' Debit & Credit Cards			Number of Other Banks' ATMs		
	l	m	u	l	m	u	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	1	1	1
Number of Bank's Debit & Credit Cards	1 1/2	2	2 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' Debit & Credit Cards	1 1/2	2	2 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' ATMs	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	1	1	1

	l	m	u
Number of Bank's ATMs	2,80	3,00	3,33
Number of Bank's Debit & Credit Cards	5,00	6,00	7,00
Number of Other Banks' Debit & Credit Cards	5,00	6,00	7,00
Number of Other Banks’ ATMs	2,80	3,00	3,33
Sum	15,60	18,00	20,67
Inverse	0,05	0,06	0,06

	l	m	u
SBA =	0,135	0,167	0,214
SDCC =	0,242	0,333	0,449
SODCC =	0,242	0,333	0,449
SOBA =	0,135	0,167	0,214

		Min
V (SBA ≥ SDCC)=	0	0,000
V (SBA ≥ SODCC)=	0	
V (SBA ≥ SOBA)=	1	
V (SDCC ≥ SBA)=	1	1,000
V (SDCC ≥ SODCC)=	1	
V (SDCC ≥ SOBA)=	1	
V (SODCC ≥ SBA)=	1	1,000
V (SODCC ≥ SDCC)=	1	
V (SODCC ≥ SOBA)=	1	
V (SOBA ≥ SBA)=	1	0,000
V (SOBA ≥ SDCC)=	0	
V (SOBA ≥ SODCC)=	0	

	W'	W
BA=	0,000	0,000
DCC=	1,000	0,500
ODCC=	1,000	0,500
OBA=	0,000	0,000
Sum=	**2,000**	**1,000**

Control element: Population Density

Comparison with: Elements in Financial cluster

	Population Density									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense						X				Expected Level of Commission Income
Commission Expense								X		Expected Level of Transaction Income
Commission Expense								X		Operational Cost
Expected Level of Commission Income							X			Expected Level of Transaction Income
Expected Level of Commission Income							X			Operational Cost
Expected Level of Transaction Income				X						Operational Cost

	Population Density			
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(2/3,1,3/2)	(2/7,1/3,2/5)	(2/7,1/3,2/5)
Expected Level of Commission Income	(2/3,1,3/2)	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)
Expected Level of Transaction Income	(5/2,3,7/2)	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(5/2,3,7/2)	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	2/3	1	1 1/2	2/7	1/3	2/5	2/7	1/3	2/5
Expected Level of Commission Income	2/3	1	1 1/2	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3
Expected Level of Transaction Income	2 1/2	3	3 1/2	1 1/2	2	2 1/2	1	1	1	2/3	1	1 1/2
Operational Cost	2 1/2	3	3 1/2	1 1/2	2	2 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	2,24	2,67	3,30
Expected Level of Commission Income	2,47	3,00	3,83
Expected Level of Transaction Income	5,67	7,00	8,50
Operational Cost	5,67	7,00	8,50
Sum	16,04	19,67	24,13
Inverse	0,04	0,05	0,06

	l	m	u
SCE =	0,093	0,136	0,206
SCI =	0,102	0,153	0,239
STI =	0,235	0,356	0,530
SOC =	0,235	0,356	0,530

		Min
V (SCE = ≥ SCI)=	0,859	0,000
V (SCE = ≥ STI)=	0	
V (SCE = ≥ SOC)=	0	
V (SCI ≥ SCE =)=	1	0,020
V (SCI ≥ STI)=	0,020	
V (SCI ≥ SOC=)=	0,020	
V (STI ≥ SCE =)=	1	1,000
V (STI ≥ SCI)=	1	
V (STI ≥ SOC)=	1	
V (SOC ≥ SCE =)=	1	1,000
V (SOC ≥ SCI)=	1	
V (SOC ≥ STI)=	1	

	W'	W
CE =	0,000	0,000
CI=	0,020	0,010
TI=	1,000	0,495
OC=	1,000	0,495
Sum=	**2,020**	**1,000**

Control element: Population Density

Comparison with: Elements in Strategic cluster

	Population Density									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment						X				Reputation Value

	Population Density	
	Customer Requests for ATM Deployment	Reputation Value
Customer Requests for ATM Deployment	(1,1,1)	(2/3,1,3/2)
Reputation Value	(2/3,1,3/2)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value		
	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	2/3	1	1 1/2
Reputation Value	2/3	1	1 1/2	1	1	1

	l	m	u
Customer Requests for ATM Deployment	1,67	2,00	2,50
Reputation Value	1,67	2,00	2,50
Sum	3,33	4,00	5,00
Inverse	0,20	0,25	0,30

	l	m	u
SCR=	0,333	0,500	0,750
SRV=	0,333	0,500	0,750

V (SCR ≥ SRV)=	1
V (SRV≥ SCR)=	1

	W'	W
CR=	1	0,500
RV	1	0,500
Sum=	**2,000**	**1,000**

Control element: Population Density

Comparison with: Elements in Commercial cluster

	Population Density									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs						X				Number of Bank's Debit & Credit Cards
Number of Bank's ATMs						X				Number of Other Banks' Debit & Credit Cards
Number of Bank's ATMs					X					Number of Other Banks' ATMs
Number of Bank's Debit & Credit Cards					X					Number of Other Banks' Debit & Credit Cards
Number of Bank's Debit & Credit Cards			X							Number of Other Banks' ATMs
Number of Other Banks' Debit & Credit Cards			X							Number of Other Banks' ATMs

	Population Density			
	Number of Bank's ATMs	Number of Bank's Debit & Credit Cards	Number of Other Banks' Debit & Credit Cards	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(2/3,1,3/2)	(2/3,1,3/2)	(1,1,1)
Number of Bank's Debit & Credit Cards	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' Debit & Credit Cards	(2/3,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' ATMs	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)

	Number of Bank's ATMs			Number of Bank's Debit & Credit Cards			Number of Other Banks' Debit & Credit Cards			Number of Other Banks' ATMs		
	l	m	u	l	m	u	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/3	1	1 1/2	2/3	1	1 1/2	1	1	1
Number of Bank's Debit & Credit Cards	2/3	1	1 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' Debit & Credit Cards	2/3	1	1 1/2	1	1	1	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' ATMs	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3	1	1	1

	l	m	u
Number of Bank's ATMs	3,33	4,00	5,00
Number of Bank's Debit & Credit Cards	4,17	5,00	6,00
Number of Other Banks' Debit & Credit Cards	4,17	5,00	6,00
Number of Other Banks' ATMs	2,80	3,00	3,33
Sum	14,47	17,00	20,33
Inverse	0,05	0,06	0,07

	l	m	u
SBA =	0,164	0,235	0,346
SDCC =	0,205	0,294	0,415
SODCC =	0,205	0,294	0,415
SOBA =	0,138	0,176	0,230

		Min
V (SBA ≥ SDCC)=	0,705	0,705
V (SBA ≥ SODCC)=	0,705	
V (SBA ≥ SOBA)=	1	
V (SDCC ≥ SBA)=	1	1,000
V (SDCC ≥ SODCC)=	1	
V (SDCC ≥ SOBA)=	1	
V (SODCC ≥ SBA)=	1	1,000
V (SODCC ≥ SDCC)=	1	
V (SODCC ≥ SOBA)=	1	
V (SOBA ≥ SBA)=	0,531	0,178
V (SOBA ≥ SDCC)=	0,178	
V (SOBA ≥ SODCC)=	0,178	

	W'	W
BA=	0,705	0,245
DCC=	1,000	0,347
ODCC=	1,000	0,347
OBA=	0,178	0,062
Sum=	**2,883**	**1,000**

Control element: Number of Bank’s ATM

Comparison with: Elements in Financial cluster

	Number of Bank's ATMs									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense							X			Expected Level of Commission Income
Commission Expense							X			Expected Level of Transaction Income
Expected Level of Commission Income				X						Expected Level of Transaction Income

	Number of Bank's ATMs		
	Commission Expense	Expected Level of Commission Income	Expected Level of Transaction Income
Commission Expense	(1,1,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)
Expected Level of Commission Income	(3/2,2,5/2)	(1,1,1)	(2/3,1,3/2)
Expected Level of Transaction Income	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income			Expected Level of Transaction Income		
	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	2/5	1/2	2/3	2/5	1/2	2/3
Expected Level of Commission Income	1 1/2	2	2 1/2	1	1	1	2/3	1	1 1/2
Expected Level of Transaction Income	1 1/2	2	2 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	1,80	2,00	2,33
Expected Level of Commission Income	3,17	4,00	5,00
Expected Level of Transaction Income	3,17	4,00	5,00
Sum	8,13	10,00	12,33
Inverse	0,08	0,10	0,12

	l	m	u
SCE =	0,146	0,200	0,287
SCI =	0,257	0,400	0,615
STI =	0,257	0,400	0,615

		Min
V (SCE = ≥ SCI)=	0,131	0,131
V (SCE = ≥ STI)=	0,131	
V (SCI ≥ SCE =)=	1,000	1,000
V (SCI ≥ STI)=	1,000	
V (STI ≥ SCE =)=	1,000	1,000
V (STI ≥ SCI)=	1,000	

	W'	W
CE =	0,131	0,061
CI=	1,000	0,469
TI=	1,000	0,469
Sum=	**2,131**	**1,000**

Control element: Number of Bank's ATM

Comparison with: Elements in Commercial cluster

	Number of Bank's ATMs									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's Debit & Credit Cards			X							Number of Other Banks' ATMs

	Number of Bank's ATMs	
	Number of Bank's Debit & Credit Cards	Number of Other Banks' ATMs
Number of Bank's Debit & Credit Cards	(1,1,1)	(3/2,2,5/2)
Number of Other Banks' ATMs	(2/5,1/2,2/3)	(1,1,1)

	Number of Bank's Debit & Credit Cards			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's Debit & Credit Cards	1	1	1	1 1/2	2	2 1/2
Number of Other Banks' ATMs	2/5	1/2	2/3	1	1	1

	l	m	u
Number of Bank's Debit & Credit Cards	2,50	3,00	3,50
Number of Other Banks' ATMs	1,40	1,50	1,67
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SDCC =	0,484	0,667	0,897
SOBA =	0,271	0,333	0,427

V (SDCC ≥ SOBA)=	1,00
V (SOBA ≥ SDCC)=	0,00

	W'	W
DCC	1,000	1,000
OBA	0,000	0,000
Sum=	**1,000**	**1,000**

Control element: Number of Bank's Debit & Credit Cards

Comparison with: Elements in Financial cluster

	Number of Bank's Debit & Credit Cards									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense								X		Expected Level of Transaction Income
Commission Expense							X			Operational Cost
Expected Level of Transaction Income						X				Operational Cost

	Number of Bank's Debit & Credit Cards		
	Commission Expense	Expected Level of Transaction Income	Operational Cost
Commission Expense	(1,1,1)	(2/7,1/3,2/5)	(2/5,1/2,2/3)
Expected Level of Transaction Income	(5/2,3,7/2)	(1,1,1)	(2/3,1,3/2)
Operational Cost	(3/2,2,5/2)	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Expected Level of Transaction Income			Operational Cost		
	l	m	u	l	m	u	l	m	u
Commission Expense	1	1	1	2/7	1/3	2/5	2/5	1/2	2/3
Expected Level of Transaction Income	2 1/2	3	3 1/2	1	1	1	2/3	1	1 1/2
Operational Cost	1 1/2	2	2 1/2	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	1,69	1,83	2,07
Expected Level of Transaction Income	4,17	5,00	6,00
Operational Cost	3,17	4,00	5,00
Sum	9,02	10,83	13,07
Inverse	0,08	0,09	0,11

	l	m	u
SCE =	0,129	0,169	0,229
STI =	0,319	0,462	0,665
SOC =	0,242	0,369	0,554

		Min
V (SCE = ≥ STI)=	0,000	0,000
V (SCE = ≥ SOC)=	0,000	
V (STI ≥ SCE =)=	1,000	1,000
V (STI ≥ SOC)=	1,000	
V (SOC ≥ SCE =)=	1,000	0,718
V (SOC ≥ STI)=	0,718	

	W'	W
CE =	0,000	0,000
TI=	1,000	0,582
OC=	0,718	0,418
Sum=	**1,718**	**1,000**

Control element: Number of Bank’s Debit & Credit Cards

Comparison with: Elements in Commercial cluster

	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
	Number of Bank's Debit & Credit Cards									
Number of Bank's ATMs			X							Number of Other Banks’ ATMs

	Number of Bank's Debit & Credit Cards	
	Number of Bank's ATMs	Number of Other Banks’ ATMs
Number of Bank's ATMs	(1,1,1)	(3/2,2,5/2)
Number of Other Banks’ ATMs	(2/5,1/2,2/3)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks’ ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	1 1/2	2	2 1/2
Number of Other Banks’ ATMs	2/5	1/2	2/3	1	1	1

	l	m	u
Number of Bank's ATMs	2,50	3,00	3,50
Number of Other Banks’ ATMs	1,40	1,50	1,67
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SBA =	0,484	0,667	0,897
SOBA =	0,271	0,333	0,427

V (SBA ≥ SOBA)=	1,00
V (SOBA ≥ SBA)=	0,00

	W'	W
BA	1,000	1,000
OBA	0,000	0,000
Sum=	**1,000**	**1,000**

Control element: Number of Other Banks' Debit & Credit Cards

Comparison with: Elements in Commercial cluster

	Number of Other Banks' Debit & Credit Cards									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs							X			Number of Other Banks' ATMs

	Number of Other Banks' Debit & Credit Cards	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(2/5,1/2,2/3)
Number of Other Banks' ATMs	(3/2,2,5/2)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/5	1/2	2/3
Number of Other Banks' ATMs	1 1/2	2	2 1/2	1	1	1

	l	m	u
Number of Bank's ATMs	1,40	1,50	1,67
Number of Other Banks' ATMs	2,50	3,00	3,50
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SBA =	0,271	0,333	0,427
SOBA =	0,484	0,667	0,897

V (SBA ≥ SOBA)=	0,00
V (SOBA ≥ SBA)=	1,00

	W'	W
BA	0,000	0,000
OBA	1,000	1,000
Sum=	**1,000**	**1,000**

Control element: Number of Other Banks' ATMs

Comparison with: Elements in Financial cluster

	Number of Other Banks' ATMs									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense							X			Expected Level of Commission Income

	Number of Other Banks' ATMs	
	Commission Expense	Expected Level of Commission Income
Commission Expense	(1,1,1)	(2/5,1/2,2/3)
Expected Level of Commission Income	(3/2,2,5/2)	(1,1,1)

	Commission Expense			Expected Level of Commission Income		
	l	m	u	l	m	u
Commission Expense	1	1	1	2/5	1/2	2/3
Expected Level of Commission Income	1 1/2	2	2 1/2	1	1	1

	l	m	u
Commission Expense	1,40	1,50	1,67
Expected Level of Commission Income	2,50	3,00	3,50
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SCE =	0,271	0,333	0,427
SCI=	0,484	0,667	0,897

V (SCE = ≥ SCI)=	0,000
V (SCI ≥ SCE =)=	1,000

	W'	W
CE	0,000	0,000
CI	1,000	1,000
Sum=	**1,000**	**1,000**

Control element: Number of Other Banks' ATMs

Comparison with: Elements in Strategic cluster

	Number of Other Banks' ATMs									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Customer Requests for ATM Deployment			X							Reputation Value

	Number of Other Banks' ATMs	
	Customer Requests for ATM Deployment	Reputation Value
Customer Requests for ATM Deployment	(1,1,1)	(3/2,2,5/2)
Reputation Value	(2/5,1/2,2/3)	(1,1,1)

	Customer Requests for ATM Deployment			Reputation Value		
	l	m	u	l	m	u
Customer Requests for ATM Deployment	1	1	1	1 1/2	2	2 1/2
Reputation Value	2/5	1/2	2/3	1	1	1

	l	m	u
Customer Requests for ATM Deployment	2,50	3,00	3,50
Reputation Value	1,40	1,50	1,67
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SCR=	0,484	0,667	0,897
SRV=	0,271	0,333	0,427

V (SCR ≥ SRV)=	1,000
V (SRV≥ SCR)=	0,000

	W'	W
CR=	1,000	1,000
RV=	0,000	0,000
Sum=	**1,000**	**1,000**

Control element: Number of Other Banks' ATMs

Comparison with: Elements in Commercial cluster

	Number of Other Banks' ATMs									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs							X			Number of Other Banks' Debit & Credit Cards

	Number of Other Banks' ATMs	
	Number of Bank's ATMs	Number of Other Banks' Debit & Credit Cards
Number of Bank's ATMs	(1,1,1)	(2/5,1/2,2/3)
Number of Other Banks' Debit & Credit Cards	(3/2,2,5/2)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' Debit & Credit Cards		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/5	1/2	2/3
Number of Other Banks' Debit & Credit Cards	1 1/2	2	2 1/2	1	1	1

	l	m	u
Number of Bank's ATMs	1,40	1,50	1,67
Number of Other Banks' Debit & Credit Cards	2,50	3,00	3,50
Sum	3,90	4,50	5,17
Inverse	0,19	0,22	0,26

	l	m	u
SBA =	0,271	0,333	0,427
SODCC=	0,484	0,667	0,897

V (SBA ≥ SODCC)=	0,000
V (SODCC ≥ SBA)=	1,000

	W'	W
DCC	0,000	0,000
OBA	1,000	1,000
Sum=	**1,000**	**1,000**

Control element: Commission Expense

Comparison with: Elements in Commercial cluster

	Commission Expense									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Number of Bank's ATMs				X						Number of Other Banks' ATMs

	Commission Expense	
	Number of Bank's ATMs	Number of Other Banks' ATMs
Number of Bank's ATMs	(1,1,1)	(2/3,1,3/2)
Number of Other Banks' ATMs	(2/3,1,3/2)	(1,1,1)

	Number of Bank's ATMs			Number of Other Banks' ATMs		
	l	m	u	l	m	u
Number of Bank's ATMs	1	1	1	2/3	1	1 1/2
Number of Other Banks' ATMs	2/3	1	1 1/2	1	1	1

	l	m	u
Number of Bank's ATMs	1,67	2,00	2,50
Number of Other Banks' ATMs	1,67	2,00	2,50
Sum	3,33	4,00	5,00
Inverse	0,20	0,25	0,30

	l	m	u
SBA =	0,333	0,500	0,750
SOBA =	0,333	0,500	0,750

V (SBA ≥ SOBA)=	1,000
V (SOBA ≥ SBA)=	1,000

	W'	W
BA	1,000	0,500
OBA	1,000	0,500
Sum=	**2,000**	**1,000**

Control element: Expected Level of Transaction Income

Comparison with: Elements in Commercial cluster

	Expected Level of Transaction Income									
	Absolutely more	Very strongly more	Strongly more	Weakly more	Equally	Weakly more	Strongly more	Very strongly more	Absolutely more	
Commission Expense						X				Operational Cost

	Expected Level of Transaction Income	
	Commission Expense	Operational Cost
Commission Expense	(1,1,1)	(2/3,1,3/2)
Operational Cost	(2/3,1,3/2)	(1,1,1)

	Commission Expense			Operational Cost		
	l	m	u	l	m	u
Commission Expense	1	1	1	2/3	1	1 1/2
Operational Cost	2/3	1	1 1/2	1	1	1

	l	m	u
Commission Expense	1,67	2,00	2,50
Operational Cost	1,67	2,00	2,50
Sum	3,33	4,00	5,00
Inverse	0,20	0,25	0,30

	l	m	u
SCE =	0,333	0,500	0,750
SOC=	0,333	0,500	0,750

V (SCE = ≥ SOC)=	1,000
V (SOC ≥ SCE =)=	1,000

	W'	W
CE	1,000	0,500
OC	1,000	0,500
Sum=	**2,000**	**1,000**

Appendix B – Coordinates of ATMs

ATM	District	Latitude	Longitude	ATM	District	Latitude	Longitude
L1	District-2	41.08793	29.03166	L61	District-5	41.07885	29.04522
L2	District-4	41.06567	29.01312	L62	District-5	41.08376	29.05069
L3	District-5	41.07648	29.04291	L63	District-5	41.07593	29.04309
L4	District-6	41.04431	29.00690	L64	District-5	41.07751	29.04370
L5	District-8	41.07788	29.02948	L65	District-5	41.07611	29.04291
L6	District-9	41.06409	29.01007	L66	District-5	41.07751	29.04370
L7	District-9	41.06470	29.00873	L67	District-5	41.07727	29.04352
L8	District-11	41.05988	29.03967	L68	District-5	41.07770	29.04370
L9	District-13	41.06713	29.01665	L69	District-5	41.08392	29.05188
L10	District-14	41.07849	29.01569	L70	District-5	41.07788	29.04431
L11	District-14	41.07953	29.02069	L71	District-5	41.07810	29.04450
L12	District-17	41.07597	29.01987	L72	District-5	41.07867	29.04572
L13	District-18	41.05072	29.02509	L73	District-5	41.07709	29.04309
L14	District-18	41.05029	29.03229	L74	District-5	41.07770	29.04388
L15	District-18	41.04773	29.02728	L75	District-5	41.07709	29.04309
L16	District-19	41.04150	29.00787	L76	District-5	41.07709	29.04309
L17	District-19	41.04230	29.00568	L77	District-5	41.07709	29.04309
L18	District-19	41.04431	29.00092	L78	District-5	41.07709	29.04309
L19	District-22	41.04248	29.00128	L79	District-5	41.07709	29.04309
L20	District-22	41.03923	28.99466	L80	District-5	41.08410	29.05320
L21	District-22	41.03923	28.99466	L81	District-6	41.04852	29.00769
L22	District-23	41.04230	29.00909	L82	District-6	41.04327	29.00690
L23	District-1	41.04968	29.00653	L83	District-6	41.04950	29.00812
L24	District-1	41.04993	29.00671	L84	District-6	41.04889	29.00787
L25	District-1	41.04968	29.00653	L85	District-6	41.04889	29.00787
L26	District-1	41.05050	29.00544	L86	District-6	41.04967	29.00664
L27	District-2	41.08789	29.02032	L87	District-6	41.04420	29.00750
L28	District-2	41.08691	29.02289	L88	District-6	41.04327	29.00682
L29	District-2	41.09229	29.02753	L89	District-6	41.04993	29.00812
L30	District-2	41.08789	29.02490	L90	District-6	41.04916	29.00799
L31	District-2	41.08440	29.02666	L91	District-6	41.04730	29.00909
L32	District-2	41.08508	29.02087	L92	District-6	41.04730	29.00909
L33	District-2	41.08087	29.02808	L93	District-6	41.04449	29.00690
L34	District-2	41.08173	29.02271	L94	District-6	41.04327	29.00690
L35	District-2	41.09210	29.02753	L95	District-6	41.04449	29.00690
L36	District-2	41.07866	29.02641	L96	District-6	41.04791	29.00769
L37	District-2	41.08789	29.03168	L97	District-6	41.04455	29.00710
L38	District-2	41.08032	29.02710	L98	District-6	41.04852	29.00769
L39	District-2	41.08551	29.02087	L99	District-6	41.04456	29.00711
L40	District-2	41.08630	29.03308	L100	District-6	41.04340	29.00660
L41	District-2	41.08807	29.02649	L101	District-7	41.05188	29.00848
L42	District-3	41.06409	29.04071	L102	District-7	41.05829	29.00732
L43	District-3	41.06689	29.04211	L103	District-7	41.05847	29.00769
L44	District-3	41.06708	29.04230	L104	District-7	41.05768	29.00208
L45	District-3	41.06769	29.04309	L105	District-7	41.05713	29.00891
L46	District-3	41.06769	29.04309	L106	District-7	41.05609	29.00513
L47	District-3	41.06409	29.04071	L107	District-7	41.05620	29.00260
L48	District-3	41.06812	29.04211	L108	District-7	41.05607	29.00570
L49	District-4	41.05829	29.01672	L109	District-7	41.05811	29.00732
L50	District-4	41.06716	29.01398	L110	District-7	41.05408	28.99988
L51	District-4	41.05908	29.01550	L111	District-7	41.05439	28.99984
L52	District-4	41.06567	29.01331	L112	District-7	41.05609	29.00549
L53	District-4	41.06348	29.01270	L113	District-7	41.05609	29.00549
L54	District-4	41.05825	29.01659	L114	District-7	41.05609	29.00592
L55	District-5	41.07910	29.04529	L115	District-7	41.05811	29.00732
L56	District-5	41.08392	29.05048	L116	District-7	41.05487	28.99951
L57	District-5	41.07727	29.04370	L117	District-7	41.05408	28.99988
L58	District-5	41.08524	29.04631	L118	District-7	41.05692	29.00444
L59	District-5	41.07727	29.04370	L119	District-7	41.05688	29.00372
L60	District-5	41.07709	29.04272	L120	District-7	41.05768	29.00110

ATM	District	Latitude	Longitude	ATM	District	Latitude	Longitude
L121	District-7	41.05640	29.00503	L181	District-10	41.08691	29.00732
L122	District-8	41.08087	29.03430	L182	District-10	41.08569	29.00787
L123	District-8	41.08866	29.03498	L183	District-10	41.08569	29.00787
L124	District-8	41.08929	29.03570	L184	District-10	41.08569	29.00787
L125	District-8	41.08612	29.03351	L185	District-10	41.09130	29.00580
L126	District-8	41.07953	29.03192	L186	District-10	41.08673	29.00891
L127	District-8	41.07813	29.02972	L187	District-10	41.10089	29.01068
L128	District-8	41.08008	29.03333	L188	District-10	41.08660	29.00800
L129	District-8	41.08008	29.03333	L189	District-10	41.08990	29.00848
L130	District-8	41.08016	29.03108	L190	District-10	41.08660	29.00800
L131	District-8	41.08087	29.03448	L191	District-10	41.10052	29.01349
L132	District-8	41.08260	29.03660	L192	District-10	41.08569	29.00769
L133	District-8	41.07836	29.03066	L193	District-10	41.09351	29.01251
L134	District-8	41.07788	29.02948	L194	District-10	41.08660	29.00800
L135	District-8	41.08032	29.03387	L195	District-10	41.10520	29.01368
L136	District-8	41.07928	29.03131	L196	District-10	41.09000	29.01120
L137	District-8	41.08069	29.03412	L197	District-10	41.08673	29.00873
L138	District-8	41.07765	29.02911	L198	District-10	41.08508	29.00909
L139	District-8	41.07765	29.02911	L199	District-10	41.08508	29.01068
L140	District-8	41.07910	29.03131	L200	District-10	41.08569	29.00787
L141	District-8	41.07928	29.03168	L201	District-10	41.08490	29.01031
L142	District-8	41.07930	29.03160	L202	District-10	41.08630	29.00769
L143	District-8	41.07953	29.03247	L203	District-10	41.08673	29.00873
L144	District-8	41.07911	29.03149	L204	District-10	41.08551	29.00787
L145	District-8	41.08008	29.03290	L205	District-10	41.08490	29.01031
L146	District-8	41.08008	29.03290	L206	District-10	41.08673	29.00873
L147	District-8	41.08090	29.03470	L207	District-10	41.08630	29.00769
L148	District-8	41.08130	29.03552	L208	District-10	41.08706	29.00710
L149	District-8	41.08130	29.03552	L209	District-11	41.05969	29.03632
L150	District-8	41.09020	29.03697	L210	District-11	41.05788	29.03017
L151	District-8	41.08282	29.03799	L211	District-11	41.05803	29.03052
L152	District-9	41.06409	29.00250	L212	District-12	41.07288	29.02869
L153	District-9	41.06409	29.00250	L213	District-12	41.07577	29.03493
L154	District-9	41.06628	29.00690	L214	District-12	41.07727	29.02588
L155	District-9	41.06110	29.01111	L215	District-12	41.07727	29.02588
L156	District-9	41.06653	29.00348	L216	District-12	41.07727	29.02588
L157	District-9	41.06073	29.01068	L217	District-12	41.06952	29.03448
L158	District-9	41.06073	29.01093	L218	District-12	41.07338	29.02831
L159	District-9	41.06488	29.00928	L219	District-12	41.07720	29.02740
L160	District-9	41.06073	29.01068	L220	District-12	41.07312	29.02850
L161	District-9	41.06653	29.00330	L221	District-12	41.07269	29.02893
L162	District-9	41.05829	29.01007	L222	District-12	41.07709	29.02667
L163	District-9	41.06427	29.00936	L223	District-12	41.07709	29.02667
L164	District-9	41.06470	29.00891	L224	District-12	41.07730	29.02720
L165	District-9	41.06628	29.00568	L225	District-12	41.07233	29.02893
L166	District-9	41.06653	29.00391	L226	District-12	41.07718	29.02677
L167	District-9	41.06653	29.00391	L227	District-12	41.07330	29.02893
L168	District-9	41.05969	29.01068	L228	District-13	41.06752	29.01450
L169	District-9	41.06470	29.00269	L229	District-13	41.06679	29.01607
L170	District-9	41.06166	29.01119	L230	District-13	41.06738	29.01629
L171	District-9	41.06073	29.01093	L231	District-13	41.06745	29.01619
L172	District-9	41.06451	29.00970	L232	District-13	41.06635	29.01715
L173	District-9	41.06470	29.00952	L233	District-13	41.06725	29.01636
L174	District-9	41.06470	29.00269	L234	District-13	41.06756	29.01467
L175	District-9	41.06311	29.01111	L235	District-13	41.06652	29.01690
L176	District-9	41.06300	29.01110	L236	District-13	41.06695	29.01606
L177	District-10	41.08700	29.00700	L237	District-13	41.06678	29.01633
L178	District-10	41.09430	29.01453	L238	District-13	41.06678	29.01633
L179	District-10	41.09412	29.01770	L239	District-13	41.06673	29.01612
L180	District-10	41.08569	29.00787	L240	District-13	41.06707	29.01671

ATM	District	Latitude	Longitude	ATM	District	Latitude	Longitude
L241	District-13	41.06731	29.01616	L301	District-14	41.07568	29.01691
L242	District-13	41.06711	29.01655	L302	District-14	41.08749	29.01752
L243	District-13	41.06738	29.01635	L303	District-14	41.07568	29.01691
L244	District-13	41.06696	29.01607	L304	District-14	41.07672	29.01691
L245	District-13	41.06707	29.01619	L305	District-14	41.07672	29.01691
L246	District-13	41.06691	29.01632	L306	District-14	41.07593	29.01593
L247	District-14	41.07532	29.01727	L307	District-14	41.07593	29.01593
L248	District-14	41.07593	29.01593	L308	District-14	41.07611	29.01611
L249	District-14	41.07593	29.01593	L309	District-14	41.07629	29.01648
L250	District-14	41.07593	29.01508	L310	District-14	41.07629	29.01648
L251	District-14	41.08771	29.01788	L311	District-14	41.07629	29.01648
L252	District-14	41.07593	29.01489	L312	District-14	41.07629	29.01648
L253	District-14	41.07593	29.01489	L313	District-14	41.07629	29.01648
L254	District-14	41.07593	29.01489	L314	District-14	41.08776	29.01760
L255	District-14	41.07410	29.01569	L315	District-15	41.05292	29.02350
L256	District-14	41.07611	29.01611	L316	District-15	41.04846	29.02568
L257	District-14	41.07611	29.01611	L317	District-15	41.04968	29.02570
L258	District-14	41.08313	29.01233	L318	District-15	41.04968	29.02570
L259	District-14	41.08191	29.01270	L319	District-15	41.04791	29.02533
L260	District-14	41.07960	29.01400	L320	District-15	41.04948	29.02556
L261	District-14	41.07910	29.01331	L321	District-15	41.04852	29.02570
L262	District-14	41.08331	29.01147	L322	District-15	41.04828	29.02490
L263	District-14	41.07570	29.01730	L323	District-15	41.05688	29.01233
L264	District-14	41.07570	29.01730	L324	District-15	41.05247	29.01676
L265	District-14	41.07568	29.01489	L325	District-15	41.04828	29.02490
L266	District-14	41.07590	29.01570	L326	District-15	41.04852	29.02631
L267	District-14	41.08313	29.01233	L327	District-15	41.04852	29.02631
L268	District-14	41.07570	29.01730	L328	District-15	41.05436	29.02002
L269	District-14	41.07593	29.01489	L329	District-15	41.05432	29.02008
L270	District-14	41.07568	29.01489	L330	District-15	41.04968	29.02570
L271	District-14	41.08313	29.01233	L331	District-15	41.04968	29.02570
L272	District-14	41.08331	29.01147	L332	District-15	41.05356	29.02306
L273	District-14	41.07410	29.01570	L333	District-15	41.05356	29.02306
L274	District-14	41.08190	29.01290	L334	District-17	41.07568	29.01990
L275	District-14	41.08289	29.01233	L335	District-17	41.07068	29.01788
L276	District-14	41.08289	29.01172	L336	District-17	41.07269	29.01648
L277	District-14	41.07593	29.01569	L337	District-17	41.07269	29.01648
L278	District-14	41.07611	29.01550	L338	District-17	41.07233	29.01831
L279	District-14	41.07550	29.01672	L339	District-17	41.07330	29.01813
L280	District-14	41.07550	29.01672	L340	District-17	41.07031	29.01532
L281	District-14	41.08091	29.01279	L341	District-17	41.07593	29.02032
L282	District-14	41.07593	29.01593	L342	District-17	41.07208	29.01831
L283	District-14	41.07593	29.01569	L343	District-17	41.07251	29.01813
L284	District-14	41.08148	29.01410	L344	District-17	41.07550	29.01892
L285	District-14	41.08148	29.01410	L345	District-17	41.07050	29.02930
L286	District-14	41.08148	29.01410	L346	District-17	41.07129	29.02789
L287	District-14	41.07593	29.01569	L347	District-17	41.07233	29.02869
L288	District-14	41.08148	29.01410	L348	District-18	41.04871	29.02771
L289	District-14	41.07593	29.01569	L349	District-18	41.05328	29.02350
L290	District-14	41.07593	29.01489	L350	District-18	41.04932	29.02808
L291	District-14	41.08096	29.01232	L351	District-18	41.05328	29.02350
L292	District-14	41.07611	29.01550	L352	District-18	41.05167	29.02443
L293	District-14	41.08069	29.01251	L353	District-18	41.04993	29.02588
L294	District-14	41.08771	29.01770	L354	District-18	41.04968	29.02588
L295	District-14	41.07593	29.01489	L355	District-19	41.04211	29.00470
L296	District-14	41.07732	29.01402	L356	District-19	41.04211	29.00470
L297	District-14	41.07550	29.01727	L357	District-19	41.04413	29.00128
L298	District-14	41.07770	29.01453	L358	District-19	41.04190	29.00490
L299	District-14	41.07608	29.01578	L359	District-19	41.04291	29.00653
L300	District-14	41.07919	29.01326	L360	District-19	41.04169	29.00787

ATM	District	Latitude	Longitude	ATM	District	Latitude	Longitude
L361	District-19	41.04187	29.00531	L409	District-21	41.06812	29.02991
L362	District-19	41.04187	29.00531	L410	District-21	41.06060	29.02900
L363	District-19	41.04169	29.00391	L411	District-22	41.04132	28.99768
L364	District-19	41.04169	29.00391	L412	District-22	41.04108	28.99707
L365	District-19	41.04169	29.00391	L413	District-22	41.04248	29.00128
L366	District-19	41.04413	29.00153	L414	District-22	41.04468	29.00031
L367	District-19	41.04169	29.00391	L415	District-22	41.04028	28.99188
L368	District-19	41.04169	29.00391	L416	District-22	41.04327	28.99768
L369	District-19	41.04248	29.00452	L417	District-22	41.04028	28.99268
L370	District-19	41.04187	29.00452	L418	District-22	41.04352	28.99750
L371	District-19	41.04187	29.00452	L419	District-22	41.04550	29.00021
L372	District-19	41.04187	29.00452	L420	District-22	41.04028	28.99188
L373	District-19	41.04388	29.00427	L421	District-22	41.04272	28.99908
L374	District-19	41.04388	29.00427	L422	District-22	41.04248	29.00149
L375	District-19	41.04248	29.00452	L423	District-22	41.04272	28.99591
L376	District-19	41.04248	29.00452	L424	District-22	41.04010	28.99231
L377	District-19	41.04431	29.00092	L425	District-22	41.04327	28.99792
L378	District-19	41.04354	29.00561	L426	District-22	41.04028	28.99188
L379	District-19	41.04309	29.00427	L427	District-22	41.04426	29.00075
L380	District-19	41.04309	29.00427	L428	District-22	41.04405	29.00118
L381	District-19	41.04300	29.00290	L429	District-22	41.03912	28.99890
L382	District-19	41.04230	29.00488	L430	District-22	41.04150	29.00348
L383	District-19	41.04230	29.00488	L431	District-22	41.04150	29.00348
L384	District-19	41.04230	29.00488	L432	District-22	41.04408	29.00112
L385	District-19	41.04413	29.00128	L433	District-22	41.04430	29.00080
L386	District-19	41.04211	29.00513	L434	District-22	41.04346	28.99711
L387	District-19	41.04211	29.00513	L435	District-23	41.04810	29.02448
L388	District-19	41.04350	29.00580	L436	District-23	41.04810	29.02448
L389	District-19	41.04350	29.00580	L437	District-23	41.04590	29.01929
L390	District-20	41.04664	29.00221	L438	District-23	41.04810	29.02448
L391	District-20	41.04470	29.00280	L439	District-23	41.04449	29.01648
L392	District-20	41.04969	29.00219	L440	District-23	41.04248	29.00952
L393	District-20	41.04608	29.00269	L441	District-23	41.04810	29.02429
L394	District-20	41.04527	29.00307	L442	District-23	41.04810	29.02429
L395	District-20	41.04527	29.00307	L443	District-23	41.04810	29.02429
L396	District-20	41.04527	29.00307	L444	District-23	41.05212	29.01007
L397	District-20	41.04950	29.00189	L445	District-23	41.05212	29.01007
L398	District-20	41.04510	29.00311	L446	District-23	41.04216	29.00826
L399	District-20	41.04968	29.00208	L447	District-23	41.04566	29.01923
L400	District-20	41.04572	29.00293	L448	District-23	41.04449	29.01611
L401	District-20	41.04510	29.00311	L449	District-23	41.04468	29.01691
L402	District-20	41.04510	29.00311	L450	District-23	41.04309	29.01147
L403	District-20	41.04468	29.00293	L451	District-23	41.04309	29.01147
L404	District-20	41.04590	29.00293	L452	District-23	41.04810	29.02448
L405	District-20	41.04661	29.00221	L453	District-23	41.04810	29.02440
L406	District-20	41.04605	29.00268	L454	District-23	41.04810	29.02429
L407	District-20	41.04605	29.00268	L455	District-23	41.04590	29.01971
L408	District-21	41.06207	29.02332	L456	District-23	41.05197	29.00993

Appendix C– Distance Matrix

I/J	1	2	3	.	.	.	.	.	228	229	230	.	.	.	.	.	.	454	455	456
1	0,0000	2,9226	1,5847	.	.	.	.	.				.	.	.	.	.	.	4,4726	4,7801	4,3940
2	2,9226	0,0000	2,7708	.	.	.	.	.				.	.	.	.	.	.	2,1673	2,2672	1,5467
3	1,5847	2,7708	0,0000	.	.	.	.	.				.	.	.	.	.	.	3,5207	3,9169	3,8817
.	.	.	.	0,0000	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	0,0000	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	0,0000	.	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	0,0000	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	0,0000	.	.	.	.	.	.	.	.	.	.	.	.
228	2,6873	0,2356	2,5815	.	.	.	.	.	0,0000	0,1553	0,1511	.	.	.	.	.	.	2,3110	2,4439	1,7708
229	2,6897	0,2768	2,4941	.	.	.	.	.	0,1553	0,0000	0,0680	.	.	.	.	.	.	2,1900	2,3430	1,7262
230	2,6237	0,3262	2,4501	.	.	.	.	.	0,1511	0,0680	0,0000	.	.	.	.	.	.	2,2469	2,4059	1,7942
.	.	.	.	.	.	.	.	.	.	.	.	0,0000	.	.	.	.	.	.	.	.
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454	4,4726	2,1673	3,5207	.	.	.	.	.	2,3110	2,1900	2,2469	.	.	.	.	.	.	0,0000	0,4550	1,2792
455	4,7801	2,2672	3,9169	.	.	.	.	.	2,4439	2,3430	2,4059	.	.	.	.	.	.	0,4550	0,0000	1,0628
456	4,3940	1,5467	3,8817	.	.	.	.	.	1,7708	1,7262	1,7942	.	.	.	.	.	.	1,2792	1,0628	0,0000

Appendix D– Weighted Total Scores for each ATM

ATM	Scores					Weigted Scores					WTS
	TV	CI	CE	BA	OBA	TV	CI	CE	BA	OBA	
L1	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L2	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L3	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L4	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L5	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L6	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L7	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L8	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L9	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L10	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L11	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L12	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L13	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L14	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L15	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L16	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L17	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L18	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L19	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L20	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L21	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L22	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L23	5	2	1	5	1	0,43755	1,04148	0,02969	2,41079	0,01485	3,93436
L24	5	2	1	5	1	0,43755	1,04148	0,02969	2,41079	0,01485	3,93436
L25	5	2	1	5	1	0,43755	1,04148	0,02969	2,41079	0,01485	3,93436
L26	5	2	1	5	1	0,43755	1,04148	0,02969	2,41079	0,01485	3,93436
L27	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L28	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L29	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L30	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L31	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L32	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L33	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L34	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L35	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L36	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L37	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L38	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L39	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L40	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L41	1	1	2	3	2	0,21877	0,20830	0,05939	1,44647	0,02970	1,96263
L42	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L43	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L44	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L45	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L46	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L47	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L48	1	1	1	5	1	0,21877	0,20830	0,02969	2,41079	0,01485	2,88240
L49	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L50	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L51	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L52	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L53	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L54	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L55	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L56	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L57	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L58	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L59	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L60	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L61	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L62	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
ATM	Scores					Weigted Scores					WTS

	TV	CI	CE	BA	OBA	TV	CI	CE	BA	OBA	
L63	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L64	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L65	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L66	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L67	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L68	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L69	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L70	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L71	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L72	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L73	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L74	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L75	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L76	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L77	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L78	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L79	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L80	2	1	2	3	2	0,21877	0,41659	0,05939	1,44647	0,02970	2,17093
L81	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L82	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L83	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L84	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L85	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L86	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L87	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L88	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L89	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L90	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L91	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L92	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L93	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L94	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L95	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L96	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L97	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L98	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L99	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L100	5	1	2	3	2	0,21877	1,04148	0,05939	1,44647	0,02970	2,79581
L101	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L102	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L103	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L104	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L105	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L106	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L107	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L108	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L109	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L110	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L111	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L112	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L113	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L114	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L115	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L116	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L117	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L118	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L119	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L120	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L121	3	2	4	5	2	0,43755	0,62489	0,11877	2,41079	0,02970	3,62170
L122	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L123	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L124	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L125	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L126	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L127	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L128	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L129	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
ATM	**Scores**					**Weigted Scores**					**WTS**
	TV	**CI**	**CE**	**BA**	**OBA**	**TV**	**CI**	**CE**	**BA**	**OBA**	

L130	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L131	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L132	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L133	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L134	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L135	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L136	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L137	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L138	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L139	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L140	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L141	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L142	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L143	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L144	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L145	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L146	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L147	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L148	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L149	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L150	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L151	3	1	4	3	3	0,21877	0,62489	0,11877	1,44647	0,04455	2,45346
L152	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L153	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L154	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L155	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L156	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L157	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L158	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L159	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L160	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L161	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L162	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L163	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L164	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L165	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L166	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L167	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L168	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L169	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L170	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L171	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L172	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L173	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L174	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L175	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L176	3	2	2	2	2	0,43755	0,62489	0,05939	0,96432	0,02970	2,11584
L177	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L178	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L179	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L180	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L181	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L182	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L183	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L184	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L185	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L186	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L187	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L188	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L189	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L190	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L191	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L192	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L193	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L194	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L195	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L196	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
ATM	**Scores**					**Weigted Scores**					**WTS**
	TV	**CI**	**CE**	**BA**	**OBA**	**TV**	**CI**	**CE**	**BA**	**OBA**	
L197	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839

L198	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L199	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L200	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L201	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L202	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L203	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L204	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L205	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L206	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L207	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L208	3	1	2	5	3	0,21877	0,62489	0,05939	2,41079	0,04455	3,35839
L209	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L210	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L211	1	1	1	3	1	0,21877	0,20830	0,02969	1,44647	0,01485	1,91809
L212	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L213	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L214	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L215	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L216	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L217	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L218	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L219	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L220	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L221	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L222	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L223	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L224	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L225	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L226	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L227	2	1	5	5	2	0,21877	0,41659	0,14847	2,41079	0,02970	3,22432
L228	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L229	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L230	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L231	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L232	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L233	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L234	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L235	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L236	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L237	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L238	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L239	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L240	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L241	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L242	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L243	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L244	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L245	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L246	2	2	1	3	2	0,43755	0,41659	0,02969	1,44647	0,02970	2,36001
L247	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L248	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L249	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L250	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L251	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L252	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L253	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L254	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L255	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L256	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L257	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L258	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L259	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L260	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L261	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L262	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L263	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
ATM	**Scores**					**Weigted Scores**					**WTS**
	TV	**CI**	**CE**	**BA**	**OBA**	**TV**	**CI**	**CE**	**BA**	**OBA**	
L264	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L265	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807

L266	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L267	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L268	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L269	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L270	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L271	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L272	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L273	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L274	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L275	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L276	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L277	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L278	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L279	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L280	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L281	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L282	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L283	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L284	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L285	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L286	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L287	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L288	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L289	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L290	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L291	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L292	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L293	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L294	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L295	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L296	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L297	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L298	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L299	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L300	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L301	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L302	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L303	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L304	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L305	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L306	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L307	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L308	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L309	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L310	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L311	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L312	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L313	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L314	4	2	4	2	5	0,43755	0,83318	0,11877	0,96432	0,07425	2,42807
L315	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L316	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L317	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L318	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L319	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L320	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L321	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L322	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L323	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L324	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L325	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L326	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L327	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L328	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L329	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L330	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
ATM	**Scores**					**Weigted Scores**					**WTS**
	TV	**CI**	**CE**	**BA**	**OBA**	**TV**	**CI**	**CE**	**BA**	**OBA**	
L331	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L332	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938
L333	4	3	2	5	2	0,65632	0,83318	0,05939	2,41079	0,02970	3,98938

L334	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L335	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L336	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L337	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L338	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L339	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L340	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L341	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L342	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L343	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L344	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L345	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L346	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L347	2	1	1	3	2	0,21877	0,41659	0,02969	1,44647	0,02970	2,14123
L348	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L349	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L350	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L351	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L352	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L353	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L354	5	5	1	1	1	1,09387	1,04148	0,02969	0,48216	0,01485	2,66205
L355	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L356	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L357	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L358	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L359	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L360	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L361	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L362	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L363	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L364	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L365	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L366	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L367	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L368	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L369	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L370	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L371	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L372	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L373	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L374	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L375	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L376	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L377	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L378	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L379	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L380	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L381	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L382	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L383	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L384	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L385	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L386	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L387	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L388	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L389	5	5	3	1	3	1,09387	1,04148	0,08908	0,48216	0,04455	2,75114
L390	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L391	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L392	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L393	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L394	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L395	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L396	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L397	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030

ATM	Scores					Weigted Scores					WTS
	TV	CI	CE	BA	OBA	TV	CI	CE	BA	OBA	
L398	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L399	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L400	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L401	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030

L402	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L403	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L404	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L405	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L406	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L407	4	2	3	5	2	0,43755	0,83318	0,08908	2,41079	0,02970	3,80030
L408	3	3	1	5	1	0,65632	0,62489	0,02969	2,41079	0,01485	3,73654
L409	3	3	1	5	1	0,65632	0,62489	0,02969	2,41079	0,01485	3,73654
L410	3	3	1	5	1	0,65632	0,62489	0,02969	2,41079	0,01485	3,73654
L411	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L412	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L413	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L414	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L415	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L416	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L417	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L418	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L419	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L420	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L421	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L422	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L423	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L424	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L425	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L426	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L427	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L428	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L429	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L430	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L431	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L432	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L433	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L434	2	1	2	1	2	0,21877	0,41659	0,05939	0,48216	0,02970	1,20661
L435	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L436	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L437	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L438	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L439	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L440	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L441	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L442	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L443	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L444	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L445	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L446	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L447	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L448	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L449	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L450	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L451	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L452	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490
L453	5	2	1	3	2	[illegible]	[illegible]	0,02969	1,44647	0,02970	2,98490
L454	5	2	1	3	2	[illegible]	[illegible]	0,02969	1,44647	0,02970	2,98490
L455	5	2	1	3	2	[illegible]	[illegible]	0,02969	1,44647	0,02970	2,98490
L456	5	2	1	3	2	0,43755	1,04148	0,02969	1,44647	0,02970	2,98490

Appendix E- Models in Lingo

E.1 Lingo Model for the Maximization of 1st Objective (Scenario I)

```
MODEL:
```

```
!The maximization of the 1st Objective (Score)-Scenario.1;

TITLE ATM Location Problem;

SETS:
      Locations:
Deployment,Capacity,Score,Setupcost,Closingcost,Operationalcost;
      Demandnodes: Demand;
      Links(Demandnodes,Locations): Assignment,Distance;
ENDSETS

!Data that is used in the model is provided below;
DATA:

!Entered values for the problem;
Capex=1110;!Total budget available for the capital costs;
Opex=2000;!Total budget available for the operational costs;
Maxdistance=0.9;! the limitation of maximum traveled distance between
demand node and alternative location;


!Set members;
Locations=L1..L456;
!ExistingLocations=L1..L22;
!NewLocations=L23..L456;

Demandnodes=D1..D456;

!Attribute values;
Capacity=19872;
Setupcost=100;
Closingcost=5;
Operationalcost=60;
Score=@OLE('Model Data.xlsx','Score');
Demand=@OLE('Model Data.xlsx','Demand');
Distance=@OLE('Model Data.xlsx','Distance');

ENDDATA
!Parameters
i = index for demand node N=(1,...,n),
j = index for possible ATM location M=(1,...,m);

!1st objective;
[OBJECTIVE] MAX=@SUM(Locations(j):Score(j)*Deployment(j));

!Objectives
```

```
MAX=@SUM(Locations(j):Score(j)*Deployment(j))
MIN=@SUM(Locations(j):Deployment(j))
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Constraint to satisfy all demand nodes;
@FOR(Demandnodes(i):[Demand_Row]
  @SUM(Locations(j):Assignment(i,j))=
    1);

!Constraint that limits the assignment of a demand node to an open
ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Assignment_Row]
Assignment(i,j)<=Deployment(j)));

!Constraint that limits the max. distance for assignment of a demand
node to an ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Distance_Row]
Distance(i,j)*Assignment(i,j)<= Maxdistance));

!Capacity constraint that restricts the amount of demand that can be
served from an open ATM not to exceed the capacity of the ATM;
@FOR(Locations(j):[Capacity_Row]
  @SUM(Demandnodes(i): Assignment(i,j)*Demand(i))<=
    Capacity);

!Budget constraint;
[SC_Row]SC=@SUM(Locations(j)| j #GE# 23:Deployment(j)*Setupcost);
[CC_Row]CC=@SUM(Locations(j)| j #LE# 22:((1-
Deployment(j))*Closingcost));
[OC_Row]OC=@SUM(Locations(j):Deployment(j)*Operationalcost);
[Opex_Row]OC<=Opex;
[Capex_Row]SC+CC<=Capex;

!Values of objective functions;
F1=@SUM(Locations(j):Score(j)*Deployment(j));
F2=@SUM(Locations(j):Deployment(j));
F3=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Zero one restriction for decision variables;
@FOR(Locations(j):@BIN(Deployment(j)));
@FOR(Links(i,j):@BIN(Assignment(i,j)));

END
```

E.2 Solution of Lingo Model for the Maximization of 1st Objective (Scenario I)

```
Global optimal solution found.
  Objective value:                              89.63502
  Objective bound:                              89.63502
  Infeasibilities:                              0.000000
  Extended solver steps:                               0
  Total solver iterations:                          4525
  Elapsed runtime seconds:                         24.59


Model Title: ATM Location Problem

Variable                        Value          Reduced Cost
CAPEX                        1110.000              0.000000
OPEX                         2000.000              0.000000
MAXDISTANCE                 0.9000000              0.000000
SC                           1100.000              0.000000
OC                           1980.000              0.000000
F1                           89.63502              0.000000
F2                           33.00000              0.000000
F3                           12632.81              0.000000

DEPLOYMENT( L1)              1.000000             -1.962630
DEPLOYMENT( L2)              1.000000             -1.918087
DEPLOYMENT( L3)              1.000000             -2.170926
DEPLOYMENT( L4)              1.000000             -2.795814
DEPLOYMENT( L5)              1.000000             -2.453458
DEPLOYMENT( L6)              1.000000             -2.115838
DEPLOYMENT( L7)              1.000000             -2.115838
DEPLOYMENT( L8)              1.000000             -1.918087
DEPLOYMENT( L9)              1.000000             -2.360007
DEPLOYMENT( L10)             1.000000             -2.428070
DEPLOYMENT( L11)             1.000000             -2.428070
DEPLOYMENT( L12)             1.000000             -2.141233
DEPLOYMENT( L13)             1.000000             -2.662051
DEPLOYMENT( L14)             1.000000             -2.662051
DEPLOYMENT( L15)             1.000000             -2.662051
DEPLOYMENT( L16)             1.000000             -2.751137
DEPLOYMENT( L17)             1.000000             -2.751137
DEPLOYMENT( L18)             1.000000             -2.751137
DEPLOYMENT( L19)             1.000000             -1.206610
DEPLOYMENT( L20)             1.000000             -1.206610
DEPLOYMENT( L21)             1.000000             -1.206610
DEPLOYMENT( L22)             1.000000             -2.984895
DEPLOYMENT( L26)             1.000000             -3.934361
DEPLOYMENT( L56)             1.000000             -2.170926
DEPLOYMENT( L191)            1.000000             -3.358388
DEPLOYMENT( L196)            1.000000             -3.358388
DEPLOYMENT( L217)            1.000000             -3.224321
DEPLOYMENT( L318)            1.000000             -3.989382
DEPLOYMENT( L320)            1.000000             -3.989382
DEPLOYMENT( L322)            1.000000             -3.989382
DEPLOYMENT( L325)            1.000000             -3.989382
DEPLOYMENT( L327)            1.000000             -3.989382
DEPLOYMENT( L329)            1.000000             -3.989382
ASSIGNMENT( D1, L1)          1.000000              0.000000
```

ASSIGNMENT(D2, L2)	1.000000	0.000000
ASSIGNMENT(D3, L3)	1.000000	0.000000
ASSIGNMENT(D4, L4)	1.000000	0.000000
ASSIGNMENT(D5, L5)	1.000000	0.000000
ASSIGNMENT(D6, L2)	1.000000	0.000000
ASSIGNMENT(D7, L2)	1.000000	0.000000
ASSIGNMENT(D8, L8)	1.000000	0.000000
ASSIGNMENT(D9, L2)	1.000000	0.000000
ASSIGNMENT(D10, L10)	1.000000	0.000000
ASSIGNMENT(D11, L5)	1.000000	0.000000
ASSIGNMENT(D12, L5)	1.000000	0.000000
ASSIGNMENT(D13, L15)	1.000000	0.000000
ASSIGNMENT(D14, L13)	1.000000	0.000000
ASSIGNMENT(D15, L13)	1.000000	0.000000
ASSIGNMENT(D16, L4)	1.000000	0.000000
ASSIGNMENT(D17, L4)	1.000000	0.000000
ASSIGNMENT(D18, L4)	1.000000	0.000000
ASSIGNMENT(D19, L4)	1.000000	0.000000
ASSIGNMENT(D20, L18)	1.000000	0.000000
ASSIGNMENT(D21, L18)	1.000000	0.000000
ASSIGNMENT(D22, L4)	1.000000	0.000000
ASSIGNMENT(D23, L4)	1.000000	0.000000
ASSIGNMENT(D24, L4)	1.000000	0.000000
ASSIGNMENT(D25, L4)	1.000000	0.000000
ASSIGNMENT(D26, L4)	1.000000	0.000000
ASSIGNMENT(D27, L196)	1.000000	0.000000
ASSIGNMENT(D28, L1)	1.000000	0.000000
ASSIGNMENT(D29, L1)	1.000000	0.000000
ASSIGNMENT(D30, L1)	1.000000	0.000000
ASSIGNMENT(D31, L1)	1.000000	0.000000
ASSIGNMENT(D32, L10)	1.000000	0.000000
ASSIGNMENT(D33, L1)	1.000000	0.000000
ASSIGNMENT(D34, L5)	1.000000	0.000000
ASSIGNMENT(D35, L1)	1.000000	0.000000
ASSIGNMENT(D36, L5)	1.000000	0.000000
ASSIGNMENT(D37, L1)	1.000000	0.000000
ASSIGNMENT(D38, L5)	1.000000	0.000000
ASSIGNMENT(D39, L10)	1.000000	0.000000
ASSIGNMENT(D40, L1)	1.000000	0.000000
ASSIGNMENT(D41, L1)	1.000000	0.000000
ASSIGNMENT(D42, L8)	1.000000	0.000000
ASSIGNMENT(D43, L8)	1.000000	0.000000
ASSIGNMENT(D44, L8)	1.000000	0.000000
ASSIGNMENT(D45, L217)	1.000000	0.000000
ASSIGNMENT(D46, L217)	1.000000	0.000000
ASSIGNMENT(D47, L8)	1.000000	0.000000
ASSIGNMENT(D48, L217)	1.000000	0.000000
ASSIGNMENT(D49, L6)	1.000000	0.000000
ASSIGNMENT(D50, L2)	1.000000	0.000000
ASSIGNMENT(D51, L2)	1.000000	0.000000
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E.3 Lingo Model for the Minimization of 2nd Objective (Scenario I)

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MODEL:
!The minimization of the 2nd Objective (number of ATM)-Scenario.1;

TITLE ATM Location Problem;

SETS:
      Locations:
Deployment,Capacity,Score,Setupcost,Closingcost,Operationalcost;
      Demandnodes: Demand;
      Links(Demandnodes,Locations): Assignment,Distance;
ENDSETS

!Data that is used in the model is provided below;
DATA:

!Entered values for the problem;
Capex=1110;!Total budget available for the capital costs;
Opex=2000;!Total budget available for the operational costs;
Maxdistance=0.9;! the limitation of maximum traveled distance between
demand node and alternative location;

!Set members;
Locations=L1..L456;
!ExistingLocations=L1..L22;
!NewLocations=L23..L456;

Demandnodes=D1..D456;

!Attribute values;
Capacity=19872;
Setupcost=100;
Closingcost=5;
Operationalcost=60;
Score=@OLE('Model Data.xlsx','Score');
Demand=@OLE('Model Data.xlsx','Demand');
Distance=@OLE('Model Data.xlsx','Distance');

ENDDATA
!Parameters
i = index for demand node N=(1,...,n),
j = index for possible ATM location M=(1,...,m);

!2nd objective;
[OBJECTIVE] MIN=@SUM(Locations(j):Deployment(j));

!Objectives
MAX=@SUM(Locations(j):Score(j)*Deployment(j))
MIN=@SUM(Locations(j):Deployment(j))
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Constraint to satisfy all demand nodes;
@FOR(Demandnodes(i):[Demand_Row]
  @SUM(Locations(j):Assignment(i,j))=
    1);
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!Constraint that limits the assignment of a demand node to an open
ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Assignment_Row]
Assignment(i,j)<=Deployment(j)));

!Constraint that limits the max. distance for assignment of a demand
node to an ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Distance_Row]
Distance(i,j)*Assignment(i,j)<= Maxdistance));

!Capacity constraint that restricts the amount of demand that can be
served from an open ATM not to exceed the capacity of the ATM;
@FOR(Locations(j):[Capacity_Row]
  @SUM(Demandnodes(i): Assignment(i,j)*Demand(i))<=
    Capacity);

!Budget constraint;
[SC_Row]SC=@SUM(Locations(j)| j #GE# 23:Deployment(j)*Setupcost);
[CC_Row]CC=@SUM(Locations(j)| j #LE# 22:((1-
Deployment(j))*Closingcost));
[OC_Row]OC=@SUM(Locations(j):Deployment(j)*Operationalcost);
[Opex_Row]OC<=Opex;
[Capex_Row]SC+CC<=Capex;

!Values of objective functions;
F1=@SUM(Locations(j):Score(j)*Deployment(j));
F2=@SUM(Locations(j):Deployment(j));
F3=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Zero one restriction for decision variables;
@FOR(Locations(j):@BIN(Deployment(j)));
@FOR(Links(i,j):@BIN(Assignment(i,j)));

END
```

E.4 Solution of Lingo Model for the Maximization of 2nd Objective (Scenario I)

```
Global optimal solution found.
  Objective value:                              11.00000
  Objective bound:                              11.00000
  Infeasibilities:                              0.000000
  Extended solver steps:                               2
  Total solver iterations:                         53437
  Elapsed runtime seconds:                         35.38


Model Title: ATM Location Problem

Variable                        Value        Reduced Cost

CAPEX                         1110.000           0.000000
OPEX                          2000.000           0.000000
MAXDISTANCE                  0.9000000           0.000000
SC                            800.0000           0.000000
CC                            95.00000           0.000000
OC                            660.0000           0.000000
F1                            30.09837           0.000000
F2                            11.00000           0.000000
F3                            21439.30           0.000000

DEPLOYMENT( L6)               1.000000           1.000000
DEPLOYMENT( L12)              1.000000           1.000000
DEPLOYMENT( L18)              1.000000           1.000000
DEPLOYMENT( L61)              1.000000           1.000000
DEPLOYMENT( L115)             1.000000           1.000000
DEPLOYMENT( L125)             1.000000           1.000000
DEPLOYMENT( L191)             1.000000           1.000000
DEPLOYMENT( L199)             1.000000           1.000000
DEPLOYMENT( L211)             1.000000           1.000000
DEPLOYMENT( L217)             1.000000           1.000000
DEPLOYMENT( L453)             1.000000           1.000000
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ASSIGNMENT(D344, L12)	1.000000	0.000000
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ASSIGNMENT(D348, L453)	1.000000	0.000000
ASSIGNMENT(D349, L211)	1.000000	0.000000
ASSIGNMENT(D350, L453)	1.000000	0.000000
ASSIGNMENT(D351, L211)	1.000000	0.000000
ASSIGNMENT(D352, L211)	1.000000	0.000000
ASSIGNMENT(D353, L453)	1.000000	0.000000
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ASSIGNMENT(D369, L18)	1.000000	0.000000
ASSIGNMENT(D370, L18)	1.000000	0.000000
ASSIGNMENT(D371, L18)	1.000000	0.000000
ASSIGNMENT(D372, L18)	1.000000	0.000000
ASSIGNMENT(D373, L18)	1.000000	0.000000
ASSIGNMENT(D374, L18)	1.000000	0.000000
ASSIGNMENT(D375, L18)	1.000000	0.000000
ASSIGNMENT(D376, L18)	1.000000	0.000000

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ASSIGNMENT( D406, L18)          1.000000            0.000000
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ASSIGNMENT( D408, L211)         1.000000            0.000000
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ASSIGNMENT( D410, L211)         1.000000            0.000000
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ASSIGNMENT( D412, L18)          1.000000            0.000000
ASSIGNMENT( D413, L18)          1.000000            0.000000
ASSIGNMENT( D414, L18)          1.000000            0.000000
ASSIGNMENT( D415, L18)          1.000000            0.000000
ASSIGNMENT( D416, L18)          1.000000            0.000000
ASSIGNMENT( D417, L18)          1.000000            0.000000
ASSIGNMENT( D418, L18)          1.000000            0.000000
ASSIGNMENT( D419, L18)          1.000000            0.000000
ASSIGNMENT( D420, L18)          1.000000            0.000000
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ASSIGNMENT( D423, L18)          1.000000            0.000000
ASSIGNMENT( D424, L18)          1.000000            0.000000
ASSIGNMENT( D425, L18)          1.000000            0.000000
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ASSIGNMENT( D427, L18)          1.000000            0.000000
ASSIGNMENT( D428, L18)          1.000000            0.000000
ASSIGNMENT( D429, L18)          1.000000            0.000000
ASSIGNMENT( D430, L18)          1.000000            0.000000
ASSIGNMENT( D431, L18)          1.000000            0.000000
ASSIGNMENT( D432, L18)          1.000000            0.000000
ASSIGNMENT( D433, L18)          1.000000            0.000000
ASSIGNMENT( D434, L18)          1.000000            0.000000
ASSIGNMENT( D435, L453)         1.000000            0.000000
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ASSIGNMENT(D436, L453)	1.000000	0.000000
ASSIGNMENT(D437, L453)	1.000000	0.000000
ASSIGNMENT(D438, L453)	1.000000	0.000000
ASSIGNMENT(D439, L453)	1.000000	0.000000
ASSIGNMENT(D440, L18)	1.000000	0.000000
ASSIGNMENT(D441, L453)	1.000000	0.000000
ASSIGNMENT(D442, L453)	1.000000	0.000000
ASSIGNMENT(D443, L453)	1.000000	0.000000
ASSIGNMENT(D444, L115)	1.000000	0.000000
ASSIGNMENT(D445, L115)	1.000000	0.000000
ASSIGNMENT(D446, L18)	1.000000	0.000000
ASSIGNMENT(D447, L453)	1.000000	0.000000
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ASSIGNMENT(D449, L453)	1.000000	0.000000
ASSIGNMENT(D450, L18)	1.000000	0.000000
ASSIGNMENT(D451, L18)	1.000000	0.000000
ASSIGNMENT(D452, L453)	1.000000	0.000000
ASSIGNMENT(D453, L453)	1.000000	0.000000
ASSIGNMENT(D454, L453)	1.000000	0.000000
ASSIGNMENT(D455, L453)	1.000000	0.000000
ASSIGNMENT(D456, L115)	1.000000	0.000000

E.5 Lingo Model for the Minimization of 3rd Objective (Scenario I)

```
MODEL:
!The minimization of the 3rd Objective (total weighted distance)-
Scenario.1;

TITLE ATM Location Problem;

SETS:
      Locations:
Deployment,Capacity,Score,Setupcost,Closingcost,Operationalcost;
      Demandnodes: Demand;
      Links(Demandnodes,Locations): Assignment,Distance;
ENDSETS

!Data that is used in the model is provided below;
DATA:

!Entered values for the problem;
Capex=1110;!Total budget available for the capital costs;
Opex=2000;!Total budget available for the operational costs;
Maxdistance=0.9;! the limitation of maximum traveled distance between
demand node and alternative location;

!Set members;
Locations=L1..L456;
!ExistingLocations=L1..L22;
!NewLocations=L23..L456;

Demandnodes=D1..D456;

!Attribute values;
Capacity=19872;
Setupcost=100;
Closingcost=5;
Operationalcost=60;
Score=@OLE('Model Data.xlsx','Score');
Demand=@OLE('Model Data.xlsx','Demand');
Distance=@OLE('Model Data.xlsx','Distance');

ENDDATA
!Parameters
i = index for demand node N=(1,...,n),
j = index for possible ATM location M=(1,...,m);

!3rd objective;
[OBJECTIVE]
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Objectives
MAX=@SUM(Locations(j):Score(j)*Deployment(j))
MIN=@SUM(Locations(j):Deployment(j))
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));
```

```
!Constraint to satisfy all demand nodes;
@FOR(Demandnodes(i):[Demand_Row]
  @SUM(Locations(j):Assignment(i,j))=
    1);

!Constraint that limits the assignment of a demand node to an open
ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Assignment_Row]
Assignment(i,j)<=Deployment(j)));

!Constraint that limits the max. distance for assignment of a demand
node to an ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Distance_Row]
Distance(i,j)*Assignment(i,j)<= Maxdistance));

!Capacity constraint that restricts the amount of demand that can be
served from an open ATM not to exceed the capacity of the ATM;
@FOR(Locations(j):[Capacity_Row]
  @SUM(Demandnodes(i): Assignment(i,j)*Demand(i))<=
    Capacity);

!Budget constraint;
[SC_Row]SC=@SUM(Locations(j)| j #GE# 23:Deployment(j)*Setupcost);
[CC_Row]CC=@SUM(Locations(j)| j #LE# 22:((1-
Deployment(j))*Closingcost));
[OC_Row]OC=@SUM(Locations(j):Deployment(j)*Operationalcost);
[Opex_Row]OC<=Opex;
[Capex_Row]SC+CC<=Capex;

!Values of objective functions;
[ValueofObj1_Row]F1=@SUM(Locations(j):Score(j)*Deployment(j));
[ValueofObj2_Row]F2=@SUM(Locations(j):Deployment(j));
[ValueofObj3_Row]F3=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance
(i,j));

!Zero one restriction for decision variables;
@FOR(Locations(j):@BIN(Deployment(j)));
@FOR(Links(i,j):@BIN(Assignment(i,j)));

END
```

E.6 Solution of Lingo Model for the Maximization of 3rd Objective (Scenario I)

```
Global optimal solution found.
  Objective value:                              532.9420
  Objective bound:                              532.9420
  Infeasibilities:                            0.1567059E-08
  Extended solver steps:                               0
  Total solver iterations:                         73827
  Elapsed runtime seconds:                         43.45


Model Title: ATM Location Problem

Variable                         Value            Reduced Cost

CAPEX                          1110.000             0.000000
OPEX                           2000.000             0.000000
MAXDISTANCE                   0.9000000             0.000000
SC                             1100.000             0.000000
OC                             1980.000             0.000000
F1                             82.42409             0.000000
F2                             33.00000             0.000000
F3                             532.9420             0.000000

DEPLOYMENT( L1)                1.000000             0.000000
DEPLOYMENT( L2)                1.000000             0.000000
DEPLOYMENT( L3)                1.000000             0.000000
DEPLOYMENT( L4)                1.000000             0.000000
DEPLOYMENT( L5)                1.000000             0.000000
DEPLOYMENT( L6)                1.000000             0.000000
DEPLOYMENT( L7)                1.000000             0.000000
DEPLOYMENT( L8)                1.000000             0.000000
DEPLOYMENT( L9)                1.000000             0.000000
DEPLOYMENT( L10)               1.000000             0.000000
DEPLOYMENT( L11)               1.000000             0.000000
DEPLOYMENT( L12)               1.000000             0.000000
DEPLOYMENT( L13)               1.000000             0.000000
DEPLOYMENT( L14)               1.000000             0.000000
DEPLOYMENT( L15)               1.000000             0.000000
DEPLOYMENT( L16)               1.000000             0.000000
DEPLOYMENT( L17)               1.000000             0.000000
DEPLOYMENT( L18)               1.000000             0.000000
DEPLOYMENT( L19)               1.000000             0.000000
DEPLOYMENT( L20)               1.000000             0.000000
DEPLOYMENT( L21)               1.000000             0.000000
DEPLOYMENT( L22)               1.000000             0.000000
DEPLOYMENT( L45)               1.000000             0.000000
DEPLOYMENT( L58)               1.000000             0.000000
DEPLOYMENT( L110)              1.000000             0.000000
DEPLOYMENT( L119)              1.000000             0.000000
DEPLOYMENT( L131)              1.000000             0.000000
DEPLOYMENT( L187)              1.000000             0.000000
DEPLOYMENT( L202)              1.000000             0.000000
DEPLOYMENT( L212)              1.000000             0.000000
DEPLOYMENT( L226)              1.000000             0.000000
DEPLOYMENT( L251)              1.000000             0.000000
DEPLOYMENT( L277)              1.000000             0.000000
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ASSIGNMENT(D3, L3)	1.000000	0.000000
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ASSIGNMENT(D5, L5)	1.000000	0.000000
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ASSIGNMENT(D7, L7)	1.000000	0.000000
ASSIGNMENT(D8, L8)	1.000000	0.000000
ASSIGNMENT(D9, L9)	1.000000	0.000000
ASSIGNMENT(D10, L10)	1.000000	0.000000
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ASSIGNMENT(D12, L12)	1.000000	0.000000
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ASSIGNMENT(D131, L131)	1.000000	0.000000
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ASSIGNMENT(D162, L2)	1.000000	0.000000
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ASSIGNMENT(D166, L7)	1.000000	5.143017
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ASSIGNMENT(D168, L6)	1.000000	3.978944
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ASSIGNMENT(D174, L2)	1.000000	0.000000
ASSIGNMENT(D175, L2)	1.000000	0.000000
ASSIGNMENT(D176, L6)	1.000000	2.148468
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ASSIGNMENT(D181, L202)	1.000000	0.2463602E-01
ASSIGNMENT(D182, L202)	1.000000	0.5723768
ASSIGNMENT(D183, L202)	1.000000	0.5575037
ASSIGNMENT(D184, L202)	1.000000	0.1290040
ASSIGNMENT(D185, L202)	1.000000	0.6239273E-01
ASSIGNMENT(D186, L202)	1.000000	2.168702
ASSIGNMENT(D187, L187)	1.000000	0.000000
ASSIGNMENT(D188, L202)	1.000000	0.4529024E-02
ASSIGNMENT(D189, L202)	1.000000	0.1159874
ASSIGNMENT(D190, L202)	1.000000	0.6752019
ASSIGNMENT(D191, L187)	1.000000	0.1289265E-01
ASSIGNMENT(D192, L202)	1.000000	0.5057527
ASSIGNMENT(D193, L251)	1.000000	1.211923
ASSIGNMENT(D194, L202)	1.000000	0.2770253
ASSIGNMENT(D195, L187)	1.000000	0.000000
ASSIGNMENT(D196, L202)	1.000000	0.000000
ASSIGNMENT(D197, L202)	1.000000	0.2898426
ASSIGNMENT(D198, L202)	1.000000	0.3233331
ASSIGNMENT(D199, L202)	1.000000	0.3213195
ASSIGNMENT(D200, L202)	1.000000	0.3455239
ASSIGNMENT(D201, L202)	1.000000	0.2409285
ASSIGNMENT(D202, L202)	1.000000	0.000000
ASSIGNMENT(D203, L202)	1.000000	0.000000
ASSIGNMENT(D204, L202)	1.000000	0.3612797
ASSIGNMENT(D205, L202)	1.000000	0.8921029E-01
ASSIGNMENT(D206, L202)	1.000000	0.3232860
ASSIGNMENT(D207, L202)	1.000000	0.5201268E-03
ASSIGNMENT(D208, L202)	1.000000	0.000000
ASSIGNMENT(D209, L8)	1.000000	14.59961
ASSIGNMENT(D210, L8)	1.000000	0.000000
ASSIGNMENT(D211, L8)	1.000000	0.5307901
ASSIGNMENT(D212, L212)	1.000000	0.000000
ASSIGNMENT(D213, L5)	1.000000	11.89533
ASSIGNMENT(D214, L226)	1.000000	0.4855286
ASSIGNMENT(D215, L226)	1.000000	2.028623
ASSIGNMENT(D216, L226)	1.000000	0.7897458
ASSIGNMENT(D217, L212)	1.000000	0.8894133
ASSIGNMENT(D218, L5)	1.000000	0.000000
ASSIGNMENT(D219, L5)	1.000000	0.000000
ASSIGNMENT(D220, L212)	1.000000	0.1382316E-01
ASSIGNMENT(D221, L212)	1.000000	0.3572490E-01
ASSIGNMENT(D222, L226)	1.000000	0.2195935
ASSIGNMENT(D223, L226)	1.000000	0.1955684
ASSIGNMENT(D224, L226)	1.000000	0.2203099
ASSIGNMENT(D225, L212)	1.000000	0.1010245
ASSIGNMENT(D226, L226)	1.000000	0.000000
ASSIGNMENT(D227, L212)	1.000000	0.2033304
ASSIGNMENT(D228, L9)	1.000000	1.547180
ASSIGNMENT(D229, L9)	1.000000	1.022997
ASSIGNMENT(D230, L9)	1.000000	0.5079414E-01
ASSIGNMENT(D231, L9)	1.000000	0.2107212
ASSIGNMENT(D232, L2)	1.000000	0.000000
ASSIGNMENT(D233, L2)	1.000000	0.000000
ASSIGNMENT(D234, L9)	1.000000	1.021534
ASSIGNMENT(D235, L9)	1.000000	0.6355650E-01
ASSIGNMENT(D236, L2)	1.000000	0.000000

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ASSIGNMENT( D237, L2)         1.000000          0.000000
ASSIGNMENT( D238, L9)         1.000000          0.1154250
ASSIGNMENT( D239, L9)         1.000000          0.6616853
ASSIGNMENT( D240, L9)         1.000000          0.3841060E-02
ASSIGNMENT( D241, L2)         1.000000          0.000000
ASSIGNMENT( D242, L2)         1.000000          0.000000
ASSIGNMENT( D243, L2)         1.000000          0.000000
ASSIGNMENT( D244, L9)         1.000000          0.3452184E-01
ASSIGNMENT( D245, L9)         1.000000          0.2117849E-02
ASSIGNMENT( D246, L2)         1.000000          0.000000
ASSIGNMENT( D247, L277)       1.000000          0.3685930
ASSIGNMENT( D248, L277)       1.000000          0.8951246E-01
ASSIGNMENT( D249, L277)       1.000000          0.7924431E-01
ASSIGNMENT( D250, L277)       1.000000          1.517307
ASSIGNMENT( D251, L251)       1.000000          0.000000
ASSIGNMENT( D252, L277)       1.000000          0.9682196E-01
ASSIGNMENT( D253, L277)       1.000000          0.3446383
ASSIGNMENT( D254, L277)       1.000000          0.2660733
ASSIGNMENT( D255, L277)       1.000000          0.2583733
ASSIGNMENT( D256, L10)        1.000000          0.000000
ASSIGNMENT( D257, L10)        1.000000          0.000000
ASSIGNMENT( D258, L202)       1.000000          2.352166
ASSIGNMENT( D259, L10)        1.000000          2.182039
ASSIGNMENT( D260, L10)        1.000000          0.4055456
ASSIGNMENT( D261, L10)        1.000000          0.000000
ASSIGNMENT( D262, L202)       1.000000          2.015219
ASSIGNMENT( D263, L277)       1.000000          0.8299531E-01
ASSIGNMENT( D264, L10)        1.000000          0.000000
ASSIGNMENT( D265, L277)       1.000000          0.5812335
ASSIGNMENT( D266, L277)       1.000000          0.4428516E-02
ASSIGNMENT( D267, L10)        1.000000          0.000000
ASSIGNMENT( D268, L277)       1.000000          1.635751
ASSIGNMENT( D269, L277)       1.000000          0.4666010
ASSIGNMENT( D270, L277)       1.000000          0.7808507
ASSIGNMENT( D271, L10)        1.000000          0.000000
ASSIGNMENT( D272, L202)       1.000000          3.650968
ASSIGNMENT( D273, L277)       1.000000          0.5889840
ASSIGNMENT( D274, L10)        1.000000          0.000000
ASSIGNMENT( D275, L10)        1.000000          0.000000
ASSIGNMENT( D276, L10)        1.000000          0.000000
ASSIGNMENT( D277, L10)        1.000000          0.000000
ASSIGNMENT( D278, L277)       1.000000          0.5094402E-01
ASSIGNMENT( D279, L10)        1.000000          0.000000
ASSIGNMENT( D280, L10)        1.000000          0.000000
ASSIGNMENT( D281, L10)        1.000000          0.1199455
ASSIGNMENT( D282, L10)        1.000000          0.000000
ASSIGNMENT( D283, L10)        1.000000          0.000000
ASSIGNMENT( D284, L10)        1.000000          0.000000
ASSIGNMENT( D285, L10)        1.000000          0.000000
ASSIGNMENT( D286, L10)        1.000000          0.000000
ASSIGNMENT( D287, L277)       1.000000          0.000000
ASSIGNMENT( D288, L10)        1.000000          4.271392
ASSIGNMENT( D289, L277)       1.000000          0.000000
ASSIGNMENT( D290, L277)       1.000000          0.3212933
ASSIGNMENT( D291, L10)        1.000000          1.373825
ASSIGNMENT( D292, L277)       1.000000          0.1982686
ASSIGNMENT( D293, L10)        1.000000          0.3657270
ASSIGNMENT( D294, L251)       1.000000          0.1743631
ASSIGNMENT( D295, L277)       1.000000          0.2244713E-01
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ASSIGNMENT(D296, L10)	1.000000	0.000000
ASSIGNMENT(D297, L277)	1.000000	0.4106123
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ASSIGNMENT(D301, L277)	1.000000	0.7369670
ASSIGNMENT(D302, L251)	1.000000	0.9169277
ASSIGNMENT(D303, L10)	1.000000	0.000000
ASSIGNMENT(D304, L10)	1.000000	0.000000
ASSIGNMENT(D305, L277)	1.000000	0.3860707E-01
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ASSIGNMENT(D308, L277)	1.000000	0.2322837
ASSIGNMENT(D309, L277)	1.000000	0.3802379
ASSIGNMENT(D310, L277)	1.000000	1.249679
ASSIGNMENT(D311, L277)	1.000000	0.2507429
ASSIGNMENT(D312, L10)	1.000000	0.000000
ASSIGNMENT(D313, L277)	1.000000	0.4211218E-02
ASSIGNMENT(D314, L251)	1.000000	0.4629153E-01
ASSIGNMENT(D315, L13)	1.000000	0.7862354
ASSIGNMENT(D316, L15)	1.000000	0.1444458
ASSIGNMENT(D317, L13)	1.000000	4.343422
ASSIGNMENT(D318, L13)	1.000000	0.7389071
ASSIGNMENT(D319, L13)	1.000000	0.000000
ASSIGNMENT(D320, L13)	1.000000	0.4260853
ASSIGNMENT(D321, L15)	1.000000	0.1774480
ASSIGNMENT(D322, L13)	1.000000	0.000000
ASSIGNMENT(D323, L119)	1.000000	0.4870713
ASSIGNMENT(D324, L13)	1.000000	0.000000
ASSIGNMENT(D325, L13)	1.000000	0.000000
ASSIGNMENT(D326, L13)	1.000000	0.000000
ASSIGNMENT(D327, L15)	1.000000	0.6706193
ASSIGNMENT(D328, L13)	1.000000	0.000000
ASSIGNMENT(D329, L13)	1.000000	0.000000
ASSIGNMENT(D330, L13)	1.000000	0.9814232
ASSIGNMENT(D331, L13)	1.000000	0.6344038
ASSIGNMENT(D332, L13)	1.000000	6.151077
ASSIGNMENT(D333, L13)	1.000000	2.142383
ASSIGNMENT(D334, L12)	1.000000	0.6702977
ASSIGNMENT(D335, L2)	1.000000	0.000000
ASSIGNMENT(D336, L277)	1.000000	0.8213993
ASSIGNMENT(D337, L2)	1.000000	0.000000
ASSIGNMENT(D338, L12)	1.000000	2.325233
ASSIGNMENT(D339, L12)	1.000000	0.2560166
ASSIGNMENT(D340, L9)	1.000000	1.022671
ASSIGNMENT(D341, L12)	1.000000	0.2659984
ASSIGNMENT(D342, L12)	1.000000	5.882124
ASSIGNMENT(D343, L12)	1.000000	0.7412797
ASSIGNMENT(D344, L12)	1.000000	0.2754630
ASSIGNMENT(D345, L5)	1.000000	0.000000
ASSIGNMENT(D346, L212)	1.000000	1.583902
ASSIGNMENT(D347, L212)	1.000000	0.1422430
ASSIGNMENT(D348, L13)	1.000000	0.000000
ASSIGNMENT(D349, L13)	1.000000	3.941790
ASSIGNMENT(D350, L13)	1.000000	0.000000
ASSIGNMENT(D351, L13)	1.000000	4.075566
ASSIGNMENT(D352, L13)	1.000000	0.1878266
ASSIGNMENT(D353, L13)	1.000000	1.123869
ASSIGNMENT(D354, L13)	1.000000	0.2942709

ASSIGNMENT(D355, L17)	1.000000	0.6873154
ASSIGNMENT(D356, L17)	1.000000	0.8627033
ASSIGNMENT(D357, L4)	1.000000	0.000000
ASSIGNMENT(D358, L17)	1.000000	0.6741366E-01
ASSIGNMENT(D359, L17)	1.000000	0.4492343
ASSIGNMENT(D360, L16)	1.000000	0.3167846
ASSIGNMENT(D361, L17)	1.000000	0.4578488
ASSIGNMENT(D362, L4)	1.000000	0.000000
ASSIGNMENT(D363, L17)	1.000000	0.5364349
ASSIGNMENT(D364, L17)	1.000000	0.7394797
ASSIGNMENT(D365, L17)	1.000000	0.6675144
ASSIGNMENT(D366, L4)	1.000000	0.000000
ASSIGNMENT(D367, L17)	1.000000	0.3576232
ASSIGNMENT(D368, L17)	1.000000	0.2111226
ASSIGNMENT(D369, L17)	1.000000	1.128876
ASSIGNMENT(D370, L17)	1.000000	0.1847818
ASSIGNMENT(D371, L17)	1.000000	3.663988
ASSIGNMENT(D372, L17)	1.000000	0.6268949
ASSIGNMENT(D373, L17)	1.000000	2.286415
ASSIGNMENT(D374, L17)	1.000000	0.8401023
ASSIGNMENT(D375, L4)	1.000000	0.000000
ASSIGNMENT(D376, L17)	1.000000	1.229469
ASSIGNMENT(D377, L18)	1.000000	0.000000
ASSIGNMENT(D378, L4)	1.000000	0.000000
ASSIGNMENT(D379, L17)	1.000000	1.183461
ASSIGNMENT(D380, L4)	1.000000	0.000000
ASSIGNMENT(D381, L19)	1.000000	0.5276252
ASSIGNMENT(D382, L17)	1.000000	0.8758882
ASSIGNMENT(D383, L17)	1.000000	0.3592159E-02
ASSIGNMENT(D384, L17)	1.000000	1.362775
ASSIGNMENT(D385, L18)	1.000000	0.1235480
ASSIGNMENT(D386, L17)	1.000000	0.2807324
ASSIGNMENT(D387, L17)	1.000000	0.5333801E-01
ASSIGNMENT(D388, L4)	1.000000	0.9097298E-01
ASSIGNMENT(D389, L4)	1.000000	0.4571827
ASSIGNMENT(D390, L18)	1.000000	4.387480
ASSIGNMENT(D391, L18)	1.000000	2.270452
ASSIGNMENT(D392, L110)	1.000000	11.35516
ASSIGNMENT(D393, L18)	1.000000	5.171557
ASSIGNMENT(D394, L18)	1.000000	1.580629
ASSIGNMENT(D395, L18)	1.000000	0.5594812
ASSIGNMENT(D396, L18)	1.000000	0.7858254
ASSIGNMENT(D397, L110)	1.000000	14.50421
ASSIGNMENT(D398, L18)	1.000000	4.506296
ASSIGNMENT(D399, L110)	1.000000	5.859833
ASSIGNMENT(D400, L18)	1.000000	0.8862165
ASSIGNMENT(D401, L4)	1.000000	0.000000
ASSIGNMENT(D402, L4)	1.000000	0.000000
ASSIGNMENT(D403, L18)	1.000000	1.590097
ASSIGNMENT(D404, L18)	1.000000	1.938501
ASSIGNMENT(D405, L18)	1.000000	2.372981
ASSIGNMENT(D406, L18)	1.000000	0.3788438
ASSIGNMENT(D407, L18)	1.000000	0.8556834
ASSIGNMENT(D408, L9)	1.000000	8.222953
ASSIGNMENT(D409, L212)	1.000000	0.000000
ASSIGNMENT(D410, L8)	1.000000	9.536629
ASSIGNMENT(D411, L19)	1.000000	1.581547
ASSIGNMENT(D412, L20)	1.000000	0.1277473
ASSIGNMENT(D413, L19)	1.000000	0.000000

ASSIGNMENT(D414, L18)	1.000000	0.1434921
ASSIGNMENT(D415, L20)	1.000000	1.914334
ASSIGNMENT(D416, L18)	1.000000	3.649399
ASSIGNMENT(D417, L20)	1.000000	0.3803504
ASSIGNMENT(D418, L18)	1.000000	1.534213
ASSIGNMENT(D419, L18)	1.000000	0.3239755
ASSIGNMENT(D420, L18)	1.000000	0.000000
ASSIGNMENT(D421, L4)	1.000000	0.000000
ASSIGNMENT(D422, L4)	1.000000	0.000000
ASSIGNMENT(D423, L17)	1.000000	0.000000
ASSIGNMENT(D424, L20)	1.000000	1.259475
ASSIGNMENT(D425, L18)	1.000000	14.07940
ASSIGNMENT(D426, L20)	1.000000	2.405821
ASSIGNMENT(D427, L4)	1.000000	0.000000
ASSIGNMENT(D428, L18)	1.000000	0.9098672E-01
ASSIGNMENT(D429, L20)	1.000000	0.9371808E-01
ASSIGNMENT(D430, L17)	1.000000	1.257954
ASSIGNMENT(D431, L17)	1.000000	1.953345
ASSIGNMENT(D432, L18)	1.000000	0.4568063E-01
ASSIGNMENT(D433, L18)	1.000000	0.6933519E-01
ASSIGNMENT(D434, L18)	1.000000	0.1281022
ASSIGNMENT(D435, L15)	1.000000	1.851152
ASSIGNMENT(D436, L15)	1.000000	0.3053004
ASSIGNMENT(D437, L15)	1.000000	1.913884
ASSIGNMENT(D438, L15)	1.000000	0.4789131
ASSIGNMENT(D439, L22)	1.000000	4.265227
ASSIGNMENT(D440, L22)	1.000000	0.5960326
ASSIGNMENT(D441, L13)	1.000000	0.000000
ASSIGNMENT(D442, L15)	1.000000	0.9773899E-01
ASSIGNMENT(D443, L13)	1.000000	0.000000
ASSIGNMENT(D444, L119)	1.000000	1.427239
ASSIGNMENT(D445, L119)	1.000000	0.1976177
ASSIGNMENT(D446, L22)	1.000000	0.1896281
ASSIGNMENT(D447, L15)	1.000000	1.581672
ASSIGNMENT(D448, L22)	1.000000	0.8561528
ASSIGNMENT(D449, L4)	1.000000	0.000000
ASSIGNMENT(D450, L4)	1.000000	0.000000
ASSIGNMENT(D451, L4)	1.000000	0.000000
ASSIGNMENT(D452, L15)	1.000000	1.507152
ASSIGNMENT(D453, L15)	1.000000	1.199282
ASSIGNMENT(D454, L15)	1.000000	0.1834749
ASSIGNMENT(D455, L15)	1.000000	0.4708602
ASSIGNMENT(D456, L119)	1.000000	0.7027492

E.7 Lingo Model for the CGM (Scenario I)

```
MODEL:
!Global Criterion Method (considering ideal & nadir values)-
Scenario.1;

TITLE ATM Location Problem;

SETS:
       Locations:
Deployment,Capacity,Score,Setupcost,Closingcost,Operationalcost;
       Demandnodes: Demand;
       Links(Demandnodes,Locations): Assignment,Distance;
ENDSETS

!Data that is used in the model is provided below;
DATA:

!Entered values for the problem;
Capex=1110;!Total budget available for the capital costs;
Opex=2000;!Total budget available for the operational costs;
Maxdistance=0.9;! the limitation of maximum traveled distance between
demand node and alternative location;
I1=89.63502;!Ideal value for total score (Obj1);
I2=11;!Ideal value for total number of ATMs located(Obj2);
I3=532.942;!Ideal value for total distance that the customers will
travel(Obj3);
N1=30.09837;!Nadir value for total score (Obj1);
N2=33;!Nadir value for total number of ATMs located(Obj2);
N3=21439.3;!Nadir value for total distance that the customers will
travel(Obj3);

!Set members;
Locations=L1..L456;
!ExistingLocations=L1..L22;
!NewLocations=L23..L456;

Demandnodes=D1..D456;

!Attribute values;
Capacity=19872;
Setupcost=100;
Closingcost=5;
Operationalcost=60;
Score=@OLE('Model Data.xlsx','Score');
Demand=@OLE('Model Data.xlsx','Demand');
Distance=@OLE('Model Data.xlsx','Distance');

ENDDATA
!Parameters
i = index for demand node N=(1,...,n),
j = index for possible ATM location M=(1,...,m);
```

```
!the objective;
[OBJECTIVE] MIN=(I1-(@SUM(Locations(j):Score(j)*Deployment(j))))/(I1-
N1)+((@SUM(Locations(j):Deployment(j)))-I2)/(N2-I2)
+((@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j)))-I3)/(N3-
I3);

!Objective functions
MAX=@SUM(Locations(j):Score(j)*Deployment(j))
MIN=@SUM(Locations(j):Deployment(j))
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Constraint to satisfy all demand nodes;
@FOR(Demandnodes(i):[Demand_Row]
  @SUM(Locations(j):Assignment(i,j))=
    1);

!Constraint that limits the assignment of a demand node to an open
ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Assignment_Row]
Assignment(i,j)<=Deployment(j)));

!Constraint that limits the max. distance for assignment of a demand
node to an ATM;
@FOR(Links(i,j):@FOR(Locations(j):[Distance_Row]
Distance(i,j)*Assignment(i,j)<= Maxdistance));

!Capacity constraint that restricts the amount of demand that can be
served from an open ATM not to exceed the capacity of the ATM;
@FOR(Locations(j):[Capacity_Row]
  @SUM(Demandnodes(i): Assignment(i,j)*Demand(i))<=
    Capacity);

!Budget constraint;
[SC_Row]SC=@SUM(Locations(j)| j #GE# 23:Deployment(j)*Setupcost);
[CC_Row]CC=@SUM(Locations(j)| j #LE# 22:((1-
Deployment(j))*Closingcost));
[OC_Row]OC=@SUM(Locations(j):Deployment(j)*Operationalcost);
[Opex_Row]OC<=Opex;
[Capex_Row]SC+CC<=Capex;

!Values of objective functions;
F1=@SUM(Locations(j):Score(j)*Deployment(j));
F2=@SUM(Locations(j):Deployment(j));
F3=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Zero one restriction for decision variables;
@FOR(Locations(j):@BIN(Deployment(j)));
@FOR(Links(i,j):@BIN(Assignment(i,j)));

END
```

E.8 Solution of Lingo Model for CGM (Scenario I)

```
Global optimal solution found.
  Objective value:                              0.9791940
  Objective bound:                              0.9791940
  Infeasibilities:                               0.000000
  Extended solver steps:                                0
  Total solver iterations:                          22586
  Elapsed runtime seconds:                          35.05


Model Title: ATM Location Problem

Variable                         Value          Reduced Cost

CAPEX                          1110.000            0.000000
OPEX                           2000.000            0.000000
MAXDISTANCE                    0.9000000           0.000000
I1                             89.63502            0.000000
I2                             11.00000            0.000000
I3                             532.9420            0.000000
N1                             30.09837            0.000000
N2                             33.00000            0.000000
N3                             21439.30            0.000000
SC                             1100.000            0.000000
CC                             10.00000            0.000000
OC                             1860.000            0.000000
F1                             87.22180            0.000000
F2                             31.00000            0.000000
F3                             1151.139            0.000000

DEPLOYMENT( L1)                1.000000            0.1248947E-01
DEPLOYMENT( L2)                1.000000            0.1323763E-01
DEPLOYMENT( L3)                1.000000            0.8990855E-02
DEPLOYMENT( L4)                1.000000           -0.1505000E-02
DEPLOYMENT( L5)                1.000000            0.4245341E-02
DEPLOYMENT( L6)                1.000000            0.9916133E-02
DEPLOYMENT( L7)                1.000000            0.9916133E-02
DEPLOYMENT( L8)                1.000000            0.1323763E-01
DEPLOYMENT( L9)                1.000000            0.5814979E-02
DEPLOYMENT( L10)               1.000000            0.4671767E-02
DEPLOYMENT( L11)               1.000000            0.4671767E-02
DEPLOYMENT( L12)               1.000000            0.9489589E-02
DEPLOYMENT( L13)               1.000000            0.7417341E-03
DEPLOYMENT( L14)               1.000000            0.7417341E-03
DEPLOYMENT( L15)               1.000000            0.7417341E-03
DEPLOYMENT( L16)               1.000000           -0.7545879E-03
DEPLOYMENT( L17)               1.000000           -0.7545879E-03
DEPLOYMENT( L18)               1.000000           -0.7545879E-03
DEPLOYMENT( L20)               1.000000            0.2518787E-01
DEPLOYMENT( L22)               1.000000           -0.4680875E-02
DEPLOYMENT( L26)               1.000000           -0.2062846E-01
DEPLOYMENT( L58)               1.000000            0.8990855E-02
DEPLOYMENT( L191)              1.000000           -0.1095420E-01
DEPLOYMENT( L199)              1.000000           -0.1095420E-01
DEPLOYMENT( L217)              1.000000           -0.8702365E-02
DEPLOYMENT( L315)              1.000000           -0.2155262E-01
```

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DEPLOYMENT(L322)	1.000000	-0.2155262E-01
DEPLOYMENT(L323)	1.000000	-0.2155262E-01
DEPLOYMENT(L326)	1.000000	-0.2155262E-01
DEPLOYMENT(L332)	1.000000	-0.2155262E-01
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ASSIGNMENT(D3, L3)	1.000000	0.000000
ASSIGNMENT(D4, L4)	1.000000	0.000000
ASSIGNMENT(D5, L5)	1.000000	0.000000
ASSIGNMENT(D6, L6)	1.000000	0.000000
ASSIGNMENT(D7, L7)	1.000000	0.000000
ASSIGNMENT(D8, L8)	1.000000	0.000000
ASSIGNMENT(D9, L9)	1.000000	0.000000
ASSIGNMENT(D10, L10)	1.000000	0.000000
ASSIGNMENT(D11, L11)	1.000000	0.000000
ASSIGNMENT(D12, L12)	1.000000	0.000000
ASSIGNMENT(D13, L13)	1.000000	0.000000
ASSIGNMENT(D14, L14)	1.000000	0.000000
ASSIGNMENT(D15, L15)	1.000000	0.000000
ASSIGNMENT(D16, L16)	1.000000	0.000000
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ASSIGNMENT(D18, L18)	1.000000	0.000000
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ASSIGNMENT(D22, L22)	1.000000	0.000000
ASSIGNMENT(D23, L4)	1.000000	0.000000
ASSIGNMENT(D24, L26)	1.000000	0.4671084E-04
ASSIGNMENT(D25, L26)	1.000000	0.2074947E-05
ASSIGNMENT(D26, L26)	1.000000	0.000000
ASSIGNMENT(D27, L199)	1.000000	0.6322136E-04
ASSIGNMENT(D28, L1)	1.000000	0.8340077E-03
ASSIGNMENT(D29, L1)	1.000000	0.3675432E-03
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ASSIGNMENT(D31, L1)	1.000000	0.9164719E-03
ASSIGNMENT(D32, L11)	1.000000	0.1310012E-04
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ASSIGNMENT(D36, L5)	1.000000	0.1040006E-04
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ASSIGNMENT(D38, L5)	1.000000	0.6028522E-03
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ASSIGNMENT(D41, L1)	1.000000	0.7907175E-04
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ASSIGNMENT(D44, L217)	1.000000	0.9194404E-04
ASSIGNMENT(D45, L217)	1.000000	0.1335949E-02
ASSIGNMENT(D46, L217)	1.000000	0.5996804E-03
ASSIGNMENT(D47, L8)	1.000000	0.000000
ASSIGNMENT(D48, L217)	1.000000	0.1131550E-03
ASSIGNMENT(D49, L323)	1.000000	0.7450598E-03
ASSIGNMENT(D50, L2)	1.000000	0.1364446E-03
ASSIGNMENT(D51, L323)	1.000000	0.4805576E-04
ASSIGNMENT(D52, L2)	1.000000	0.3299492E-05
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ASSIGNMENT(D202, L199)	1.000000	0.2281184E-03
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ASSIGNMENT(D344, L12)	1.000000	0.1317604E-04
ASSIGNMENT(D345, L217)	1.000000	0.000000
ASSIGNMENT(D346, L217)	1.000000	0.2356681E-03
ASSIGNMENT(D347, L217)	1.000000	0.6434908E-04
ASSIGNMENT(D348, L13)	1.000000	0.000000
ASSIGNMENT(D349, L315)	1.000000	0.2440601E-04

ASSIGNMENT(D350, L326)	1.000000	0.000000
ASSIGNMENT(D351, L315)	1.000000	0.2523430E-04
ASSIGNMENT(D352, L13)	1.000000	0.8984186E-05
ASSIGNMENT(D353, L317)	1.000000	0.1517181E-04
ASSIGNMENT(D354, L317)	1.000000	0.1622728E-05
ASSIGNMENT(D355, L17)	1.000000	0.3287590E-04
ASSIGNMENT(D356, L17)	1.000000	0.4126512E-04
ASSIGNMENT(D357, L4)	1.000000	0.000000
ASSIGNMENT(D358, L17)	1.000000	0.3224553E-05
ASSIGNMENT(D359, L17)	1.000000	0.2148793E-04
ASSIGNMENT(D360, L16)	1.000000	0.1515255E-04
ASSIGNMENT(D361, L17)	1.000000	0.2189998E-04
ASSIGNMENT(D362, L4)	1.000000	0.000000
ASSIGNMENT(D363, L17)	1.000000	0.2565893E-04
ASSIGNMENT(D364, L17)	1.000000	0.3537104E-04
ASSIGNMENT(D365, L17)	1.000000	0.3192878E-04
ASSIGNMENT(D366, L4)	1.000000	0.000000
ASSIGNMENT(D367, L17)	1.000000	0.1710596E-04
ASSIGNMENT(D368, L17)	1.000000	0.1009849E-04
ASSIGNMENT(D369, L17)	1.000000	0.5399679E-04
ASSIGNMENT(D370, L17)	1.000000	0.8838547E-05
ASSIGNMENT(D371, L17)	1.000000	0.1752571E-03
ASSIGNMENT(D372, L17)	1.000000	0.2998585E-04
ASSIGNMENT(D373, L17)	1.000000	0.1093646E-03
ASSIGNMENT(D374, L17)	1.000000	0.4018406E-04
ASSIGNMENT(D375, L4)	1.000000	0.000000
ASSIGNMENT(D376, L17)	1.000000	0.5880839E-04
ASSIGNMENT(D377, L18)	1.000000	0.000000
ASSIGNMENT(D378, L4)	1.000000	0.000000
ASSIGNMENT(D379, L17)	1.000000	0.5660771E-04
ASSIGNMENT(D380, L4)	1.000000	0.000000
ASSIGNMENT(D381, L18)	1.000000	0.3784105E-04
ASSIGNMENT(D382, L17)	1.000000	0.4189578E-04
ASSIGNMENT(D383, L17)	1.000000	0.1718214E-06
ASSIGNMENT(D384, L17)	1.000000	0.6518474E-04
ASSIGNMENT(D385, L18)	1.000000	0.5909591E-05
ASSIGNMENT(D386, L17)	1.000000	0.1342808E-04
ASSIGNMENT(D387, L17)	1.000000	0.2551282E-05
ASSIGNMENT(D388, L4)	1.000000	0.4351451E-05
ASSIGNMENT(D389, L4)	1.000000	0.2186812E-04
ASSIGNMENT(D390, L18)	1.000000	0.2098634E-03
ASSIGNMENT(D391, L18)	1.000000	0.1086010E-03
ASSIGNMENT(D392, L26)	1.000000	0.2971087E-03
ASSIGNMENT(D393, L18)	1.000000	0.2473677E-03
ASSIGNMENT(D394, L18)	1.000000	0.7560518E-04
ASSIGNMENT(D395, L18)	1.000000	0.2676130E-04
ASSIGNMENT(D396, L18)	1.000000	0.3758787E-04
ASSIGNMENT(D397, L26)	1.000000	0.4110529E-03
ASSIGNMENT(D398, L18)	1.000000	0.2155467E-03
ASSIGNMENT(D399, L26)	1.000000	0.1591757E-03
ASSIGNMENT(D400, L18)	1.000000	0.4238981E-04
ASSIGNMENT(D401, L4)	1.000000	0.000000
ASSIGNMENT(D402, L4)	1.000000	0.000000
ASSIGNMENT(D403, L18)	1.000000	0.7605804E-04
ASSIGNMENT(D404, L18)	1.000000	0.9272302E-04
ASSIGNMENT(D405, L18)	1.000000	0.1135053E-03
ASSIGNMENT(D406, L18)	1.000000	0.1812099E-04
ASSIGNMENT(D407, L18)	1.000000	0.4092934E-04
ASSIGNMENT(D408, L9)	1.000000	0.3933231E-03

ASSIGNMENT(D409, L217)	1.000000	0.000000
ASSIGNMENT(D410, L8)	1.000000	0.4561593E-03
ASSIGNMENT(D411, L20)	1.000000	0.7924349E-04
ASSIGNMENT(D412, L20)	1.000000	0.6110451E-05
ASSIGNMENT(D413, L18)	1.000000	0.3334301E-03
ASSIGNMENT(D414, L18)	1.000000	0.6863565E-05
ASSIGNMENT(D415, L20)	1.000000	0.9156707E-04
ASSIGNMENT(D416, L18)	1.000000	0.1745593E-03
ASSIGNMENT(D417, L20)	1.000000	0.1819305E-04
ASSIGNMENT(D418, L18)	1.000000	0.7338499E-04
ASSIGNMENT(D419, L18)	1.000000	0.1549651E-04
ASSIGNMENT(D420, L18)	1.000000	0.000000
ASSIGNMENT(D421, L4)	1.000000	0.000000
ASSIGNMENT(D422, L4)	1.000000	0.000000
ASSIGNMENT(D423, L17)	1.000000	0.000000
ASSIGNMENT(D424, L20)	1.000000	0.6024365E-04
ASSIGNMENT(D425, L18)	1.000000	0.6734507E-03
ASSIGNMENT(D426, L20)	1.000000	0.1150760E-03
ASSIGNMENT(D427, L4)	1.000000	0.000000
ASSIGNMENT(D428, L18)	1.000000	0.4352108E-05
ASSIGNMENT(D429, L20)	1.000000	0.4482755E-05
ASSIGNMENT(D430, L17)	1.000000	0.6017090E-04
ASSIGNMENT(D431, L17)	1.000000	0.9343307E-04
ASSIGNMENT(D432, L18)	1.000000	0.2185012E-05
ASSIGNMENT(D433, L18)	1.000000	0.3316464E-05
ASSIGNMENT(D434, L18)	1.000000	0.6127429E-05
ASSIGNMENT(D435, L322)	1.000000	0.1527436E-04
ASSIGNMENT(D436, L322)	1.000000	0.2519117E-05
ASSIGNMENT(D437, L322)	1.000000	0.7057719E-04
ASSIGNMENT(D438, L322)	1.000000	0.3951643E-05
ASSIGNMENT(D439, L22)	1.000000	0.2040158E-03
ASSIGNMENT(D440, L22)	1.000000	0.2850963E-04
ASSIGNMENT(D441, L326)	1.000000	0.000000
ASSIGNMENT(D442, L322)	1.000000	0.1013742E-05
ASSIGNMENT(D443, L13)	1.000000	0.000000
ASSIGNMENT(D444, L26)	1.000000	0.3893761E-04
ASSIGNMENT(D445, L26)	1.000000	0.5391361E-05
ASSIGNMENT(D446, L22)	1.000000	0.9070358E-05
ASSIGNMENT(D447, L322)	1.000000	0.5915989E-04
ASSIGNMENT(D448, L22)	1.000000	0.4095179E-04
ASSIGNMENT(D449, L22)	1.000000	0.000000
ASSIGNMENT(D450, L4)	1.000000	0.000000
ASSIGNMENT(D451, L4)	1.000000	0.000000
ASSIGNMENT(D452, L322)	1.000000	0.1243592E-04
ASSIGNMENT(D453, L322)	1.000000	0.1089892E-04
ASSIGNMENT(D454, L322)	1.000000	0.1902990E-05
ASSIGNMENT(D455, L322)	1.000000	0.1720948E-04
ASSIGNMENT(D456, L26)	1.000000	0.1828987E-04

Appendix F- Assignment Problem

F.1 Lingo Model for the Assignment Problem

```
MODEL:

TITLE Assignment Problem;

SETS:
      Locations: Capacity;
      Demandnodes: Demand;
      Links(Demandnodes,Locations): Assignment,Distance;
ENDSETS

!Data that is used in the model is provided below;

DATA:

!Set members;
Locations=L1..L22;
!ExistingLocations=L1..L22;
!NewLocations=L23..L456;

Demandnodes=D1..D456;

!Attribute values;
Capacity=19872;
Demand=@OLE('Assignment Model Data.xlsx','Demand');
Distance=@OLE('Assignment Model Data.xlsx','Distance');

ENDDATA
!Parameters
i = index for demand node N=(1,...,n),
j = index for possible ATM location M=(1,...,m);

!3rd objective;
[OBJECTIVE]
MIN=@SUM(Links(i,j):Assignment(i,j)*Demand(i)*Distance(i,j));

!Constraint to satisfy all demand nodes;
@FOR(Demandnodes(i):[Demand_Row]
  @SUM(Locations(j):Assignment(i,j))=
    1);

!Capacity constraint that restricts the amount of demand that can be
served from an open ATM not to exceed the capacity of the ATM;
@FOR(Locations(j):[Capacity_Row]
  @SUM(Demandnodes(i): Assignment(i,j)*Demand(i))<=
    Capacity);

!Zero one restriction for decision variables;
@FOR(Links(i,j):@BIN(Assignment(i,j)));

END
```

F.2 Solution of Lingo Model for the Assignment Problem

```
  Global optimal solution found.
  Objective value:                              1338.068
  Objective bound:                              1338.068
  Infeasibilities:                              0.000000
  Extended solver steps:                               0
  Total solver iterations:                             0
  Elapsed runtime seconds:                          0.25


  Model Title: Assignment Problem

Variable                       Value          Reduced Cost

MAXDISTANCE                   2.450000          0.000000
ASSIGNMENT( D1, L1)           1.000000          0.000000
ASSIGNMENT( D2, L2)           1.000000          0.000000
ASSIGNMENT( D3, L3)           1.000000          0.000000
ASSIGNMENT( D4, L4)           1.000000          0.000000
ASSIGNMENT( D5, L5)           1.000000          0.000000
ASSIGNMENT( D6, L6)           1.000000          0.000000
ASSIGNMENT( D7, L7)           1.000000          0.000000
ASSIGNMENT( D8, L8)           1.000000          0.000000
ASSIGNMENT( D9, L9)           1.000000          0.000000
ASSIGNMENT( D10, L10)         1.000000          0.000000
ASSIGNMENT( D11, L11)         1.000000          0.000000
ASSIGNMENT( D12, L12)         1.000000          0.000000
ASSIGNMENT( D13, L13)         1.000000          0.000000
ASSIGNMENT( D14, L14)         1.000000          0.000000
ASSIGNMENT( D15, L15)         1.000000          0.000000
ASSIGNMENT( D16, L16)         1.000000          0.000000
ASSIGNMENT( D17, L17)         1.000000          0.000000
ASSIGNMENT( D18, L18)         1.000000          0.000000
ASSIGNMENT( D19, L19)         1.000000          0.000000
ASSIGNMENT( D20, L20)         1.000000          0.000000
ASSIGNMENT( D21, L20)         1.000000          0.000000
ASSIGNMENT( D22, L22)         1.000000          0.000000
ASSIGNMENT( D23, L2)          1.000000          0.000000
ASSIGNMENT( D24, L4)          1.000000          4.918966
ASSIGNMENT( D25, L4)          1.000000          0.2018525
ASSIGNMENT( D26, L4)          1.000000          2.103017
ASSIGNMENT( D27, L11)         1.000000          1.419303
ASSIGNMENT( D28, L1)          1.000000          17.43606
ASSIGNMENT( D29, L1)          1.000000          7.683990
ASSIGNMENT( D30, L1)          1.000000          2.568134
ASSIGNMENT( D31, L1)          1.000000          19.16009
ASSIGNMENT( D32, L11)        1.000000          0.2738759
ASSIGNMENT( D33, L1)         1.000000          0.000000
ASSIGNMENT( D34, L11)        1.000000          0.6096377
ASSIGNMENT( D35, L1)         1.000000          4.022390
ASSIGNMENT( D36, L5)         1.000000          0.2174273
ASSIGNMENT( D37, L1)         1.000000          0.4282502E-02
ASSIGNMENT( D38, L5)         1.000000          12.60344
ASSIGNMENT( D39, L1)         1.000000          0.000000
ASSIGNMENT( D40, L1)         1.000000          2.475163
ASSIGNMENT( D41, L1)         1.000000          1.653102
```

ASSIGNMENT(D42, L2)	1.000000	0.000000
ASSIGNMENT(D43, L8)	1.000000	13.57909
ASSIGNMENT(D44, L8)	1.000000	2.251942
ASSIGNMENT(D45, L8)	1.000000	34.08439
ASSIGNMENT(D46, L8)	1.000000	15.29979
ASSIGNMENT(D47, L2)	1.000000	0.000000
ASSIGNMENT(D48, L3)	1.000000	3.349476
ASSIGNMENT(D49, L6)	1.000000	33.18380
ASSIGNMENT(D50, L2)	1.000000	2.852559
ASSIGNMENT(D51, L6)	1.000000	1.999775
ASSIGNMENT(D52, L2)	1.000000	0.6898035E-01
ASSIGNMENT(D53, L6)	1.000000	0.7347674
ASSIGNMENT(D54, L2)	1.000000	0.000000
ASSIGNMENT(D55, L3)	1.000000	0.4749170
ASSIGNMENT(D56, L3)	1.000000	1.403498
ASSIGNMENT(D57, L3)	1.000000	1.477470
ASSIGNMENT(D58, L3)	1.000000	15.24209
ASSIGNMENT(D59, L3)	1.000000	0.8263982
ASSIGNMENT(D60, L1)	1.000000	0.000000
ASSIGNMENT(D61, L3)	1.000000	1.476142
ASSIGNMENT(D62, L3)	1.000000	5.189539
ASSIGNMENT(D63, L3)	1.000000	0.9424748E-01
ASSIGNMENT(D64, L1)	1.000000	0.000000
ASSIGNMENT(D65, L3)	1.000000	0.7310371E-01
ASSIGNMENT(D66, L1)	1.000000	0.000000
ASSIGNMENT(D67, L3)	1.000000	2.778740
ASSIGNMENT(D68, L3)	1.000000	1.459323
ASSIGNMENT(D69, L1)	1.000000	0.000000
ASSIGNMENT(D70, L1)	1.000000	0.000000
ASSIGNMENT(D71, L3)	1.000000	2.855935
ASSIGNMENT(D72, L3)	1.000000	2.337452
ASSIGNMENT(D73, L1)	1.000000	0.000000
ASSIGNMENT(D74, L3)	1.000000	0.9085757
ASSIGNMENT(D75, L3)	1.000000	0.7079933
ASSIGNMENT(D76, L3)	1.000000	0.9270781E-01
ASSIGNMENT(D77, L3)	1.000000	0.4480356
ASSIGNMENT(D78, L3)	1.000000	0.2690406
ASSIGNMENT(D79, L3)	1.000000	0.1483012
ASSIGNMENT(D80, L3)	1.000000	2.190641
ASSIGNMENT(D81, L4)	1.000000	3.601894
ASSIGNMENT(D82, L4)	1.000000	1.509822
ASSIGNMENT(D83, L2)	1.000000	0.000000
ASSIGNMENT(D84, L4)	1.000000	0.3724112
ASSIGNMENT(D85, L2)	1.000000	0.000000
ASSIGNMENT(D86, L4)	1.000000	0.4651143
ASSIGNMENT(D87, L4)	1.000000	0.2271029
ASSIGNMENT(D88, L4)	1.000000	1.450183
ASSIGNMENT(D89, L2)	1.000000	0.000000
ASSIGNMENT(D90, L4)	1.000000	0.9813784
ASSIGNMENT(D91, L2)	1.000000	0.000000
ASSIGNMENT(D92, L4)	1.000000	9.703750
ASSIGNMENT(D93, L4)	1.000000	0.1790832
ASSIGNMENT(D94, L4)	1.000000	0.4151428
ASSIGNMENT(D95, L4)	1.000000	0.9909761E-01
ASSIGNMENT(D96, L4)	1.000000	0.7435579
ASSIGNMENT(D97, L2)	1.000000	0.000000
ASSIGNMENT(D98, L4)	1.000000	3.354956
ASSIGNMENT(D99, L4)	1.000000	0.8335981E-01
ASSIGNMENT(D100, L4)	1.000000	0.3649050

ASSIGNMENT(D101, L4)	1.000000	15.08072
ASSIGNMENT(D102, L6)	1.000000	13.41790
ASSIGNMENT(D103, L2)	1.000000	0.000000
ASSIGNMENT(D104, L7)	1.000000	0.5331230
ASSIGNMENT(D105, L2)	1.000000	0.000000
ASSIGNMENT(D106, L6)	1.000000	10.82248
ASSIGNMENT(D107, L2)	1.000000	0.000000
ASSIGNMENT(D108, L6)	1.000000	1.405466
ASSIGNMENT(D109, L6)	1.000000	13.04231
ASSIGNMENT(D110, L18)	1.000000	25.05373
ASSIGNMENT(D111, L18)	1.000000	12.77798
ASSIGNMENT(D112, L6)	1.000000	2.287505
ASSIGNMENT(D113, L6)	1.000000	2.832150
ASSIGNMENT(D114, L6)	1.000000	13.43732
ASSIGNMENT(D115, L2)	1.000000	0.000000
ASSIGNMENT(D116, L18)	1.000000	9.425700
ASSIGNMENT(D117, L18)	1.000000	55.40940
ASSIGNMENT(D118, L6)	1.000000	1.352278
ASSIGNMENT(D119, L6)	1.000000	65.09586
ASSIGNMENT(D120, L7)	1.000000	54.84984
ASSIGNMENT(D121, L6)	1.000000	9.576114
ASSIGNMENT(D122, L5)	1.000000	16.06300
ASSIGNMENT(D123, L1)	1.000000	17.78292
ASSIGNMENT(D124, L1)	1.000000	0.3700850
ASSIGNMENT(D125, L1)	1.000000	6.551093
ASSIGNMENT(D126, L1)	1.000000	0.000000
ASSIGNMENT(D127, L5)	1.000000	0.6095909E-01
ASSIGNMENT(D128, L1)	1.000000	0.000000
ASSIGNMENT(D129, L5)	1.000000	3.464499
ASSIGNMENT(D130, L1)	1.000000	0.000000
ASSIGNMENT(D131, L5)	1.000000	18.13168
ASSIGNMENT(D132, L1)	1.000000	0.000000
ASSIGNMENT(D133, L1)	1.000000	0.000000
ASSIGNMENT(D134, L5)	1.000000	0.1525515E-02
ASSIGNMENT(D135, L5)	1.000000	3.768118
ASSIGNMENT(D136, L5)	1.000000	1.749551
ASSIGNMENT(D137, L5)	1.000000	2.003137
ASSIGNMENT(D138, L1)	1.000000	0.000000
ASSIGNMENT(D139, L1)	1.000000	0.000000
ASSIGNMENT(D140, L5)	1.000000	1.804542
ASSIGNMENT(D141, L1)	1.000000	0.000000
ASSIGNMENT(D142, L5)	1.000000	0.9581803
ASSIGNMENT(D143, L5)	1.000000	3.486282
ASSIGNMENT(D144, L1)	1.000000	0.000000
ASSIGNMENT(D145, L5)	1.000000	0.3567824
ASSIGNMENT(D146, L5)	1.000000	2.243238
ASSIGNMENT(D147, L5)	1.000000	5.065045
ASSIGNMENT(D148, L5)	1.000000	1.583183
ASSIGNMENT(D149, L5)	1.000000	13.36942
ASSIGNMENT(D150, L1)	1.000000	0.2268047
ASSIGNMENT(D151, L1)	1.000000	2.957597
ASSIGNMENT(D152, L7)	1.000000	0.1385557
ASSIGNMENT(D153, L7)	1.000000	3.907982
ASSIGNMENT(D154, L7)	1.000000	3.155092
ASSIGNMENT(D155, L6)	1.000000	1.122743
ASSIGNMENT(D156, L7)	1.000000	1.418297
ASSIGNMENT(D157, L6)	1.000000	0.3440914
ASSIGNMENT(D158, L6)	1.000000	1.151684
ASSIGNMENT(D159, L7)	1.000000	0.5337671E-01

ASSIGNMENT(D160, L2)	1.000000	0.000000
ASSIGNMENT(D161, L2)	1.000000	0.000000
ASSIGNMENT(D162, L2)	1.000000	0.000000
ASSIGNMENT(D163, L6)	1.000000	0.1191423
ASSIGNMENT(D164, L7)	1.000000	0.1064012E-01
ASSIGNMENT(D165, L2)	1.000000	0.000000
ASSIGNMENT(D166, L7)	1.000000	5.143017
ASSIGNMENT(D167, L2)	1.000000	0.000000
ASSIGNMENT(D168, L6)	1.000000	3.978944
ASSIGNMENT(D169, L2)	1.000000	0.000000
ASSIGNMENT(D170, L6)	1.000000	3.254326
ASSIGNMENT(D171, L6)	1.000000	1.043954
ASSIGNMENT(D172, L6)	1.000000	0.9617331E-01
ASSIGNMENT(D173, L7)	1.000000	0.2501125
ASSIGNMENT(D174, L2)	1.000000	0.000000
ASSIGNMENT(D175, L2)	1.000000	0.000000
ASSIGNMENT(D176, L6)	1.000000	2.148468
ASSIGNMENT(D177, L10)	1.000000	12.06598
ASSIGNMENT(D178, L1)	1.000000	2.766456
ASSIGNMENT(D179, L1)	1.000000	2.873181
ASSIGNMENT(D180, L10)	1.000000	13.76767
ASSIGNMENT(D181, L10)	1.000000	0.3869064
ASSIGNMENT(D182, L10)	1.000000	8.509653
ASSIGNMENT(D183, L10)	1.000000	8.288533
ASSIGNMENT(D184, L10)	1.000000	1.917931
ASSIGNMENT(D185, L10)	1.000000	0.1779588
ASSIGNMENT(D186, L10)	1.000000	20.72455
ASSIGNMENT(D187, L1)	1.000000	29.41864
ASSIGNMENT(D188, L10)	1.000000	0.1196813
ASSIGNMENT(D189, L10)	1.000000	0.4015902
ASSIGNMENT(D190, L10)	1.000000	17.84249
ASSIGNMENT(D191, L1)	1.000000	0.1117088
ASSIGNMENT(D192, L10)	1.000000	7.781858
ASSIGNMENT(D193, L10)	1.000000	2.605688
ASSIGNMENT(D194, L10)	1.000000	7.320508
ASSIGNMENT(D195, L1)	1.000000	0.000000
ASSIGNMENT(D196, L1)	1.000000	0.000000
ASSIGNMENT(D197, L10)	1.000000	3.176821
ASSIGNMENT(D198, L10)	1.000000	1.652214
ASSIGNMENT(D199, L10)	1.000000	0.9520113
ASSIGNMENT(D200, L10)	1.000000	5.136982
ASSIGNMENT(D201, L10)	1.000000	0.7529380
ASSIGNMENT(D202, L10)	1.000000	18.35686
ASSIGNMENT(D203, L1)	1.000000	0.000000
ASSIGNMENT(D204, L10)	1.000000	4.110103
ASSIGNMENT(D205, L10)	1.000000	0.2787957
ASSIGNMENT(D206, L10)	1.000000	3.543377
ASSIGNMENT(D207, L10)	1.000000	6.011156
ASSIGNMENT(D208, L1)	1.000000	0.000000
ASSIGNMENT(D209, L8)	1.000000	14.59961
ASSIGNMENT(D210, L2)	1.000000	0.000000
ASSIGNMENT(D211, L8)	1.000000	0.5307901
ASSIGNMENT(D212, L5)	1.000000	13.96002
ASSIGNMENT(D213, L5)	1.000000	11.89533
ASSIGNMENT(D214, L5)	1.000000	1.995786
ASSIGNMENT(D215, L5)	1.000000	8.338740
ASSIGNMENT(D216, L5)	1.000000	3.246284
ASSIGNMENT(D217, L5)	1.000000	1.480287
ASSIGNMENT(D218, L1)	1.000000	0.000000

ASSIGNMENT(D219, L1)	1.000000	0.000000
ASSIGNMENT(D220, L5)	1.000000	0.2373848
ASSIGNMENT(D221, L5)	1.000000	0.7160310
ASSIGNMENT(D222, L5)	1.000000	4.128020
ASSIGNMENT(D223, L5)	1.000000	3.676385
ASSIGNMENT(D224, L5)	1.000000	1.156801
ASSIGNMENT(D225, L5)	1.000000	0.9710785
ASSIGNMENT(D226, L5)	1.000000	67.65642
ASSIGNMENT(D227, L5)	1.000000	2.008557
ASSIGNMENT(D228, L9)	1.000000	1.547180
ASSIGNMENT(D229, L9)	1.000000	1.022997
ASSIGNMENT(D230, L9)	1.000000	0.5079414E-01
ASSIGNMENT(D231, L9)	1.000000	0.2107212
ASSIGNMENT(D232, L2)	1.000000	0.000000
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ASSIGNMENT(D234, L9)	1.000000	1.021534
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ASSIGNMENT(D240, L9)	1.000000	0.3841060E-02
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ASSIGNMENT(D248, L10)	1.000000	1.249897
ASSIGNMENT(D249, L10)	1.000000	1.106519
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ASSIGNMENT(D251, L11)	1.000000	32.15666
ASSIGNMENT(D252, L10)	1.000000	0.4260666
ASSIGNMENT(D253, L10)	1.000000	1.516586
ASSIGNMENT(D254, L10)	1.000000	1.170860
ASSIGNMENT(D255, L12)	1.000000	0.5174737
ASSIGNMENT(D256, L1)	1.000000	0.000000
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ASSIGNMENT(D268, L12)	1.000000	2.580773
ASSIGNMENT(D269, L10)	1.000000	2.053285
ASSIGNMENT(D270, L10)	1.000000	3.469353
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ASSIGNMENT(D273, L12)	1.000000	1.178287
ASSIGNMENT(D274, L1)	1.000000	0.000000
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ASSIGNMENT(D278, L10)	1.000000	0.5296822
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ASSIGNMENT(D282, L1)	1.000000	0.000000
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ASSIGNMENT(D284, L1)	1.000000	0.000000
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ASSIGNMENT(D286, L1)	1.000000	0.000000
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ASSIGNMENT(D299, L1)	1.000000	0.000000
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ASSIGNMENT(D302, L11)	1.000000	21.66686
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ASSIGNMENT(D304, L1)	1.000000	0.000000
ASSIGNMENT(D305, L10)	1.000000	0.6338105E-01
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ASSIGNMENT(D324, L2)	1.000000	0.000000
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ASSIGNMENT(D326, L2)	1.000000	0.000000
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ASSIGNMENT(D328, L2)	1.000000	0.000000
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ASSIGNMENT(D333, L13)	1.000000	2.142383
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ASSIGNMENT(D344, L12)	1.000000	0.2754630
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ASSIGNMENT(D353, L13)	1.000000	1.123869
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ASSIGNMENT(D365, L17)	1.000000	0.6675144
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ASSIGNMENT(D447, L15)	1.000000	1.581672
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ASSIGNMENT(D455, L15)	1.000000	0.4708602
ASSIGNMENT(D456, L4)	1.000000	0.8282472

BIOGRAPHICAL SKETCH

Derya Türkoğlu was born in 1984 in İzmir. She received high school degree from İzmir Türk College-Science High School in 2002. She graduated from Industrial Engineering Department of Kırıkkale University in 2006 as 3rd among 2005-2006 graduates. Then, in 2008, she completed her M.Sc. in Manufacturing Systems Engineering in University of Warwick. She started her professional life in ING Bank Turkey in Organization and Quality Department in 2008. Furthermore, in 2010, she started her Ph.D. program in Industrial Engineering at Galatasaray University. She also worked at Business Process Management Department in ING Bank, Quality and Process Management Department in Telpa Telecommunication Company, Organization and Process Management Department in Aktif Bank respectively. She has been working as Department Manager in Organization and Process Development Department in Çalık Holding since 2015.

Her publications are:

Erol Genevois, M., Celik, D., & Ulukan, H. Z. (2015a). Analytic Network Process Approach for Automatic Teller Machines Deployment Problem. In *International Conference on Industrial Engineering and Systems Management (IESM)* (pp. 1171–1178). Seville: IEEE. https://doi.org/10.1109/IESM.2015.7380301

Erol Genevois, M., Celik, D., & Ulukan, H. Z. (2015b). ATM Location Problem and Cash Management in Automated Teller Machines. In *International Journal of Social, Behavioral, Educational, Economic, Business and Industrial Engineering* (Vol. 9, pp. 2506–2511). Paris: World Academy of Science, Engineering and Technology.