Smart Grids Maturity Level For Natural Gas Networks In Metropolitan Cities: A Case Study For Istanbul

A thesis submitted to the
Graduate School of Natural and Applied Sciences

by

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in partial fulfillment for the
degree of Master of Science

in

Industrial and Systems Engineering

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I, Hüseyin Bıyıkcı, declare that this thesis titled, "Smart Grids Maturity Level For Natural Gas Networks In Metropolitan Cities: A Case Study For Istanbul" and the work presented in it are my own. I confirm that:

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- I have acknowledged all main sources of help.
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Abstract

Due to the increase of energy need as a consequence of rapid population growth, structuring and mega investments in metropolitan cities, optimum operation of natural gas network infrastructure has become an important goal. The fact that this goal can be realized with smart network concept has prioritized the need for new investments to be made as per smart network concept.

In metropolitans, natural gas must be transmitted to customers with specific temperatures and pressure rates. The necessity to supply natural gas sustainable and efficient way by evaluating the parameters such as weather temperatures, consumption amounts, business processes, field equipment defects requires smart network systems. Infrastructure asset management of natural gas, which has a vital role in the cities, must be performed adequately.

The purpose of this thesis is to examine the smart grid maturity and to discuss improvement potentials for companies distributing natural gas for the city. Several maturity models were compared in order to generate smart grid maturity model and accordingly smart grid maturity roadmap has been established. Field applications of four natural gas distribution companies were evaluated to determine key performance indicators which govern the maturity level and the importance rate of smart grid systems by using Analytical Hierarchy Process. Action plans were defined according to smart grid by using GAP analysis results for companies that desire a change and development on smart grid. Additionally, smart grid maturity level of Istanbul was examined by using the established model and the comparative analysis results have been presented. Therefore, with the results presented in this study, smart grid maturity level analysis and necessity steps for improvement activity have been stated for natural gas distribution.

Keywords: Smart Grids, Information technology, Maturity Level, , Smart city, Istanbul

Büyük Şehirlerde Doğal Gaz Şebekesinde Akıllı Şebeke Olgunluk Seviyesi Analizi: İstanbul İçin Durum Çalışması

Hüseyin Bıyıkcı

Öz

Büyük şehirlerde nüfus artışı, yapılaşma ve mega yatırımlar sebebiyle şehirlerde enerji ihtiyacının artması, doğal gaz şebekesinin optimum işletilmesi hususu önemli bir hedef olmuştur. Bu hedefin sadece akıllı şebekeler konseptiyle yapılabilecek olması yapılacak yatırımların akıllı şebeke konseptiyle yapılması ihtiyacını ön plana çıkarmaktadır.

Büyük şehirlerde doğal gazın, sanayi ve konut kullanımında müşteriye belli sıcaklık ve basınçta ulaştırılması gerekmektedir. Mevsimsel olarak değişen tüketim değerleri, hava sıcaklıkları, arıza, iş süreçleri, saha ekipmanları vb. parametreleri bütünsel olarak değerlendirip kesintisiz ve verimli bir şekilde gaz arzının sağlanması arayışı akıllı şebeke sistemlerini zorunlu kılmıştır. Şehirde doğal gaz gibi yaşamsal öneme sahip bir enerji kaynağının alt yapısının varlık yönetimi en kusursuz biçimde yapılmalıdır.

Bu tez çalışmasının amacı, şehir doğal gaz dağıtımı yapan bir şirketin akıllı şebeke olgunluğunu incelemek ve iyileştirilmeye açık alanlar temas etmektir. Akıllı şebeke olgunluk modelini oluşturmak amacıyla birçok olgunluk modeli karşılaştırılmış ayrıca bu doğrultuda olgunluk yol haritası da tayin edilmiştir. Olgunluk seviyesini belirleyen temel performans kriterlerini belirlemek amacıyla dört doğal gaz dağıtım şirketinin saha uygulamaları incelenmiş ve Analitik Hiyerarşi Süreci ile kullanılan sistemlerin önem ağırlıkları değerlendirilmiştir. Bu performans kriterlerine göre akıllı şebeke dönüşüm ve değişimi yapmak isteyen bir dağıtım şirketi için GAP analizinin sonuçları kullanılarak aksiyon planları oluşturulmuştur. Ayrıca İstanbul özelinde akıllı şebeke kullanım oranı bu model kullanılarak incelenmiştir. Dolayısıyla bu çalışmada sunulan sonuçlarla akıllı şebeke analizi ve iyileştirme faaliyet için gereken adımlar belirtilmiştir.

Anahtar Sözcükler:Akıllı Şebeke, Bilgi teknolojileri, Olgunluk Seviyesi, , Akıllı Şehir, İstanbul

Acknowledgments

I would like to thank to my advisor Asst. Prof. Kemal Ozdemir for his valuable guidance and contribution. I also want to thank my co-advisor Dr. Cevat Ozarpa for his valuable contribution for my thesis. I also want to thank Prof. Koc and Asst. Prof. Küçükvar for their valuable contribution. Special thanks go to Asst. Prof. Hatice Tekiner Moğulkoç and Prof. Gürkan Kumbaroğlu for serving on my thesis committee.

Finally, I would like to express my most sincere appreciation to my wife for her support, contribution, patience, and guidance. Without her patience and sacrificing hours for me, this thesis would never have been written. Your encouragement throughout my study has kept me stronger.

Contents

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Abbreviations

AHP	**A**nalytic **H**iererchy **P**rocess **S**upport
BEMS	**B**uilding **E**nergy **M**anagement **S**ystem
CMMI	**C**apability **M**aturity **M**odel **I**ntegration
CPS	**C**athodic **P**rotection **S**ystem
CRM	**C**ustomer **R**elation **M**anagement
CSS	**C**yber **S**ecurity **S**ystem
ERP	**E**nterprise **R**esources **P**lanning
ERRS	**E**arthquake **R**isk **R**eduction **S**ystem
GCC	**G**as **C**ontrol **C**enter
GIS	**G**eographic **I**nformation **S**ystem
EBB	**E**lectronic **B**ulletin **B**oard
GPRS	**G**eneral **P**acket **R**adio **S**ervice
GPS	**G**lobal **P**ositioning **S**ystem
IT	**I**nformation **T**echnology
KPI	**K**ey **P**erformance **I**ndicator
MCDM	**M**ulti **C**riteria **D**ecision **M**aking
RFID	**R**adio **F**requency **I**dentification
R&D	**R**esearch & **D**evelopment
SCADA	**S**upervisory **C**ontrol **A**nd **D**ata **A**cquisition

Chapter 1

Introduction

Natural gas, which is called as the prince of hydrocarbons, is the quickest growing energy source in the world. As it has diverse extensive usage areas, natural gas has a very important role in human life. Natural gas plays a main role in petrochemical manufacturing, ceramic industry, chemical products, transportation fuel, home heating and cooking, as a plentiful supply. It is the most flexible one among all primary fossil fuels. Additionally, natural gas is considered as an environmentally friendly fuel while emitting fewer harmful pollutants than other fossil fuels. In the past, natural gas could not be transported to the end consumers because of limited technologies such as insufficient pipeline and availability of LNG. Technological improvements and declining costs have been considered by some researchers as allowing gas to overcome these challenges in order to become the fuel of the future. Especially, in the developing economies natural gas demand will continue to increase. Worldwide consumption of natural gas is forecasted to double by 2030. The era of oil, Chandra [8] argues, is poised to give way to natural gas.

Natural gas, oil, and coal are mainly made up of hydrocarbons. Hydrocarbons are composed of the elements such as hydrogen and carbon as well as various impurities. Natural gas is mostly made up of methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}). Natural gas can also include non-hydrocarbon components such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), hydrogen, argon, helium, and nitrogen.

1.1 Motivation

Across the globe, more people reside in urban areas than in rural areas, with 54% of the world's population living in urban areas in 2014. United Nations reported that in 1950, 30% of the world's population was urban, and by 2050, 66% of the world's population is projected to be urban [1]. The increase in the proportion of the urban population is even more apparent in the 2050 projection. This increase is shown in the Figure 1.1.

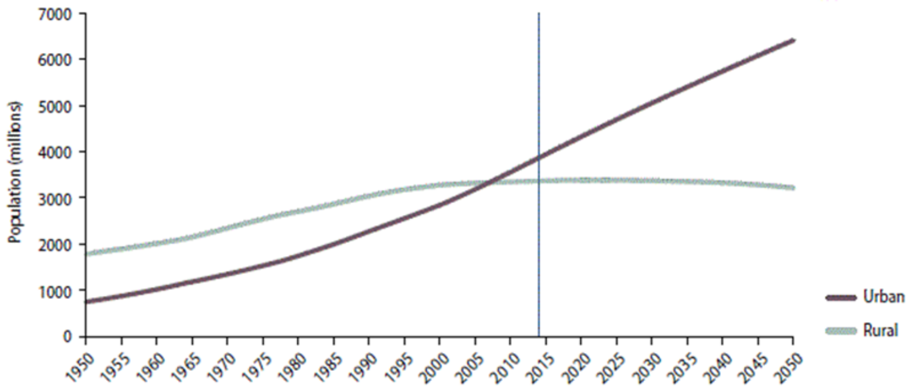

FIGURE 1.1: Population of world in urban and rural areas, 1950-2050

The world population has been steady concentrating in cities rather than rural areas. Additionally, by year 2008, and for the first time in human history, more than half of the world's population now lives in cities. On the other hand, Turkish Statistical Institute (TSI) report stated that the city's population density is constantly increasing in Turkey [9]. The statistics, which is published by UN, shows urban population (% of total) in Turkey between 1960-2015 years in Figure 1.2 [1].

Cities by definition are a focal point of energy consumption. Crowded cities are center of energy demand. Growing cities and increasing industrialization steadily promote energy demand. Figure 1.3 shows energy consumption from 2004 in the world. World energy consumption was on decline at two times because of economic crisis in 2008 and 2011. Additionally, International Energy Agency (IEA) presents an energy consumption outlook till 2040 where all energy types' demand rapidly increases in the world [2].

As can be seen from the Figure 1.4, natural gas total production and consumption are too close each other. There is supply and demand balance in the natural gas market. Natural gas demand gradually increases.

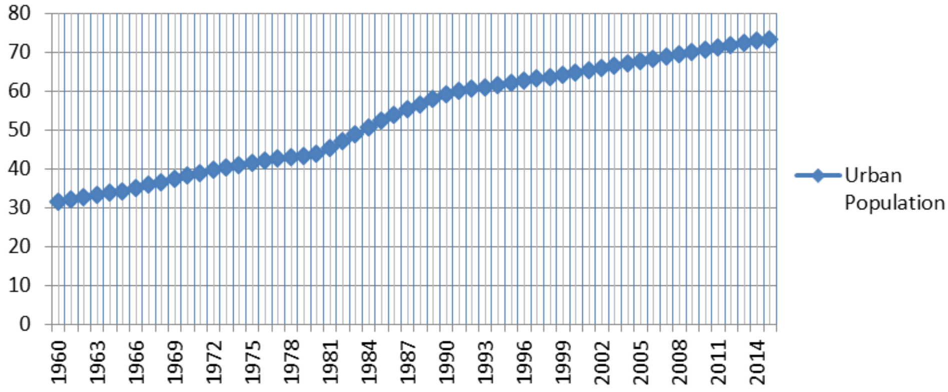

FIGURE 1.2: Urban population in Turkey (percentage in total) [1]

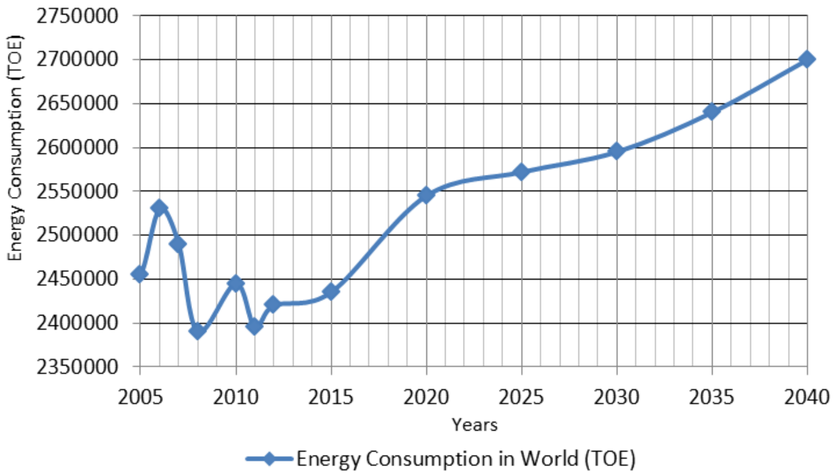

FIGURE 1.3: Energy Consumption in the World [2]

Table 1.1 shows the share and type of consumed energy in Turkey [7]. This figure shows that 25% of the total energy needs being met from natural gas. Moreover, World Energy Council reported that while petroleum demands decrease, natural gas demand is fixing the location. According to this report, Turkey will meet one fourth of energy needs from natural gas at next decade. Another consequence gathered from the table is growing coal consumption emphasizes the importance of natural gas as a friendly fuel.

In Turkey, natural gas consumption has increased rapidly in the past decade. It reached a new peak of 48.1 billion cubic meters (m3) in 2014. The annual cost of natural gas consumption was approximately 48 billion Turkish Liras in 2014 [4]. Natural gas supply contracts and their validity periods are shown in Table 1.2.

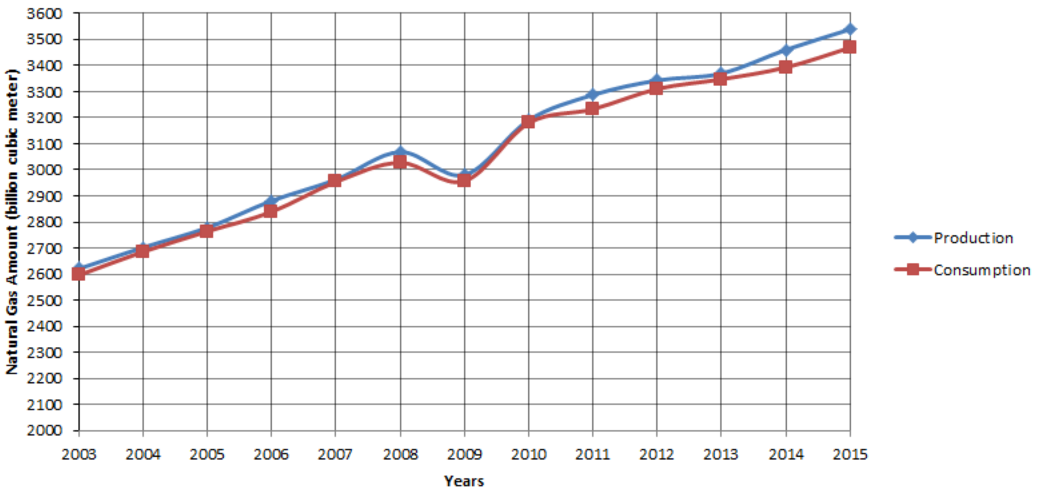

FIGURE 1.4: Natural gas total production and consumption in the world [3]

TABLE 1.1: The share and type of consumed energy in Turkey [7]

	Supply Portion (%)		
	2000	2010	2020
Petroleum	40,6	26,1	21,6
Natural Gas	16,0	29,3	25,2
Coal	30,4	37,3	42,5
Hydroelectric	3,0	3,3	2,8
Other	10,0	4,0	7,9

TABLE 1.2: Natural gas supply contracts and their validity periods [4]

Available Agreement	Amount (billion m3/years)	Signature Date	Duration (year)	Status	Supply Start
Russian (West)	6	14.02.1986	25	On	1987
Algeria (LNG)	4	14.04.1988	20	On	1994
Nigeria (LNG)	1,2	09.11.1995	22	On	1999
Iran	10	08.08.1996	25	On	2001
Russia (Black sea)	16	15.12.1997	25	On	2003
Turkmenistan	16	21.05.1999	30	-	-
Azerbaijan	6,6	12.03.2001	15	On	2007

Natural gas portion in Turkey economic size was 2 percent in 2015 [10]. The city population, which is mentioned above, has a direct effect on energy demand and energy infrastructure services. Their forms have a significant bearing on the balance of energy demand and energy infrastructure services, which are the two things that are directly affected by city population.

TABLE 1.3: The share and type of consumed energy in Turkey

Natural Gas/Economic Size	Quantity	Convert	Total Price
Natural Gas Import	48,4 billion m3	1 TL / m3	48 billion TL
Turkey Economic Size	718,2billiondolars	1Dolar / 3,5TL	2513,7 billionTL

Heating purposes and industrial energy needs, which are arisen from formation of metropolitan areas, are met with large amounts of natural gas. Figure 1.5 shows share of sectorial consumption in 2014 [4].

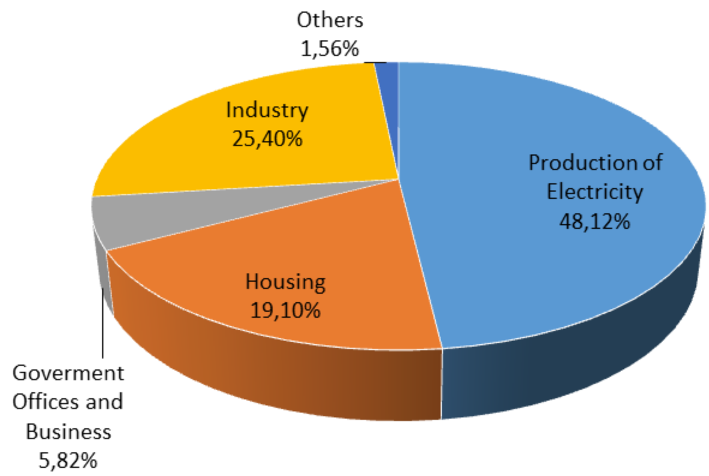

FIGURE 1.5: Share of sectorial consumption in 2014 [4]

These infrastructure services have a very important place as an essential trivet for city life. Because of increase in city population, the control of these infrastructure services has become crucial. Growing population and increasing demand of natural gas have made it impossible to use and control of infrastructure without IT applications. In order to have improved grid reliability and operational efficiency in the distribution networks, intelligence needs to be utilized more effectively monitor by real-time gas flow control and enhanced optimal pressure. Current distribution networks were not planned by using smart grid concept. They were planned for cost efficient and rapid activation of promoting economies [11]. Secure gas supply must be ensured continuously. Natural gas storage costs are very high thus the management of the natural gas supply has great importance. For a service as vital as natural gas to the economy and daily life, this was an unsustainable situation. Well-designed smart grid can deliver significant additional benefits such as; consumer benefits, environmental, health, and other social benefits.

1.2 Problem Definition

Worldwide progress of economies leads to the creation of metropolitans. In recent years, these metropolitan areas will be more crowded. Energy need of those metropolitan areas reflects to governments and infrastructure management. This energy supply target is provided with infrastructure in cities. In other words, the infrastructure's management is a critical issue for the city so civilization substantially based on accurate and smart infrastructure management.

Energy states are fundamental and indispensable element of a dominant repulsive economy and development. The share of natural gas in the economy of our country's (Turkey) energy imports should be observed via projections of money in this economic size. In other words, energy efficiency; heat, gas, steam, compressed air, electricity, such as the evaluation of all types of waste, which may be the energy losses in a variety of forms or recovery or without loss of production by the use of new technology is the reduction of energy consumption without hampering social welfare. Studies, which are on energy efficiency and savings in consumption, cover preventive approach to both the supply side [12].

Ministry of Energy and Natural Resource's report states that in the process of compliance with European Union, the technologies, which will increase quality, efficiency and effectiveness in energy production, transmission, and distribution, will be ensured to be implemented. Additionally, the technologies, which will decrease emission amount in combustion and especially in flue gas, will be developed. The technologies, which ensure high efficiency, and quality, and low emission, will be used in the planned plant. It is needed that scientific and technical reasons must be revealed to make necessary investments [13].

Society's utility needs like water, electricity, and gas, achieving the city harmony depends on well-directed infrastructure design. Thus, infrastructure design and management have a critical role in the city's balance. Precise infrastructure design has a vital importance in modern metropolis.

In metropolitan cities, optimum operation of natural gas network infrastructure has become an important objective. Since this objective can be realized only with smart network concept, new investments should be made as per smart network approach. The necessity to supply natural gas in a sustainable and efficient way by evaluating the parameters such as weather temperatures, consumption amounts, business processes, and field equipment defects requires smart network systems. Emerging technologies allows the use of smart gas distribution system effectively. Nowadays, smart grid is a popular concept but the framework of smart grid for natural gas network has not been determined.

Maturity of network operation is the other significant issue. Maturity evaluation of smart network systems depends on key factors, which we will focus on in this study. Key Performance Indicators (KPIs) of these smart grid systems have not been identified. These KPIs refer to security of supply, efficient operation, and lower costs. Smart grid applications are used in different sizes and shapes however maturity evaluation of these applications has not been reported in the literature. This maturity evaluation is necessary in order to determine the achievement rate of these applications.

1.3 Contribution

First of all, fully understanding of smart grid concept is necessary for efficient management of gas distribution. Asset management of all these structures is the most important point of operation process. ISO 55001 Asset management requirements provide:

Thus we confined our research under seven titles. These are

(i) Making certain the integration of the asset management system requirements into the organization's business processes;

(ii) communicating the significance of effective asset management and of validating to the asset management system requirements;

(iii) elevating cross-functional collaboration within the organization;

(iv) elevating incessant improvement;

(v) making sure that the approachment used for administering risk in asset management is aligned with the organization's approachment for administering risk [14].

Smart grid concept aims to achieve these mentioned targets. Nowadays, smart grid is a popular concept and applications vary among gas distribution companies. However, framework of smart grid has not been determined. Thus, we generally focus on the frame of smart grid applications in natural gas infrastructure for the first time as explained below: Maturity models procure prescriptive definition of good executions. The maturity levels confirm a goal standard that companies can endeavor for. In this study, we secondly discuss maturity level in natural gas infrastructure for the first time and we determine key performance indicators of measurement of maturity level. Measurement method is based on various maturity models and Key Performance Indicator (KPI) such as; secure gas supply, service duration for warning situation, efficient operation, etc.

Thirdly, we categorize smart grid applications in natural gas distribution management as six parts. We are going to determine importance order of and importance weight by means of Analytic Hierarchy Process (AHP) method. Fourthly, we generate Process Performance Evaluation Cycle in smart grid applications of Gas distribution and explain innovation concept. Finally, we generate total evaluation method for smart grid applications in natural gas distribution. Additionally, we generate detection method for recoverable areas and final report indicating maturity level of each smart grid applications by means of software.

The content of the following chapters are stated below.

Chapter 2 presents literature review about smart grids and smart cities concepts.

Chapter 3 presents information about method of our study.

Chapter 4 presents case study for İstanbul.

Chapter 5 gives information about Results and Discussions.

Chapter 2

Literature Review

The world is facing an increasing urbanization while, simultaneously, major cities have become a magnet for driver of economic growth. With the urbanization and technological advancements, redesign of all energy grid and infrastructures continue non- stop [15]. Accordingly, various researches and projects have been realized for all aspects of city life. Here, we have focused on smart city, smart grid, and smart grids on natural gas networks in the literature review respectively.

2.1 Smart City

The concept of smart city contains energy infrastructure, traffic management, waste management, health care, transportation, water, and other services. Therefore, service provider and citizen have a mutual interaction in a smart city. Information and communication technologies (ICT) are used in the smart city to increase grade, performance, and coaction of urban service. Additionally, smart cities intend to decrease costs and resource depletion and to progress communication between citizens and state. Smart city studies have started by 2000s. There are a lot of definitions for smart city. For instance, a smart city can be described as a mergence of solid infrastructure and quality of data communication and organizational infrastructure. Nijkamp et al. pointed out that smart city can be comprised with some conditions. Enterprises in human and social capital and classic (transport) and contemporary (ICT) communication infrastructure must enhance maintainable economic boost and a high value of life. Furthermore, natural sources must be managed with an intelligent management, through attender governance [16].

On the other, hand smart city solutions essentially enable incisive decision making through integrated and real-time information, which comes from information technologies (IT) of other infrastructure systems such as City Information System (CIS) and Geographical Information System (GIS) [17]. International Organization for Standardization (ISO) reports that: There are many statements for Smart Cities in use worldwide. Smart Cities are defined as a new concept, which applies the rising production of IT, alike the internet of objects, cloud technology, big information and geographical information integrating, to enable the planning, building, management and smart services of cities. The basic aim for promoting smart cities is to maintain:

(i) Suitability of the urban utilities;

(ii) Elegancy of city administration;

(iii) Livability of living area;

(iv) Smartness of infrastructures;

(v) Long-term efficiency of grid security [18].

International Telecommunication Union (ITU)-T Centre Group for Smart Endurable Cities examined almost 100 statements and used these to advance the below definition: A smart sustainable metropolis is an modern city that uses ICTs and other definitions to develop quality of live, effectiveness of urban work and utilities, and competitiveness. Additionally, it meets present and future generations' necessities corresponding economic, public and environmental angles [19].

The British Standard, Publicly Available Specification (PAS 181), which is about the smart city indicates that a smart city is an operative integration of digital, tangible, and human systems in the established environment to submit a sustainable, comfortable and comprehensive tomorrow for its natives [20].

Birmingham City Council expresses that the objective of a smart city approach is to expedite and allow the delivery of outcomes across various sectors, via a rightly integrated treatment. There is no one solution for a smart city. We know that the traditional ways of serving urban populations and operating cities are no longer fit for purpose. Cities are already struggling to cope with the sheer number, diversity and expectations of service users, while relying on an ageing infrastructure that was put in place decades ago. The advent of Internet connectivity and digital technologies and the relentless pace of their development are changing how societies interact and govern themselves. The consistent and innovative exploitation of such technologies can help us change how cities operate and make them more responsive and adaptable to the pressures they face. This is integral to the smart city approach. Figure 2.1 shows establishing a collaborative and interconnected smart city eco-system in Birmingham [5].

FIGURE 2.1: Smart city eco-system in Birmingham [5]

New Age of Energy report of Siemens points out: Energy distribution systems become increasingly complex because of the consolidation of distributed energy resources and stock, smart metering, and require reply. In combination with increased network automation, this causes inundating public utilities' systems with information that needs to be incisively managed. Simultaneously, public utilities are covered by growing regulations and client pressure to maximize network utilization and ensure reliability at all times [21].

All automation systems are feeder devices for smart grid concepts. The use of smart feeder machines, an open IEC 61850 telecommunication architecture, strong substation computers, equipment information modules and local storage are all necessary elements to be considered for the smart city [22].

Natural gas distribution IT applications must become coordinated and integrated. The integrity of infrastructure services is the other significant point of city life. Integration of all other infrastructures is possible through smart grids. This integration enable smart city. Additionally Brand Cities can be formed only with organizational alignment of all infrastructure services such as natural gas, electricity, water etc.

Moreover, the fact that 70% of the population live in urban areas in Turkey, indispensably means that metropolis have a significant role in developing energy productivity and decreasing carbon emissions, as advancing energy resilience with regard safety of supply and cost [23]. Thus, smarter cities and intelligent network are necessary if the globe desires to reply efficaciously to the fragile challenges being faced [11].

Business, Innovation-Skills (BIS) forecasts that the world promenade for smart city systems for transportation, energy, water, health care, and trash will equal to about $400 Billion by year 2020 [24].

Turkey can empower its status as a worldwide hub of expertness at a term when metropolis entirely the globe is searching advanced resolutions to the problems of planned urbanization.

2.2 Smart Grids

Infrastructure services have a very important position as an essential component for city life. Because of the increase in city population, the control of these infrastructure services has become crucial. Growing population made it impossible to use and control of infrastructure without Information Technology (IT) applications.

ISO, which is about the optimized management of physical assets, indicates that infrastructure management must be holistic, systematized, risk based, optimum, and sustainable. Systematized and interconnected movements and exercise through an foundation which optimally and continuously controls its entities and entity systems, engaged execution, risks and expenses over their exposure time for the aim of success its organizational vital plans are necessary [25]. This systematic control necessity requires smart grids.

Smart grid field communication is based on the IEC 61850 standard. The IEC 61850 protocol standard for sub-station allows the mergence of all conservation, computation, test, and monitoring operations by one standard protocol [22]. Otherwise devices from different manufacturers, a lot of protocols and interfaces to connect with each other without mutual adaptation or parallel to each other would not be able to use much. Equipment standardization and interoperability in the field of technical is applied installations for a long time [26].

Smart Grids and the New Age of Energy report of Siemens points out that the targets set for Smart Grids are as varied as they are stirring and competitive. In place of overburden, constrictions and brownouts, Smart Grids will guarantee the stability, sustainability and effectiveness of energy supplies. Communication and Information systems inside the grid will be consistently enlarged and homogenised. Mechanization will rise substantially, and fittingly equipped intelligent substations will assist decrease the expenditure and working intensity of preparation and operation. Ongoing, extensive monitoring will develop the way which equipment, factory, and the network are run [21]. Moreover, ICT composes the vital links among energy generation, transmitting, deployment and consumption.

The mechanization and security of sub-stations have to be upgraded to safely meet the enlarged necessities of further Smart Grids. Sub-station is in the proceeding of enhancing a joint on the public utility Information Technology grid for whole data from the distributor to the client. For example, to improve the system; information coming over the feeder mechanization units, power property, meters, eccentrical energy sources and house automation systems should be gathered and examined. Additionally, the modern Smart Grid problems, the familiar tasks of safety, command and mechanization have to stay as secure and proficient as ever. The targets for substations are starting to cross departmental boundaries, covering operations, and overhaul and safety requirements.

Smart grids concept targets the flexible control of distribution and transmission system for the efficient and reliable energy supply, storage, consumption through the use of information technology and communication systems. Additionally, natural gas distribution and water-wastewater networks and systems processes in the operating company, which are developed for the information technology and processes similar to electricity distribution, are available in these sectors [26].

A main element to effectually approve full treasure of smart grid actualization is engineering science with the performance and capacity to accomplish bound entirely integrated, scaleable, and interoperable answers. In this new, smarter world, customers will be able to view their energy usage via mobile devices, the Internet, or special home monitors, and the utility will do the same through a meter data management system. The meter will also serve as a grid sensor, which can help to detect power fluctuations and outages and be used to remotely connect or disconnect service [11].

A critical challenge of deploying a smart grid is having a consistent view of cyber security across all applications. External interfaces should be protected with sophisticated boundary defenses that provide multiple layers of defense against intrusion.

Furthermore, examine of operational practices and grid architectures provides enhancing of energy efficiency and significant cost reduction by means of as a energy management tool called CISCO EnergyWise [27].

2.3 Smart Grids on Natural Gas Networks

Natural gas distribution network is defined as a system consisting of pipes with different diameters, which enables distribution of the natural gas to the consumers by reducing gas pressure transported to the cities through high-pressure transmission line.

Distribution networks is the system, which ensures the delivery of the low pressure gas from city gate stations to the industrial, commercial, and residential buildings through the lines which have different pressure classes and which consist of steel and polyethylene (PE) pipes. Distribution networks consists of the following parts; Regulation and Measuring Stations (RMS) stations, the main carrier (steel) lines, regional stations distribution lines, service boxes, and service lines.

A variety of network simulation and calculation programs are used for the design and calculation of natural gas transmission and distribution network models, revision of existing networks, simulation and monitoring of the networks, and integration of Geographical Information System (GIS) and Supervisory Control and Data Acquisition (SCADA). There are a lot of advantages of these automation programs, which are used to measure the current and future situation of the network and to analyze the networks according to their types and loads [28].

Natural gas is as vital as the services such as environmental, health and other social benefits to the economy and daily life. Well-designed smart grids can deliver significant additional benefits such as minimum losses, lower costs and higher efficiency.

In addition to classical compression units, steel pipes and regulation station, a set of IT system has become essential to achieve this control. This emerging smart grid has been described as the convergence of infrastructure system and information technologies. The smart network ensures endeavor-wide resolutions that submit far-reaching advantages for both services and their end users. Services that accept smart network technologies can gather significant advantages in decreased capital and working cost, advanced power quality, enhanced customer gratification, and a favorable environmental impact. Smart grids enhance not only activated solutions but also merged solutions that state business and working concerns and submit meaningful, countable, and sustainable advantages to the service, the user, the thrift, and the environment [11].

Improving grid reliability and operational efficiency is possible using smarter in the distribution network to monitor gas flow in real-time and to improve optimum pressure. The requirements of smart grid are quite different; therefore, reengineering of the current grid is imminent [11]. Hence, the measurement of smart grid maturity levels of our natural gas infrastructure is mandatory which is defined in the present study.

EPRI published The Smart Grid Demonstration Initiative, which is a 7 year comprehensive research work to design, perform, and utilize how to combine distributed energy resources (DER) into utility network and market functions. This update of research results from the EPRI Smart Grid Demonstration Initiative is a collection of 48 case study summaries produced by 17 collaborating and host utilities in the Initiative [29]. Thus, the studies, which are related to smart grid, have great importance.

Chapter 3 provides information about steps of model building, key performance indicators of the systems, and analytic hierarchy process in this study.

Chapter 3

Methodology Of Data Gathering

It is an obvious fact that It is not possible to manage what you cannot control and you cannot control what you cannot measure as Peter Drucker said [30]. Nowadays the concept of smart grid has not been defined totally in the natural gas distribution market. Some methods must be used to analyse and evaluate maturity of natural gas networks. Firstly, all items of work need to be determined. Secondly indicator selections need to be performed. Weighting of all items in natural gas distribution can then be realized by means of AHP Method. Finally, smart grid maturity model can be built for natural gas distribution. In this study, these defined steps are followed.

3.1 Data Collection

The natural gas infrastructure takes a major place to meet energy need of the city. In other words, this infrastructure's management is a critical issue for the city. For this critical issue, as well as in the other technical fields, the rule of infrastructure's management is directly associated with many agreements and standards. Therefore procedure and principle of soft-ware based automation systems being used in infrastructure management must be determined in consideration of standards.

However, due to the absence of any prepared agreement about the natural gas smart grid applications, assessment and evaluation cannot be realized completely in this field. In order to make an accurate assessment in this field, we have reviewed the literature and collected data about this area. For the aim of determining the framework, scope and purpose of smart grid applications, we have maintained our study by considering the ISO 50001 energy management standard. ISO 50001 ensures an outline of requirements permitting organizations to:

(i) Enhance a plan for more effective usage of energy

(ii) Adjust targets and aims to apply the plan

(iii) Make better decisions relating energy consumption by using data

(iv) Compute the results

(v) Review the efficiency of the plan

(vi) Permanently develop energy management [31]

Smart grid field applications in natural gas distribution must be collected to determine smart grid management principles. These applications vary by region so these differences prevent to identify principles of smart grid management. In order to overcome this issue, the key parts of smart grid management and their performance indicators need to be defined by assessing all smart grid applications comparatively. The purpose of these bench marking and analysis is to measure the maturity of smart grid applications in the natural gas distribution field. As a result of these bench marking and analysis, we have categorized all natural gas smart grid applications by six main sections. These sections are 1) Pipeline integrity management, 2) Flow management, 3) Data management, 4) Catastrophe management, 5) Installation management and 6) Force management. We classify natural gas distribution applications in the related sections. We set the key performance indicator for each application.

3.2 Indicator Selection and Categorization

The other important part of aforementioned energy need is its security and the supply of efficient energy. This is major target for governments and international corporations. This target is one of the most important points in energy sector. Smart grid applications are designed to achieve this target. However, effectiveness of these applications should be analyzed. Key Performance Indicator (KPI)of these smart grid components have not been previously identified. Hence, we decided to examine each KPI of smart grid components for a natural gas distribution companies. Firstly, we generated KPI Detection process. It is illustrated in Figure 3.1.

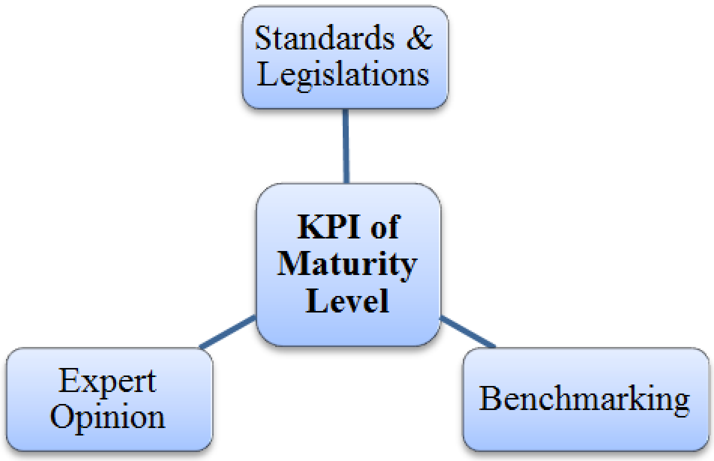

Figure 3.1: KPI Detection process

There is not any standard directly about smart grid. Hence, we decided to examine Key Performance Indicators (KPIs) of each smart grid components for natural gas distribution systems. We generate KPI based on these three elements. These are Standards - Legislations related the each system, Expert Opinion (system user) and Benchmarking among different distribution companies. We researched all standards related to smart grid components. We interviewed system users from different gas distribution companies. We collected all data from expert, standards, and benchmarking.

Additionally, these levels are categorized dependently the performance evaluation process cycle which we will mention below. We generate performance evaluation process as a cycle. We categorize all generated KPIs according to this process. This process describes an evolutionary path. In addition to this, maturity level develops a significant base of the system's processes, getting ready it to proceed to the next level. Thus, our model recommends a roadmap to improve the processes and services for a system. If the system achieve a KPI, it can pass the next level. Thus, our model recommends a roadmap to improve the processes and services for each system.

Capability Maturity Model Integration (CMMI) system has a similar manner to work.

CMMI models are accumulation of best samples that administrate organizations to enhance their processes. The CMMI model contributes guidance for performing CMMI best samples in a utility provider organization. Thus, our model similarly provides best practices by focusing on activities, which generate quality services to end users. Moreover, this model requires processes that address service relevant practices for an organization. An organization should describe its all processes to examine existence of processes. This system evaluates effectiveness of implemented process, which is performed in the system CMMI [32].

The KPIs have been associated with five maturity levels. Each level designates KPI content. Process performance evaluation cycle offers a manner to develop system's performance. This is shown in Figure 3.2.

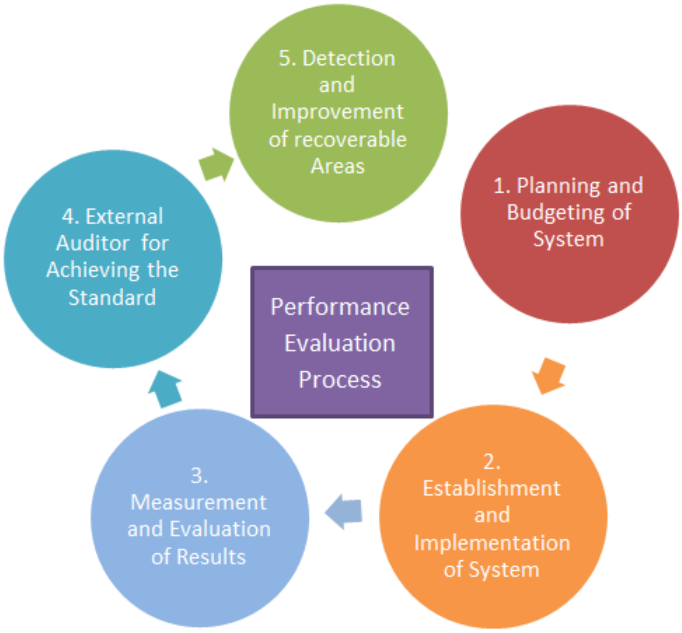

FIGURE 3.2: Process Performance Evaluation Cycle

In this table each level contains the KPI related to same topic. Topics of each level are explained below.

- At level 1, system is described by leave their processes in case of crisis, and is unable to replicate its achievements. It refers to planning and budgeting of a system.

- At level 2, operation groups, operation activities, processes, operation products, and utilities are managed. The service supplier ensures that processes are designed properly policy. It refers to establishment and implementation of a system.
- At level 3, system and service suppliers use outlined processes for controlling work and evaluating results. It refers to measurement and evaluation of results.
- At level 4, system and service suppliers establish quantitative targets for grade and process productivity and use key performance indicator in controlling processes. It refers to external auditor for achieving the standard.
- At level 5, a system continually should be enhanced its processes. Business targets and performance needs should be established on a quantitative percept. It refers to detection and improvement of recoverable areas by focusing on customer.

This process describes an evolutionary path. These KPIs are presented for each component at the Chapter 4.

3.3 AHP Method and Weighting

The AHP model prioritizes alternatives by identifying criteria and sub criteria. Criteria weights signify the significance of each criterion and sub criterion. Synthesizing of the scoring performs with each of them against alternative. These scores or weights represent result in the comprehensive assessment of the problem. Criteria significance in each grade is evaluated with regard to their partner. The importance measures are determined subjectively, benefit from the advantages being offered by AHP and dual comparisons. Thus, this method provides to abstain from the direct weight evaluation which can be faulty in many situations [33].

AHP is based on direct comparison with respect to both the factors affecting the decision, and the importance value of decision points for such factors by using a pre-defined comparison scale on a decision hierarchy. As a result, differences of importance convert into percentage distribution on decision points.

In our AHP model, we evaluate gas distribution companies. After a market research, we observe that as of now natural gas distribution infrastructures composed of eighteen software based automation systems, which have been used in service. We categorized these systems in six sections. These sections are flow management, data management, work management, pipeline integrity management, catastrophe management, and installation management. To calculate total maturity level of gas distributor companies, we determine importance weighting of these automation systems. In this work, the model performs decision-making for a limited number of alternatives. However each has several attributes. It is complex to represent some of those characteristics. The model defined in this work composed of four grades. At the top grade is the target of the study followed by the criteria at grade two. Alternatives are at grade four while various automation systems are at the third level. The frame of model is shown in Figure 3.3.

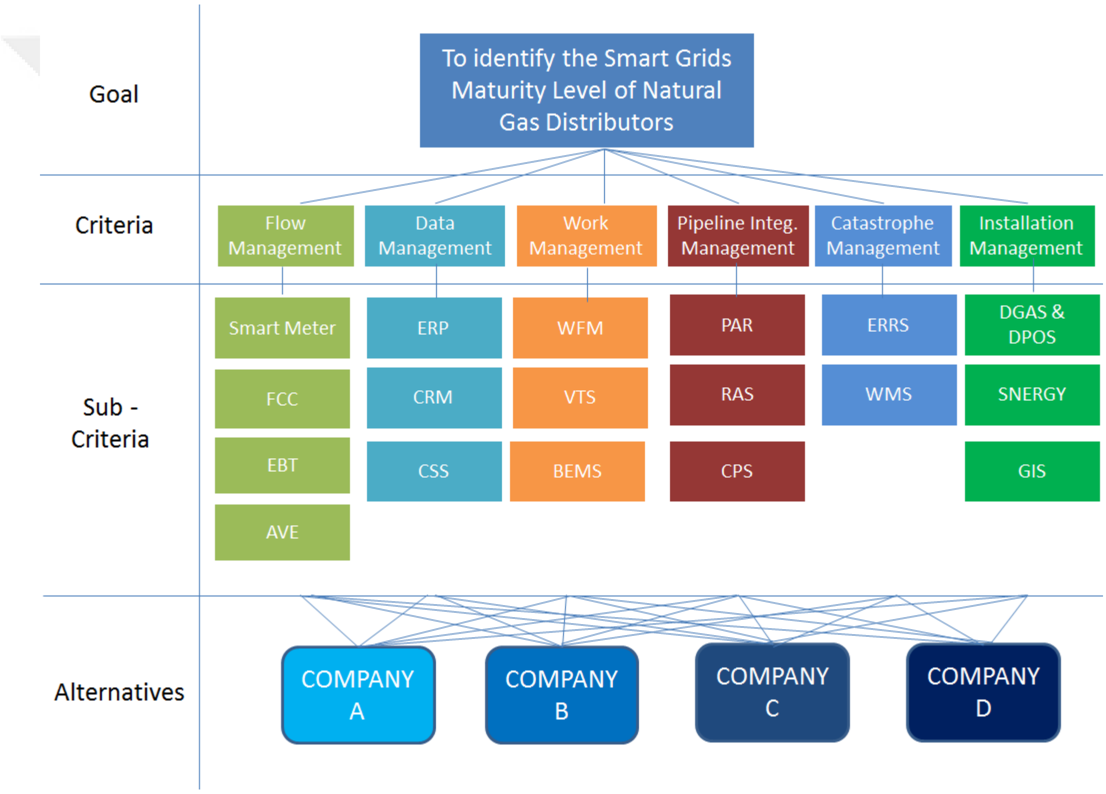

FIGURE 3.3: The Proposed AHP Model

This work used eighteen sub-criteria in six classifications to evaluate mature smart grid application because of difficulty in choosing the optimal alternative among various distributor companies. Pipeline integrity method, Catastrophe management, Data management, Flow management, Work management, and Installation management are compared with pairwise comparison. In this stage, a comparison matrix is created among factors as can be seen in Figure 3.4.

$$A = \begin{bmatrix} a_{1_1} & a_{1_2} & . & . & a_{1_n} \\ a_{1_1} & a_{2_2} & . & . & a_{2_n} \\ . & & . & . & . \\ . & & . & . & . \\ . & & . & . & . \\ a_{n_1} & a_{n_2} & . & . & a_{n_n} \end{bmatrix}$$

FIGURE 3.4: Pairwise matrix

Pairwise matrix shows the level of importance of factors according to a specific logic. However, a comparison matrix is created in order to determine weight of such factors among the whole picture, in other words to determine the distribution of percentage.

$$a_{ij} = \frac{1}{a_{ji}} \tag{3.1}$$

Taking into account the example given above, if the component in the first row and the third column (i=1,j=3) is taken as 3, the third row and the first column (i=3,j=1) of comparison matrix will be taken as 1/3 from the equation (3.1). Pairwise comparison is performed in accordance with AHP importance scale [34]. The AHP importance scale is shown in Table 3.2.

TABLE 3.1: AHP Importance Scale

Scale	**Description**
1	A is equally as important as B
3	A is moderately more important than B
5	A is strongly more important than B
7	A is very strongly more important than B
9	A is extremely more important than B

Furthermore, pairwise comparisons permit for exact subjective assessment criteria. A consistency examines helps to assessment judgements performed in pairwise comparison. Details of consistency calculations are presented in the appendix. In this part, six types of natural gas distribution components are assessed using three end node criteria that were properly designed under the AHP. Furthermore, these assessments are executed by many experts in natural gas distribution market. We have calculated weighted average of expert's evaluations as per their experience. Comparison of management categories through pairwise comparison is given in Table 3.3. These are Pipeline Integrity Management (PIM),Catastrophe Management (CM), Data Management (DM), Flow Management (FM), Work Management (WM), and Installation Management (IM).

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \tag{3.2}$$

Each cell shows a comparison for two intersecting managements. During this stage, a second table is created by dividing each value to the sum of the all columns. Also, the average of values obtained is calculated. This calculation is done by using equation (3.2). The calculated values are shown in Table 3.3.

Table 3.2: Pairwise comparison of management categories

	PIM	C M	D M	F M	B M	I M
PIM	1	3	3	1	7	7
C M	0,333	1	0,333	1	5	3
D M	0,333	3	1	1	5	3
F M	1	1	1	1	5	3
W M	0,142	0,2	0,2	0,2	1	0,333
I M	0,142	0,333	0,333	0,333	3	1
TOTAL	2,95	8,533	5,866	4,533	26	17,333

As it is shown in the table, pipeline integrity management is the most important criteria for a natural gas distributor due to safety of life and property and the importance of supply secure. Secondly, data management has second priority since millions of operations and customer data must be protected and recorded properly.

Table 3.3: Importance Weights of Data Management Parts

Smart Grid Management	Weight
PIPELINE INTEGRITY MANAGEMENT	29,4
DATA MANAGEMENT	24,1
FLOW MANAGEMENT	20,1
CATASTROPHE MANAGEMENT	14,7
INSTALLATION MANAGEMENT	8,0
WORK MANAGEMENT	3,7
TOTAL	100.0

With the help of average values obtained in this way (average values for comparison evaluation in AHP method), the accuracy of homogeneity and weighting procedure has been increased by repeatedly performing them by experts. Thirdly, in order to perform secondary evaluation for systems in each category, the systems having management components are checked with pairwise comparison. To give an example, the pairwise comparison table for Enterprise Resource Planing (ERP), Customer Relation Managemet (CRM), and Cyber Sequrity System (CSS), which are components of Data management, are given in Table 3.4.

Table 3.4: Pairwise comparison of Data Management Elements

	ERP	CRM	CSS
ERP	1	5	1
CRM	0,2	1	0,142
CSS	1	7	1
TOTAL	2,2	13	2,142

In the second stage, a second table is created by dividing each value to the sum of the columns. Also, the average of values obtained is calculated. Distribution of importance weights of ERP, CRM, and CSS systems is showed in Table 3.5.

Table 3.5: Importance Weight of Data Management Elements

	ERP	CRM	CSS	AVERAGE
ERP	0.45454	0.38461	0.46685	0.43533
CRM	0.09090	0.07692	0.06629	0.07804
CSS	0.45454	0.53846	0.46685	0.48662
TOTAL	1	1	1	1

Moreover, as a result of AHP assessment, the importance weights of each management part are presented in Table 3.6. These results are on the scale of hundred. In the evaluation of natural gas distributors, these weights will be used.

Moreover, as a result of AHP assessment, the importance weights of each smart grid component are presented in Table 3.7. These results are on the scale of hundred. In the evaluation of natural gas distributors, these weights will be used.

Gas control center and cyber security are the most important fields in smart grid applications. Gas control center provides monitor and control of all field equipments. Cyber security should be prioritized because of the huge effect on the automation system and business.

TABLE 3.6: Importance weights of Smart Grid automation systems in NGD

Smart Grid Automation System	Weight (Percentage)
PIPELINE ANALYSIS ROBOT	9,8
RISK ASSESSMENT SYSTEM	9,8
CATHODIC PROTECTION SYSTEM	9,8
ENTERPRISE RESOURCE PLANING	10,5
CUSTOMER RELATION MANAGEMENT	1,9
CYBER SECURITY SYSTEM	11,7
SMART METER	2,7
GAS CONTROL CENTER	11,7
ELECTRONIC BULLETIN BOARD	4,2
AVE	1,5
EARTHQUAKE RISK REDUCTION SYS.	11
WARNING MANAGEMENT SYS.	3,7
DPAS-DICS	1,6
SNERGY	1,6
GEOGRAPHIC INFORMATION SYS.	4,8
WORK FORCE MANAGEMENT SYS.	2,7
VEHICLE TRACKING SYS.	0,3
BUILDING ENERGY MANAGEMENT SYS.	0,7

3.4 Model Building

There are a lot of benefits of maturity models. They are an examination tool for allow reflection on the actual status of a system. The resulting designation of forcefulness and meagerness can act as an outline for prioritizing practices. A model can lead awareness about a specific strategically process among the system users.

The use of maturity models supplies a number of benefits. Volker et al. sum up them, generally, in the following. Several maturity models were compared in order to apply to their infrastructure potential [35]. We can determine three products as follows: roadmap, maturity evaluation, and maturity model. All forms are necessary to evaluate processes. Additionally, they advise on process improvement. A conceptual maturity model can be considered as the combination of targets, levels and process fields on a conceptual form. Matrix structure can be used to analyze a system, by evaluating the strategic targets. Moreover the maturity model helps an organization to describe the current weaknesses and strength of a system. The roadmap is necessary to implement transforms. In a roadmap, levels progress from initial, respectively, initial, managed, defined, quantitatively managed, optimized, and they ensure continuous improvement.

Multi criteria decision making (MCDM) techniques are used to optimisation of distribution networks [36]. There are a lot of decision making methods such as electra, promethee, topsis etc. However, we prefered Analytic Hierarchy Process (AHP)method. The AHP is a mighty tool which can be utilized for the hierarchic gradation. It is structured method for examining complex decisions. It is a widely utilized method for decomposition of complex problems. For instance, choice of renewable energy resources for sustainable electric producing system has been benefiting from AHP [37].

Thus, we have built smart grid maturity model by means of the mentioned maturity models. We have discussed different methods and the maturity models. Finally, we used AHP method and CMMI maturity model. We determined approximately 300 KPIs for all system to measure their maturities using KPI detection process which is mentioned above. We assumed that the total number of KPIs equals 10 points. Thus,we have determined the score of the system according to the number of successful KPIs. These KPIs are categorized dependently the performance evaluation process which is mentioned previously. Moreover, the best gas distribution company based on the developed model is determined as well as weighting importance assessments of each system and management part have been determined by means of AHP analysis.

Chapter 4 presents a case study for the city of İstanbul. We will focus on working principle and evaluation of all automation systems, which is facilitating to natural gas distribution in the next chapter. All smart grid components of natural gas infrastructure will be examined.

Chapter 4

Smart Grids Maturity Level For Natural Gas Network In Metropolitan Cities: A Case Study For Istanbul

According to statistics, it is expected that the most important increase in the usage will be for natural gas. The increasing population in cities and thus increasing demand for natural gas necessitate optimum natural gas distribution. Smart grid has become inevitable need in terms of optimizing natural gas distribution. In other respects, there is not any framework for the smart grid concept in natural gas distribution. We generally focus on frame of smart grid applications in natural gas infrastructure for the first time. We categorize smart grid applications in natural gas distribution management as six parts. These are data management, work management, flow management, pipeline integrity management, catastrophe management, and installation management as shown in Figure 4.1.

We determined all necessary components of smart grids on natural gas networks. We especially predicate our study on natural gas distribution in Istanbul. These components of natural gas networks are elaborated at Figure 4.2.

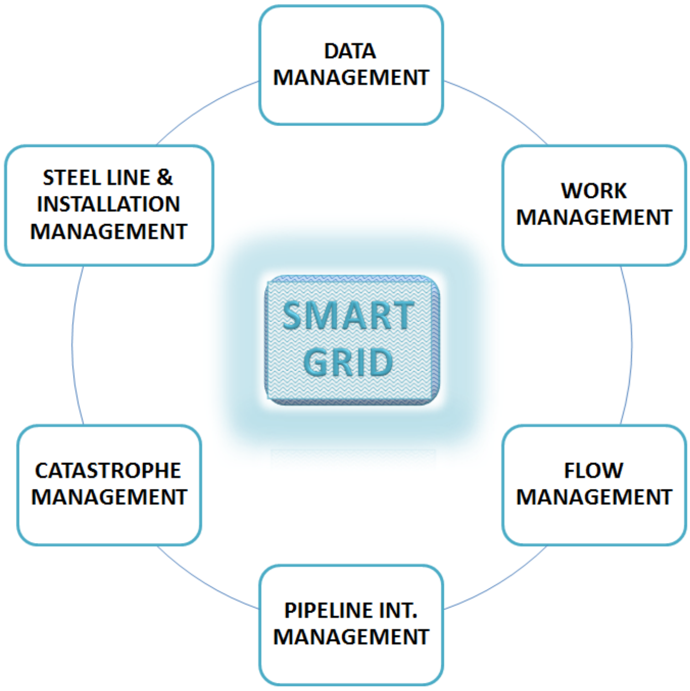

Figure 4.1: Smart Grid Framework

4.1 Flow Management

Primarily, flow control is a significant issue for secure supply in distribution of natural gas. A common deficiency among most distribution systems is the incompleteness of data, which is regarding material types, installation conditions and general performance history. This condition seems to be differing among all operators, due to service of computer system [38].

In gas industry, the accurate measurement of quantity of gas passing through a pipe cross-section per unit time (volumetric or mass flow rate) has paramount importance. Additionally, measurement and control of natural gas distribution mainly needs Supervisory Control and Data Acquisition (SCADA) system and other metering systems for the secure flow management. In other words, monitor and control of all distribution components are significant for secure gas supply.

Generally, distribution system is composed of pressure reduction facilities, regulating and measurement stations (RMS), service lines, region regulator, service box and meters. Distribution systems are generally operated at different pressures and different pipelines, which has variable diameter. Operationally, distribution of natural gas requires many

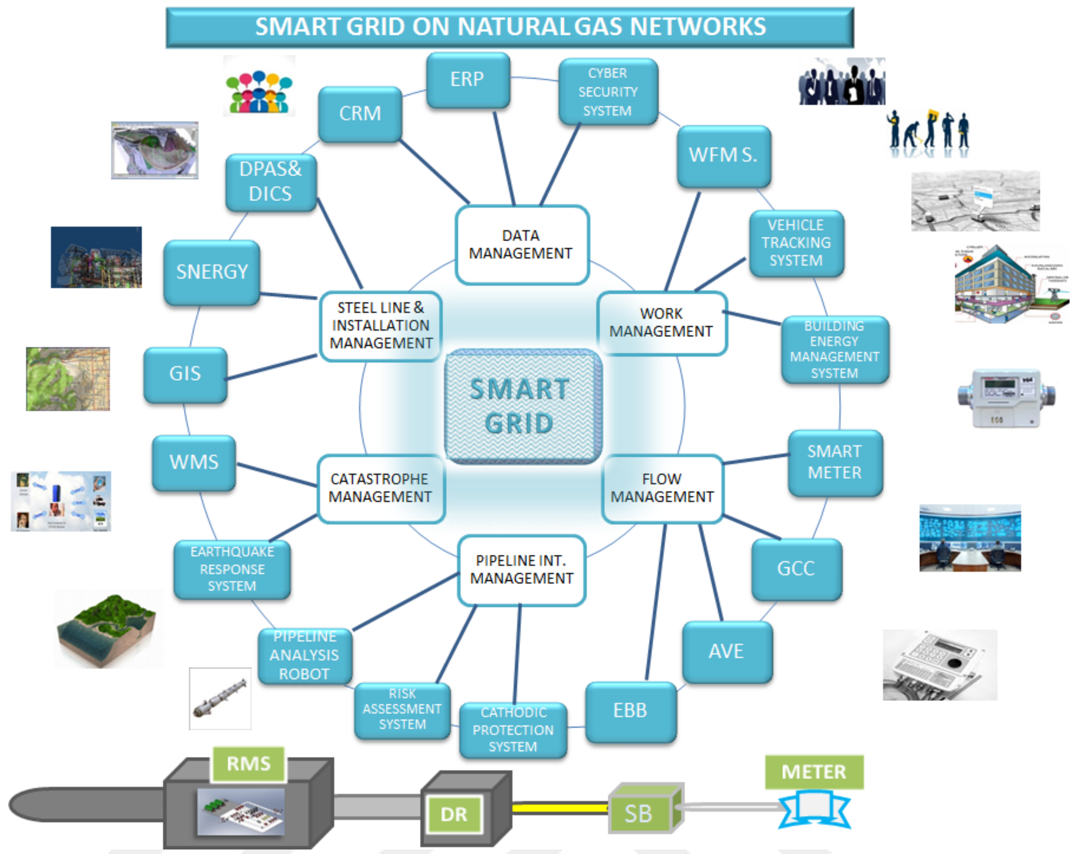

FIGURE 4.2: Components of Smart Grid Framework

monitoring and control systems. Currently, SCADA system is titled as gas control center. Moreover, smart metering has become one of the most significant topics in the energy industry. Smart Grid is supposed to solve the challenge of the ever growing energy demand on the one end and increasing scarcity of energy resources. Gas control center, electronic bulletin board system, AVE system, and smart meter system will be expressed at next parts.

4.1.1 Gas Control Center (GCC) on Natural Gas Network

Gas Control Center (GCC) collects various data from distribution system. However, maturity of these components associated with accuracy, frequency and variety of the imported data. The data, which is imported from GCC, must have twenty features. Characteristics of data, which are collected from GCC stations, differ among companies. Energy Market Regulatory Authority (EMRA) specified the necessary data on the Supervisory Control And Data Acquisition (SCADA). Nowadays, fast growing of automation technology and widespread usage of computers has revived the SCADA. In recent years, the most popular application in this area is SCADA, which is composed of observation, data collection and control systems. SCADA applications used in the energy sector have important advantages such as centrally monitoring and controlling of the field instruments, which are spread, in a wide geographic area by reducing operating costs and accidents, increasing in productivity and safety.

Additionally, SCADA applications involve management process of gas distribution with preventative maintenance in all gas distribution instruments. This preventive maintenance affects efficiency totally.

The Institute of Electrical and Electronics Engineers (IEEE) reported that Modern SCADA stations use software and hardware in a distribution network. The operating power is distributed among several computers and servers that transmit with each other through a real-time connected LAN in the monitor center. SCADA and Automation systems can be seen as enhancing specific key operation, such as:

(i) Computations

(ii) Status monitoring

(iii) Control

(iv) Ancillary services

(v) Time synchronism

(vi) Programmed logic functions

The system plan needs to cover a statement of the necessary functions. Once the necessary functions are founded, an evaluation should be performed to define the necessary performance. Typical performance requirements are following; Online periodicity (seconds), Accuracy (%), Unavailability (hours/month), Delay (seconds), Resolution (%) and Clock skew (seconds) [39]. GCC's regulation instruments and process are documented with detailed drawing at Figure 4.3.

All technical specifications of these tools have an effect on efficiency. Additionally, selection of these instruments is analyzed. We mainly discuss automation system of GCC.

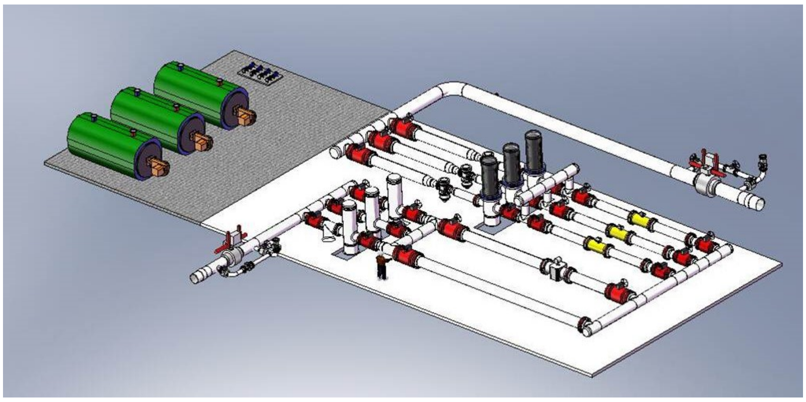

FIGURE 4.3: Gas Control Center representation [6]

Moreover, GCC has big gas consumption, approximately 2 million cubic meters gas per year. Natural gas is getting cold while expanding thus we must heat it to control its temperature between specific range. Efficiency in natural gas distribution examine in three points: Efficiency in domestic distribution, Efficiency in site regulator, and Efficiency in GCC. Automation system in GCC directly affects optimum natural gas combustion. Perfect gas combustion is the other significant subject in this area. The optimum heating of gas flowing through the GCC is the other issue, which must be deliberated in energy area.

We secondly discuss measurement process in RMS. Measurement process is based on various properties such as; temperature, pressure, diameter of pipe, and flow rate. Content of natural gas is the other important issue. Chromatograph determines contents of natural gas and provides related the data. We notice natural gas filtering. Selection of filter and packness of filter are monitored by GCC automation system.

Thirdly, we discussed preventive maintenance in all gas distribution instruments in GCC. This maintenance affects efficiency totally. In addition to this, operation and maintenance are connected with each other. Safety of operation is another KPI for GCC. These are related to efficiency indirectly. Addition to this, data transfer method and alternatives of GCC are another significant issue. Moreover, power supply and alternative energy source have importance for GCC.

Additionally, 14 RMS / A City entry stations, 95 steel critical valves with actuated steel valve system, 769 Regional Regulators, 726 customer stations, 20 Cathodic Protection Transformer Rectifier Unit, 10 Scorching System, 7 endpoints odor Pressure and temperature, filter pollution, regulator position information, station door open / closed information, Steel Valve open and closed information, and alarms are taken online and sent to our intelligent mobile devices of our emergency teams via SCADA System in Istanbul.

The list showing KPI sample for GCC is presented below. We demonstrate all key performance indicators for GCC stations in natural gas distribution. We determine level of these factors by comparison of many GCC stations. These KPIs discuss regulation process in GCC with regards to natural gas specifications.

Table 4.1: GCC Maturity Level - KPI

	GCC Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Customer-Driven Focus	Setting up a system without any security vulnerabilities which will enable customers to monitor their invoices and consumptions free of charge over a central database	Process Analysis	Level 5
3	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
4	Data Security	Within the scope of relevant standard (ISO 27001), precautions for physical and technical safety standards should be taken	Certificate Checks	Level 4
5	Data Security Certification	Ensuring certification and validity of the system from a certification body which is accredited by Turkish Accreditation Institution showing that the center shows activities in accordance with TS ISO/IEC 27001 Information Security Management System standards	Registration Check	Level 4
6	Integration	Ensuring integration of Geographic Information System, Infrastructure/Subscriber Information Management System, Emergency Action Plan, odorization, load estimation, load balance, and customer contract management with the Centers	ERP Query	Level 4
7	Online Odor Measurement	Online monitoring of odorization work made in RSM stations from end points of the network	Visual Inspection	Level 3
8	Valve Check with Actuators	Remote control of gas flow for regional regulators and customer stations of the centers	Visual Inspection	Level 3

Table 4.1: (continued)

	GCC Characteristics	Required information	Method	Level
9	Measurement Values - BR	Keeping records of Pressure, Temperature, Regulator position, Filter full, Pressure - Temperature bottom/upper threshold values, Door open/closed measurement values and alarm states with date-time stamp	Log Review	Level 3
10	Backup and Functionality	Performing server and data backup, and installing backup servers at locations where they still operate in case of disasters, attacks, etc	Physical Checks	Level 3
11	Physical Qualification	Capacity of the center against loads which may be created by the number of potential subscribers in the distribution region which will be possible to improve as well	SNERGY	Level 3
12	Energy Back-Up	Providing energy and communication backup in order to perform continuous function of the center	Visual Inspection	Level 3
13	Measurement Values-GCC	Corrected and uncorrected indexes-keeping records of date-time tagged logs for measurement values of momentary flows, Pressure, Temperature, and Gas components	Log Review	Level 3
14	Alarm States	Bottom/upper threshold values for valve position, Regulator position, filter full, Pressure, Temperature, flow and consumption data; keeping date-time tagged logs for Flow computer, boiler, generator fault data, and power cut alarm state values	Log Review	Level 3
15	Alarm Management	Classification of alarm based on their importance level, providing alarm elimination methods, determining alarm elimination procedures of operation and other relevant departments, and documentation pursuant to Natural Gas Emergency Action Plan of distribution companies	Action Plan Query	Level 3
16	Monitoring Online Consumption	Enabling view of consumption values over Internet or mobile applications to each customer who has a corrector	Process Analysis	Level 2
17	Data Migration	Without allowing security gaps of centers, designing in a manner allowing remote data input to Customer Stations, and keeping log records regarding such transaction	Log Review	Level 2
18	Data Sharing with Transmission Companies	Sending data over GCC to the transmission companies which have been affiliated with distribution companies that will be required for the operation of transmission network at intervals and within scope specified by transmission company	EBB Check	Level 2

TABLE 4.1: (continued)

	GCC CHARACTERISTICS	REQUIRED INFORMATION	METHOD	LEVEL
19	EBB Data Detail Records	Viewing information sent by BOTAS-EBB and received from EBB (EBB Record-Approval), and keeping logs, and in case of manual data input, archiving detailed information and the reason for manual input	Log Review	Level 2
20	EBB Immediate Data Delivery	Sending immediate data to EBB of BOTAS with 15 minutes or lower intervals	Log Review	Level 2
21	Location of the Center	Designing the center in a manner controlling critical points determined by distribution companies and entrance station of each city according to the network infrastructure of city	Location Checks	Level 1
22	Creating a Single Center	If there are more than one center, possibility of monitoring also from a main center, and performing server and data backup from this common center	Visual Inspection	Level 1
23	Modernization of the System	Performing necessary planning and specifications work required for GCC modernization	Process Analysis	Level 1

GCC system has been evaluated according to these KPIs. Maturity level of GCC system is 8,1 out of 10 in the Istanbul. There are some improvable areas. These are five top elements of the KPI list.

4.1.2 Electronic Bulletin Boards on Natural Gas Network

Another system required for the construction of natural gas distribution networks in smart grid concept is Electronic Bulletin Board (EBB). EBB is a system operated by Transmission Company which is established in order to follow the movements of operating stakeholders in the market [40]. The main purpose of EBB system is to ensure optimum usage of pipeline. To ensure security of supply during peak periods in winter natural gas consumption is monitored. Such data are reported via EBB and are used as data repository to generate crisis scenarios. Accurate consumption forecasts and modifying contracts are possible thanks to these data. Moreover, EBB system prevents "buy or pay" penalty which is applied in natural gas purchase and sales contracts. If the gas received under of "take-or-pay" commitment, then the difference between the received amount and undertaken amount must be paid to the seller [41].

Flow Control Centers of Natural Gas Distribution Companies transmit the report to EMRA through this system. EMRA has made it obligatory for all gas distributors to establish this system until December 31, 2004. In accordance with Regulations Natural Gas Transmission Network Operation Regulations, natural gas distribution companies deliver the measurement data to Petroleum Pipeline Corporation (BOTAS) which is necessary in order to follow the operations through this system. Additionally, it is aimed to increase the maturity of the system through gas market studies. The transmission company, BOTAS, monitors the functioning of transmission network through this system such as transferred amount, scheduled and delivered quantities, request for cuts or reductions, and capacity allocation systems.

IGDAS, on the other hand, transfers all measurement data of the RMS-A station online and automatically to BOTAS EBB system of BOTAS [42]. In order to ensure security of supply and the annual amount of gas to be consumed, gas statistics for that year have utmost importance. Similarly the accuracy of the information transmitted in the system will affect assessments generated by the system. Therefore, providing data to EBB in an accurate, instant, correct, and specific way shows the maturity of the system. Performance indicators have been documented additionally in order to determine such maturity. We demonstrate all key performance indicators for EBB in natural gas distribution. We determine level of these factors by investing legislation and specification about EBB. These KPIs are presented at Table 4.2.

Table 4.2: EBB Maturity Level - KPI

	EBB Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line) and Determining - compensating of system's inadequacy against cyber attack	System Check	Level 5
3	Reporting	Downtime / Restriction / Increase instructions, Difficulty and Limited Capacity Day, Preparing Daily Imbalance reports	Log Survey	Level 4
4	Reporting	Instantaneous flow quantities at the Input and Main Output Points, instantaneous upper thermal value, instant delivery pressure and total flow amounts at the end of the day, average upper thermal value and average delivery pressure reporting	Log Survey	Level 4
5	Current Capacity Information	Available allocated capacity information on subordinate Outlets and All Main In - Outlets linked to Main Outlets	Log Survey	Level 4

Table 4.2: (continued)

	EBB Characteristics	Required information	Method	Level
6	Passive Capacity Information	Passive capacities at all Input and Main Output Points	Log Survey	Level 3
7	Reporting	Reporting of Maximum Separable Capacities for Input / Output points	Log Survey	Level 3
8	Reporting	Reporting of Maximum Hourly Amounts (ASM) and maximum daily withdrawals allowed for each subordinate Outpost	Log Survey	Level 3
9	Reporting	Reporting of the Transmission Network Minimum Stock level separately for each segment of the Main Transmission Network at the beginning of each Gas Year	Log Survey	Level 3
10	EBB Instant Data Transfer	BOTAS Electronic Bounce Board (EBB) should be 15 minutes or less for the instant data transmission time	Log Survey	Level 2
11	EBT Data Detail Records	Visualization and recording of the information which is sent BOTAS the return from EBB (EBB Registration - Confirmation) and to be submitted to BOTAS, and archive and the records of detailed information manual entry reason in case of manual data entry	Log Survey	Level 2
12	Generate Demand	Execution of Capacity transfer, capacity change due to supplier change, and capacity transfer requests	System Check	Level 1
13	Planning the System	Preparing budget and specifications for setting up the EBB system	Process Analysis	Level 1

EBB system has been evaluated according to these KPIs. Maturity level of EBB system is 8,4 out of 10 in the Istanbul. There are some improvable areas. These are five top elements of the KPI list.

4.1.3 AVE on Natural Gas Network

AVE is another essential system which supports smart grid in the natural gas distribution. The main objective of AVE system is to track and record gas consumption amount of customers which consume gas higher than 300 mbar pressure. The system can measure and record the data accurately by correcting flow rate based on pressure and temperature values by using a so-called corrector (electronic volume corrector) device, which are integrated to natural gas network. The system makes measurements and corrections in every 15 min intervals. Furthermore, the system records normal volume, corrected volume, pressure, temperature and corrections factors. In other words, the system performs volume correction for billing purposes and online reporting. Thus the firms, which consume gas, can analyze consumption profile by following their consumption. The system also provides connection to SCADA system by using the physical equipment scadapack-RTU at the area regulator. RTU, which is a part of AVE system, is an electronic device which transmits signals and data from the field to the central control system and information center and vice versa. AVE system provides crucial contribution to natural gas distribution network as a component of automation systems. Operation principle of system is correctly measure gas consumption amount of customers which consume gas with high pressure and transmit measure data to SCADA unit through GPRS. Thus, AVE system contributes to accurate measurement, analyzing, and reporting of gas consumption amounts. The performance criteria of AVE system are attached herewith. We indicate all key performance indicators for AVE in natural gas distribution. We determine level of these factors by investing legislation and specification about AVE. These KPIs are presented at Table 4.3.

Table 4.3: AVE Maturity Level - KPI

	AVE Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Customer Focus	Setting up a system without any security vulnerabilities which will enable customers to monitor their invoices and consumptions free of charge over a central database	Process Analysis	Level 5
3	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
4	Data Security	Within the scope of relevant standard (ISO 27001), precautions for physical and technical safety standards should be taken	Standard	Level 4
5	Communication System	Flawless operation of GPRS-RF-SATELLITE communication system	Visual Inspection	Level 4
6	Information Provided	Logging over the system each 15 minutes for the corrected consumption values such as temperature, pressure, correction factor, and regular consumption of the gas used by customers who are using it over 300 mbar, and viewing them by customers	Website Monitoring	Level 3
7	SCADA Connection	Providing access to SCADA system with the help of physical field equipment Scadapack RTU (Remote Terminal Unit) in regional regulators of the system, creating alarms, and transferring data	SCADA Test	Level 3

Table 4.3: (continued)

	AVE Characteristics	Required information	Method	Level
8	Distribution of Gas Consumption	Possibility of creating a report showing distribution of gas taken from RMS to the regional regulators and skids	Visual Inspection	Level 3
9	Energy Back-Up	Ensuring back-up of power supply which provides online reading	Visual Inspection	Level 3
10	Customer Station Alarms	Instant reporting of any intervention to customer stations	Visual Inspection	Level 3
11	Monitoring Online Consumption	Enabling view of consumption values over Internet or mobile applications to each customer who has a corrector	Process Analysis	Level 2
12	Fault Condition	Creating a warning over the system in case correctors don't work (running out batteries, showing the same values all the time)	Log Review	Level 2
13	Setting Up the System	Setting up devices such as correctors, Scadapack-RTU which will be required for the setting up of the AVE system	Ping Analysis	Level 1
14	Planning the System	Preparing budget and specifications for setting up the AVE system	Process Analysis	Level 1

AVE system has been evaluated according to these KPIs. Maturity level of AVE system is 7,2 out of 10 in the Istanbul. There are some improvable areas. These are five top elements of the KPI list.

4.1.4 Smart Meter on Natural Gas Network

Smart meters are essential tools for smart grid concept. Smart meters are one of the most important components that facilitate the flow of natural gas distribution management. The main purpose of smart meters is to read consumption data of end-users remotely and identify losses on the network. Smart meters enable determining total regional losses thanks to instant reading capability on the system. In this respect, smart meters are important tools for smart grid concept.

There are two types of smart meters. These are the ones with fully electronic gas meters performing measurement and communication, and the ones which can be attached to regular meters modularly. Bellows and rotary type meters which perform volume measurement can be included to the scope of smart meters with an attached module. Turbine and ultrasonic meter types are fully electronic gas meters. These two types of smart meters are used in the industry for testing purposes. Smart meters are generally not preferred in houses. Another feature of smart meters is to determine corrected gas volume with a correction coefficient obtained by using temperature and pressure values thanks to a corrector device. In industrial consumptions, it is used for customers who consume more than 300 mbar gas.

The cost of the smart meters should be borne by distribution companies based on the provision of Energy Market Regulatory Authority (EMRA) "Meters are owned by distribution companies, and such meters shall be supplied by distribution companies without any fee apart from subscription fee, and these meters shall be included to the system". Also, smart meters are not widely used in the industry due to high battery replacement and maintenance costs. This makes the implementation progress slower. Increasing the lifetime of batteries for smart meters which is around 4-5 years as of now will eliminate this obstacle. Distribution companies cannot achieve savings due to the provision of EPDK which says: "notification and/or invoice shall be delivered to the address of the subscriber at least seven days before the payment due date". The usage of smart meters is expected to become widespread with the help of changes performed by smart meter producers and regulatory institutions according to the industry needs [40].

There are many standards regarding measurement and data transfer for smart meters. European Community has specified characteristics of meters in the Regulation on Meters Directive (MID) [43]. In this respect, MID approval is required in smart meters. Another point specifying performance criteria of smart meters is performed over GPRS (operator) and RF (radio frequency). The M-bus (Meter-Bus) where data transfer is performed in this field is the communication platform according to the European standard [44]. It ensures reading smart meters remotely or monitoring energy balance of the building flexibly by performing data transfer to an external central control device. This protocol has been defined by IEC (International Electro-technical Commission), and the IP 55 protection code is required for preventing any external intervention and transferring consumption data [45]. These protection protocols ensure cyber security of smart meters. There are many performance criteria of smart meters such as battery life, max-min temperature, humidity operating range, data transfer capacity, etc. We indicate all key performance indicators for Smart Meter in natural gas distribution. Performance criteria with levels are presented in Table 4.4.

Table 4.4: Smart Meter Maturity Level - KPI

	Smart Meter Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5

Table 4.4: (continued)

	Smart Meter Characteristics	Required information	Method	Level
2	Cyber Security	Determining and compensating of system's inadequacy against cyber attack	System Check	Level 5
3	Communication Protocol	Having a IP 55 protection code for communication protocol	System Check	Level 4
4	Standards	Meeting all CE or TSE certificated for smart meter	Certification Control	Level 4
5	ATEX Directive	Corresponding to ATEX Directive for smart meter	Certification Control	Level 4
6	MID Approve	Having MID (Measuring Instruments Directive) (2004/22/EC) approval for smart meter	Certification Control	Level 4
7	Leakage Control	Constant, continuous and low gas flows passing through the smart meter are detected as leakage and generate alarm	Visual Inspection	Level 3
8	Storage of Consumption Statistic	Storage feature of smart meter for consumption statistics	Log Inspection	Level 3
9	Device Lifetime and Calibration	Smart meter has at least 5 years lifetime and calibration responsibility belongs manufacturer firm	Certification Control	Level 3
10	Remote Data Transfer Method	Smart meter must be able to transfer data via MBUS, GPRS, and RF	System Check	Level 3
11	Compression Strength	Compression strength of smart meter must be able to accord with operating pressure	Visual Inspection	Level 3
12	Operating Temperature	Operating temperature of smart meter must be between - 20 degree C / + 60 degree C	Visual Inspection	Level 3
13	Humidity Strength	Humidity strength of smart meter must be able to endure at least 95 percentage relative humidity (52 degree C)	Visual Inspection	Level 3
14	Remote Gas Cutting	Smart meter must be able to cut and open gas usage	Visual Inspection	Level 2
15	References	Smart meter must have usage reference at any country	Log Inspection	Level 2
16	Pulse Generation Method	Smart meter must be able to generate pulse with reed sensor and magnetic coupling	Visual Inspection	Level 1
17	Planning the System	Preparing budget and specifications for setting up the AVE system	Process Analysis	Level 1

Smart meter system has been evaluated according to these KPIs. Maturity level of Smart meters system is 7 out of 10 in the Istanbul. There are some improvable areas. These are four top elements of the KPI list.

4.2 Flow Management

Data management is one of the most important fields in the industry. Especially, data management is an essential element to achieve infrastructure services properly. Nowadays, the information, which belongs to millions of customers, maintenance operations, invoices, payments, necessitates data management for a natural gas distributor. If there is one element that produces a city smart, it is information. Additionally, components of smart grid technology generate data regularly. Thus, a gas distribution company has three ingredients to manage, develop, protect, control, enhance, and deliver data. These are Enterprise Resource Planning (ERP), Customer Relations Management (CRM), and Cyber Security System. These components will be examined at next parts.

4.2.1 ERP on Natural Gas Network

ERP is essential tool for smart grid concept. ERP is one of the most important components that facilitate the flow of natural gas distribution management. In the globalizing world, ERP projects have enhanced an absolute necessity with respect contributing efficiency by optimizing process. Moreover, ERP increase speed of operations. ERP is also the information infrastructure of the whole data exchange. Business continuity is the most significant part of ERP. The requirement of ISO 22301 Business continuity management (BCM) must be met via ERP. Performance of ERP project can be measured with KPI [42]. There are many performance criteria of ERP such as the maximum allowable downtime (MTPoD), acceptable downtime (RTO) and acceptable data loss (BIA) etc. We indicate all key performance indicators for ERP in natural gas distribution. We state these factors by investing legislation and specification about ERP. Performance criteria are presented as a list. Each number states level, control method, ERP Characteristics, and Required information.

Table 4.5: ERP Maturity Level - KPI

	ERP Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Business Continuity	The maximum allowable downtime (MTPoD), acceptable downtime (RTO) and acceptable data loss (BIA) values must be within the desired ranges to avoid business interruption	BCM Control	Level 5

Table 4.5: (continued)

	ERP Characteristics	Required information	Method	Level
4	Leak Control	Determination of the leakage amount locally by providing instant reading of the amount of gas that has passed through the zone regulator and invoiced in counters with smart meters	System Check	Level 4
5	Flow Control	Transfer of natural gas amount information from RMS to ERP	System Check	Level 4
6	Gas Open - Cut	Transmission of the gas cutting work order to the mobile hand terminal via ERP according to the invoice amount and total debt amount of the unpaid customer. The delivery of the gas opening job order to the mobile hand terminal via ERP	System Check	Level 4
7	Billing	The billing of the customer who opens the gas should be done with the mobile hand terminals via the ERP system, depending on the daily temperature, pressure and natural gas unit price information received from the relevant units	System Check	Level 4
8	Contract Fee Detection	Recalculation of contract fee of the client which has a approved project as regard the capacity (m3), purpose of use, and usage area (m2)	System Check	Level 3
9	Gas Opening	Activation of the gas-opening state of the building approved by the project via ERP system, If the company has an appointment, Notification of gas opening hours to the customer and the company via the system	System Check	Level 3
10	Execute Contract	Determination of contract price according to project information (capacity, meter, pressure) and current EMRA pricing via ERP system	System Check	Level 3
11	Project approval record	Information transfer of the approved internal installation project such as capacity (m3), bbs (number of independent units) and gas usage intent via the ERP program	System Check	Level 3
12	Subscription Fee Detection	When the line withdrawal and box setting transactions are completed, determination of the actual manufacturing price through the system	System Check	Level 3
13	Additional Box Projecting	In the absence of line, (Project supervision) of the gas usage demands above the certain capacity is sent to the related project (construction supervision) via the system	System Check	Level 2

Table 4.5: (continued)

	ERP Characteristics	Required information	Method	Level
14	Box Putting	In the absence of box, generate a work order to building audit for box putting	System Check	Level 2
15	Building Identification	In the absence of box, Integration of ID with ERP via Geographic Information Systems (GIS), identification of the distance of the existing natural gas pipeline and entry into the system	System Check	Level 2
16	New Subscription	Identification of the ERP system of the building which is requested to use gas depending on the building address	PSystem Check	Level 2
17	Software Improvement	Up-to-date use of patch software required for the ERP system	System Check	Level 1
18	Planning the System	Preparing budget and specifications for setting up the ERP system	Process Analysis	Level 1

ERP system has been evaluated according to these KPIs. Maturity level of ERP is 7 out of 10 in the Istanbul. There are some improvable areas. These are four top elements of the KPI list.

4.2.2 CRM on Natural Gas Network

CRM data is analyzed with the aim of increasing customer satisfaction and service quality and attempts are made to reveal the underlying causes of claims and complaints. By using CRM data, the improvement areas are attempted to be determined by analyzing the life cycle customer perspective of IGDAS customer. Thus, customer requests have important effects in network design and procedure of the operation. Evaluation of CRM reports' gives a valuable contribution to composition of smart grid. To measure CRM maturity level KPI list presented at Table 4.6 is utilized. We choose all key performance indicators for CRM in natural gas distribution. We determine level of these factors by investing legislation and specification about CRM.

Table 4.6: CRM Maturity Level - KPI

	CRM Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Determining - compensating of system's inadequacy against cyber attack	System Check	Level 5

Table 4.6: (continued)

	CRM Characteristics	Required information	Method	Level
3	Grid Improvement	Evaluating customer requests and conducting application improvement studies in urgent situation	Process Analysis	Level 4
4	CRM Performans	Executing performance evaluation such as the number of incoming calls, average call lengths, average waiting time, number of missed calls, connect and disconnect times, CRM record quality with the reports to be received via CRM software	Process Analysis	Level 4
5	Request Topics	Performing necessity CRM process improvements by examining of request topics	Process Analysis	Level 4
6	Accessibility Ratio	Accessibility and service rates must be at the level specified in the procedure	Process Analysis	Level 3
7	Closing Request	Closing requests in the duration which is stated at the procedure	Process Analysis	Level 3
8	Communication Procedure	Creation of CRM communication procedure	Process Analysis	Level 2
9	Training Process	Training of personnel employed in CRM on natural gas and communication	Process Analysis	Level 2
10	Call Priorities	Classify incoming calls according to solution priorities	Process Analysis	Level 1
11	Planning the System	Preparing budget and specifications for setting up the EBB system	Process Analysis	Level 1

CRM system has been evaluated according to these KPIs. Maturity level of CRM is 9,7 out of 10 in the Istanbul. There are some improvable areas. There is only one element of the KPI list.

4.2.3 CSS on Natural Gas Network

Nowadays, cyber security comes at the beginning of the most popular topics because of the huge effect on the automation system and business. According to statistics, cyber-attacks cause financial loss in the oil and gas industry about $8.4 million per day, and over 50% of these are turned at SCADA systems [46]. Due to these hazards, the work on cyber security has gained speed. For an enterprise application, there are many layers that need to be considered in terms of cyber security. These layers can be called data center security, device security, operating system security, middleware security, data warehouse security, network security, access security, and encryption security. These are called OSI layer. The work required for each layer requires different specializations and sensitivities [47].

The security vulnerabilities in operating system and middleware software that enterprise applications are working on must be followed by authorized personnel and the security patches that close the security vulnerabilities of these products should be kept up to date. Another dimension of cyber security is the ability to have a business continuity management system. Business continuity is one of the most significant parameter for automation systems security. In case of process interruption, business continuity must be provided according to the concepts of maximum tolerable period of disruption (MTPOD), recovery time objective (RTO), and recovery point objective (RPO) [48]. Furthermore, Information systems and security systems should be designed and managed as independent structures that supervise each other. Evaluation of CSS's reports gives a valuable contribution to composition of smart grid. To measure CSS maturity level, KPI list at Table 4.7 is utilized. We determine all key performance indicators for CSS in natural gas distribution. We state level of these factors by investing legislation and specification about CSS.

Table 4.7: CSS Maturity Level - KPI

	CSS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Off Line Working	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Information Security Standard	The organization has ISO 27001 information security standard	Process Analysis	Level 5
4	Business Continuity	Establishment of the Business Continuity Management System (BCMS) in order to ensure business continuity in case of cyber intervention	Process Analysis	Level 4
5	Anti-Virus Programs	Updating anti-virus programs against interferences with viruses, worms and other malicious code, and setting up the virus warning system	Security Analysis	Level 4
6	Firewalls	Access to SCADA systems that control the natural gas network via firewalls	Security Analysis	Level 4
7	OSI Layers Analysis	Surveying of OSI layers (WEB Application, Systems, Server, Session, Transmission, Network, Data Link, and Physical) cyber security vulnerabilities	Security Analysis	Level 4
8	Data Transfer Protocols	Protocols used for data transfer are encrypted	Security Analysis	Level 4
9	Cyber Security of Systems	Detection and elimination of cyber security vulnerabilities of all used systems	Security Analysis	Level 4

Table 4.7: (continued)

	CSS Characteristics	Required information	Method	Level
10	Cyber Security of Devices	Detecting and fixing modem cyber security vulnerabilities of all devices connected to the system	Security Analysis	Level 4
11	Data Backup	Ensure that corporate records are backed up to a secure server and recovered from backup if deleted	Security Analysis	Level 4
12	Control of Unusual Movements	CPU usage, system density, collecting disk activity data, detecting abnormal changes and reporting to the system administrator	Security Analysis	Level 3
13	Unauthorized - Unnecessary Access	Identification of unauthorized - unnecessary access actions in corporate networks	Security Analysis	Level 3
14	Outside Intervention to the System	Detection and intervention of the system when it is interfered with from the outside	Security Analysis	Level 3
15	Remote access	Turning off external access (VPN) including staff to our institution's network	Security Analysis	Level 3
16	Electronic Signature Security	In the institution and stakeholder companies, training of awareness about information security is given to personnel with electronic signatures	Certification Control	Level 2
17	Device Usage Follow-up	Closing access to the system from within the organization, except for compulsory hours, and restricting non-mandatory users	Security Analysis	Level 2
18	Data Transfer Control	Preventing access to web based mail (Gmail, Hotmail, etc.), cloud storage (WeTransfer, Dropbox, etc.) from corporate computers, and filtering content filtering of corporate emails	Security Analysis	Level 2
19	USB and Port Control	Prevention of USB ports and serial ports of computers in corporate use	Security Analysis	Level 2
20	Data Transfer Control	Blocking access to social media (Facebook, Twitter, etc.) applications and video sharing applications from corporate computers	Security Analysis	Level 1
21	Planning the System	Preparing budget and specifications for setting up the CSS system	Process Analysis	Level 1

CSS system has been evaluated according to these KPIs. Maturity level of CSS is 6,3 out of 10 in the Istanbul. There are some improvable areas. There are top ten element of the KPI list.

4.3 Work Management

Managing of work teams and assets effectively is realizable with usage a strong work management system. WFM system offers a detailed way on how to accomplish coherence in business skills. WFM system is an essential tool to efficient power usage especially in the field of natural gas distribution. Work management capability for a natural gas distribution company has been evaluated at this part via work force management system, vehicle tracking system, and building energy management system respectively.

4.3.1 WFM on Natural Gas Network

Work Force Management (WFM) system provides crucial contribution to natural gas distribution network as a component of automation systems. Currently, effective management of field teams for the company operating in the infrastructure sector is critical to business continuity. As the service network expands, this system becomes inevitable for planning, managing and reporting operations. Evaluation of WFM system's reports gives a valuable contribution to composition of smart grid. To measure WFM system maturity level, KPI list presented at Table 4.8 is developed. We choose all key performance indicators for WFM in natural gas distribution. We determine level of these factors by investing legislation and specification about WFM.

TABLE 4.8: WFM Maturity Level - KPI

	WFM CHARACTERISTICS	REQUIRED INFORMATION	METHOD	LEVEL
	WFM Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Working Offline	The system can be operated off-line and recording via 3G when it is plugged in	System Check	Level 4
4	Required SCADA Information	Information (network regulator flow rate, flow temperature and pressure) that network personnel need for periodical maintenance can be displayed online	System Check	Level 4
5	Material Inventory	When the job order is completed, displaying of the material record from the inventory and dropping from the records when used in the operation	System Check	Level 4

Table 4.8: (continued)

	WFM Characteristics	Required information	Method	Level
6	Estimated Time	Transfer of the information about job acceptance, estimated arrival, estimated turnaround time, and previous operation from the teams to CRM during arrival	System Check	Level 3
7	Performance Measurement	Performance measurement and follow-up of job to be performed	System Check	Level 3
8	New Line Registration	Combining the path and line location information by processing the system data with the SDK (software development kit) from the SCADA, GIS (Geographic Information Systems) and API (Application Programming Interface) of the additional lines	System Check	Level 3
9	Importance Order	Determination of importance order and type of work (Operation, maintenance, etc.)	System Check	Level 2
10	Following Team	Ability to follow up on work, team, material and time basis	System Check	Level 2
11	Adding Image	Entering and recording of damage photo in the system	System Check	Level 2
12	Pipe Line - Road Map	The position of the line can be selected from the map	System Check	Level 1
13	Planning the System	Planning and preparing specifications for WFM system	Process Analysis	Level 1

WFM system has been evaluated according to these KPIs. Maturity level of WFM is 7.3 out of 10 in the Istanbul. There are some improvable areas. There are top three elements of the KPI list.

4.3.2 Vehicle Tracking System on Natural Gas Network

Vehicle Tracking System (VTS) provides crucial contribution to natural gas distribution network as a component of automation systems. Evaluation of VTS's reports gives a valuable contribution to composition of smart grid. To measure VTS system, maturity level KPI list presented at Table 4.9 has been developed. We state all key performance indicators for VTS in natural gas distribution. We determine level of these factors by investing legislation and specification about VTS.

Table 4.9: VTS Maturity Level - KPI

	VTS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line) - Detection and elimination of deficiencies against cyber interventions	System Check	Level 5
3	Violation Reporting	In case of the defined violations in the system 7/24 reporting via e-mail and SMS	System Check	Level 4
4	Motion Information	Access to the current and past movement information of the company vehicle via computer or mobile devices over the Internet	Log Survey	Level 4
5	Fuel consumption	Reporting on monthly average fuel amounts of company vehicles	Log Survey	Level 3
6	Path Road	Reporting of the average monthly rate of corporate vehicles	Log Survey	Level 2
7	Vehicle Location	In case of an accident for the safety of workers, the place where your vehicle is located and the information of your vehicle are transmitted to the GSM / GPRS (APN) line via GPS satellites	System Check	Level 1
8	Planning the System	Preparing budget and specifications for setting up the WFM system	Process Analysis	Level 1

VTS system has been evaluated according to these KPIs. Maturity level of VTS is 7.9 out of 10 in the Istanbul. There are some improvable areas. There are top two elements of the KPI list.

4.3.3 Building Energy Management System on Natural Gas Network

Building Energy Management System (BEMS) contributes public and unofficial market companies with management policies to enhance energy productivity, decrease expenditures and upgrade energy performance [49]. Moreover, the usage of smart meters at buildings and transformation of buildings to smart buildings will lead to the necessary improvements in network design. Smart applications in the company's own buildings are a crucial step in the transition to smart grids. Evaluation of BEMS's reports gives a valuable contribution to composition of smart grid. To measure BEMS, maturity level KPI list presented at Table 4.10 has been developed. We choose all key performance indicators for BEMS in natural gas distribution. We determine level of these factors by investing legislation and specification about BEMS.

Table 4.10: BEMS Maturity Level - KPI

	BEMS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Protection of the system against cyber-attack and operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	System Reporting	Increasing the energy efficiency by eliminating deficits that increase energy consumption and reporting of the energy consumption via system	System Check	Level 4
4	Alternative Energy	Preference for using solar energy panels and wind turbines in company buildings	System Check	Level 4
5	Heating - Cooling	Working with highest efficiency of heating, ventilation and air conditioning (HVAC) systems in buildings	System Check	Level 4
6	Urgent Power Supply	Emergency energy distribution in the buildings for computers, servers and elevators	Visual Inspection	Level 3
7	Lighting	Providing building lighting with motion-sensitive sensors and conservative illuminators	Visual Inspection	Level 3
8	Energy Expert Control	Inspection and reporting of company buildings by energy experts	Process Analysis	Level 2
9	Continuous Energy Supply	Emergency power distribution (UPS) line to fire and security systems, lighting, elevators and process control systems in buildings	System Check	Level 2
10	Water Consumption	Usage of the taps which are motion-sensitive in the company to reduce waste of water	Visual Inspection	Level 2
11	Classification of Company Wastes	Classification of waste such as paper, plastic, battery and recycling and prevention of environmental pollution	Visual Inspection	Level 1
12	Planning the System	Preparing budget and specifications for setting up the BEMS	Process Analysis	Level 1

BEMS has been evaluated according to these KPIs. Maturity level of BEMS is 7.8 out of 10 in the Istanbul. There are some improvable areas. There are top two elements of the KPI list.

4.4 Pipeline Integrity Management

Pipeline integrity management (PIM) requires three functional activities. These are prevention, detection, and mitigation activities. All records of material, design and construction are necessary for building of satisfactory PIM [50]. These are key indicators of other systems. PIM can be performed in accordance with in-line inspection robotic system and cathodic protection system, and risk assessment system. These systems are presented next parts. Moreover, natural gas, oil and coal are mainly made up of hydrocarbons. Hydrocarbons are composed of the elements hydrogen, carbon and various impurities. Natural gas is mostly made up of methane (CH_4), ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), Natural Gas can also include non-hydrocarbon components such as carbon dioxide (CO2), hydrogen sulfide (H2S), hydrogen, nitrogen, helium and argon. A typical natural gas composition is presented in Table 4.11 [51]. Additionally, CO_2 and H_2S must be separated from the natural gas stream prior to sale since these can cause air pollution and pipeline corrosion.

Table 4.11: Typical Composition of Natural Gas

Component	Typical Analysis (mole %)	Range (mole %)
Methane CH4	95.2	87.0-96.0
Ethane C2H6	2.5	1.5-5.1
Propane C3H8	0.2	0.1-1.5
iso - Butane C4H10	0.03	0.01-0.3
normal - Butane C4H10	0.03	0.01-0.3
iso - Pentane C5H12	0.01	trace-0.14
normal - Pentane C5H12	0.01	trace-0.04
Hexane plus C6H14	0.01	trace-0.06
Nitrogen N2	1.3	0.7-5.6
Carbon Dioxide CO2	0.7	0.1-1.0

4.4.1 Cathodic Protection System (CPS) on Natural Gas Network

Cathodic protection of pipelines is a system, which is used for approximately a century. There are innumerable elements that impress the live of the pipeline and other facilities. These contain structure quality, properties of gas, environmental situations, materials preferred and quality of maintenance, and cathodic protection (CP) systems. Corrosion is the most important cause of problems in gas pipelines. It besides is a danger for gas distribution networks and services. Corrosion can cause the slow reduction of the pipe thickness and loss of strength. Additionally, billions of dollars are lost annually due to corrosion. There are many elements that make complex mitigation of corrosion, thus, direct observation of the majority of pipeline is necessary. Natural gas can include small amounts of contaminants such as water vapor and carbon dioxide. These ingredients can lead internal corrosion. Corrosion is dependent on many factors thus; the principal kinds of corrosion- control systems require real survey data and laboratory knowledge during the complex engineering and calculate of the study. A productive corrosion-protection program encourages early designation of potential dangers and results and resolves issues at the soonest possible phase. A successful corrosion-control program will apply three key phases: anticipation, risk and threat evaluations, corrosion control, and corrosion monitoring. In design of pipeline corrosion-control methods, engineers must consider for a holistic protection. Otherwise, corrosion issues can cause more costs for repair of failure and correction of design. A mature corrosion management plan can prevent these extra costs [52]. Additionally, water bodies, neighboring railway systems, different voltage transmission lines, and other pipeline systems in the surroundings, underground water levels, pH levels, and redox potentials that point the corrosivity of the terrain are among other criterion which must be stated for the successful cathodic protection. Underground steel pipelines needs protect with application of EN 12954 cathodic protection rules [53]. Thus, there are many performance criteria of CPS such as pH levels, other infrastructure transitions, and corrosivity etc. Performance criteria are presented in Table 4.12. We state all key performance indicators for CPS in natural gas distribution. We determine level of these factors by investing legislation and specification about CPS.

Table 4.12: CPS Maturity Level - KPI

	CPS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Protection of the system against cyber-attack and operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Transformer / Redressor Unit	Establishment of transformer and rectifier units which will generate energy to protect steel natural gas pipelines against corrosion, maintenance and connection with SCADA system	System Check	Level 4
4	Redressor Unit Battery	The battery level can be monitored from the center of the rectifier units, the remaining time estimate can be calculated, and the battery change alarm is generated for the system critical level	System Check	Level 4
5	System Working	System can run on virtual servers without problems	System Check	Level 4
6	System Monitoring	Monitoring the data of the users with the interface of the data measured by the field devices and transferred to the center	System Check	Level 4

Table 4.12: (continued)

	CPS Characteristics	Required information	Method	Level
7	Other Infrastructure Transitions	Determination of the intersection points of steel line with other infrastructure systems (Metro, water, electricity etc.) and taking the appropriate additional measures (Chain Resistance, Transformer-Diode, etc.)	System Check	Level 3
8	System Reporting	Reporting of the data measured by the field devices and transferred to the center and monitoring of the reports via WEB	System Check	Level 3
9	Current Measurement	Establishment of current measurement points on the steel line for cathodic protection and integration with the SCADA system	System Check	Level 3
10	Data Protocol	Storing collected data in the standard database	System Check	Level 2
11	Standard	Application of TS 5141 EN 12954 cathodic protection rules of underground steel pipelines	System Check	Level 2
12	System improvement	Improvement of the cathodic protection system periodically to increase supply security	System Check	Level 2
13	Specification Preparation	Preparation of specifications for the cathodic protection system	System Check	Level 1
14	Planning the System	Preparing budget and specifications for setting up the CPS	Process Analysis	Level 1

CPS has been evaluated according to these KPIs. Maturity level of CPS is 7.8 out of 10 in the Istanbul. There are some improvable areas. There are top two elements of the KPI list.

4.4.2 Pipeline Analysis Robot (PAR) on Natural Gas Network

Pipeline Analysis Robot (PAR) provides crucial contribution to natural gas distribution network as a component of automation systems. In-line examination contains the usage of technologically innovative equipment, often assigned to as "smart pigs" or in-line inspection equipment, which are spread in the pipeline. Smart robots were essentially named for the squealing sound they make while travelling through a pipeline. Originally, smart pigs were preferred to clean out sweeps and distract water from a line. Now, they are prevalently used to equipped specific technology that can internally control a pipeline for abnormal situation.

There are many performance criteria of PAR such as accuracy limits, quality of data etc. Performance criteria are presented in Table 4.13. We choose all key performance indicators for PAR in natural gas distribution. We determine level of these factors by investing legislation and specification about PAR.

Table 4.13: PAR Maturity Level - KPI

	PAR Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Cyber Security	Detecting and eliminating the system security flaws	System Check	Level 5
4	Accuracy Limits	Ability to ensure the accuracy parameters when robot's findings compared with those stemming from verification digs	Visual Inspection	Level 4
5	Verification Digs	recording the sizes of defects correctly in the verifications digs considering the pipeline properties and internal-external environmental conditions	Visual Inspection	Level 4
6	In-Line Inspection	Ability to detect the metal loss on the pipeline and to classify them according to terms in the technical specification Sheet	Examination of Metal Loss	Level 4
7	Classification Of Defects	Ability to detect the geometrical deformations on the pipeline and to classify them according to terms in the technical specification Sheet	System Check	Level 3
8	Mapping	Ability to record the data which ensures the pipeline mapping	Logs Inspection	Level 3
9	Quality Of Data	Ability to record the inspection data with the acceptable level of noise, disturbance etc.	Logs Inspection	Level 3
10	Qualified Personnel	Providing adequate level of qualification for the personnel who will manage the ILI procedures as being entitled to certain levels of ILI-PQ	Certification Control	Level 2
11	Motion Ability	Entering and recording of damage photo in the system	Device Check	Level 2
12	Duration Of Working	ability to function for the time period designated in the technical specifications sheet when the pressure temperature and cleanliness conditions are applicable	Device Check	Level 2
13	Preparation Of Specification Sheet	Preparation of technical specification of ILI Robot	Process Analysis	Level 1

TABLE 4.13: (continued)

	PAR CHARACTERISTICS	REQUIRED INFORMATION	METHOD	LEVEL
14	Preparation Of Specification Sheet	Budget allocation for ILI robot	Process Analysis	Level 1

PAR system has been evaluated according to these KPIs. Maturity level of PAR is 6 out of 10 in the Istanbul. There are some improvable areas. There are top five elements of the KPI list.

4.4.3 Risk Assessment System (RAS) on Natural Gas Network

Risk Assessment System (RAS) provides crucial contribution to natural gas distribution network as a component of automation systems. There are many performance criteria of RAS such as pipeline information, metal loss etc. Performance criteria are presented in Table 4.14. We state all key performance indicators for RAS in natural gas distribution. We determine level of these factors by investing legislation and specification about RAS.

TABLE 4.14: RAS Maturity Level - KPI

	RAS CHARACTERISTICS	REQUIRED INFORMATION	METHOD	LEVEL
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	RAS Software	Implementation of Risk Assessment Software	System Check	Level 4
4	Risk Algorithms	Generating risk algorithms	System Check	Level 4
5	Data mining	Analysis of data	System Check	Level 4
6	Risk Maps	Preparation of pipeline information and production of risk map	System Check	Level 4
7	Performance Data	Removing Intelligent Robot performance data	System Check	Level 3
8	Certification	Completion of Smart Robot certification processes	System Check	Level 3
9	Robot Tests	Completion of Smart Robot tests	Process Analysis	Level 3
10	Robot Construction	Construction of the ILI robot, a device that generates the necessary information for integrity assessment	System Check	Level 3

TABLE 4.14: (continued)

	RAS CHARACTERISTICS	REQUIRED INFORMATION	METHOD	LEVEL
11	Damage Cost Account	Calculation of the estimated costs of the problems that may occur in the pipeline	Process Analysis	Level 2
12	Pipeline Information	Provision of the necessary data (Pipeline class, material, diameter, manufacturer, etc.) for PIM on GIS	System Check	Level 2
13	PIM Awareness	Raising and educating PIM awareness of relevant personnel	Process Analysis	Level 2
14	Specification Preparation	Preparing budget and specifications for setting up the PIM system	Process Analysis	Level 1
15	Planning the System	Preparing budget and specifications for setting up the RAS system	Process Analysis	Level 1

RAS system has been evaluated according to these KPIs. Maturity level of RAS is 6 out of 10 in the Istanbul. There are some improvable areas. There are top six elements of the KPI list.

4.5 Catastrophe Management

Catastrophe can occur at anytime, anywhere, in many ways - earthquakes, storm, flood, fire, hazardous materials, etc., thus previously risk evaluation must be performed to guarantee secure of gas supply. ISO 22320 defines best study for founding instructs and command organizational frameworks and procedures, judgment support, traceability and data management [54]. Catastrophe management on the natural gas network can be realized via two components. These are Earthquake Risk Reduction System and Warning Management System.

4.5.1 Earthquake Risk Reduction System (ERRS) on Natural Gas Network

One of the other necessary components of smart grid is risk of earthquake decreasing. With the collaboration of KOERI (Kandilli Observatory and Earthquake Research Institute) and TUBITAK (Turkish Scientific and Technological Research Centre), the IGDAS Natural Gas Network Earthquake Risk Reduction System (IGRAS) project has been carried out in the following 4 stages: 1. Risk Analysis: Scenario based hazard and damage assessment studies for Istanbul Natural Gas Network have been conducted. 2. Monitoring - Early Warning - Emergency Response Info Service: The district regulators of

IGDAS network is being monitored, the real-time ground motion data parameters are being computed and shut-off mechanism is being deployed according to threshold exceedance of ground motion parameters with or without Earthquake Early Warning alert. The emergency response information is distributed through the system. 3. Information Exchange and Communication: The data is made simple and comprehensible to enable the relevant persons to give the required response. Probable damage and alert warnings are spread through intra-company, national and international communication channels. 4. Emergency Response Capacity: With earthquake scenarios planned, Earthquake Risk Reduction System plays a key role in making IGDAS Emergency Response teams understand risks they would face and learn how they should respond to these risks. This system collects vibration data through strong ground motion (SGM) sensor and gives information about devastation on the all physical part of asset. Its basic requirements are listed Table 4.15. We choose all key performance indicators for ERRS in natural gas distribution. We determine level of these factors by investing legislation and specification about ERRS.

Table 4.15: ERRS Maturity Level - KPI

	ERRS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Disaster Management Standard	Having a disaster management standard (ISO 22320)	Certification Check	Level 5
4	Destruction Report	It can compare jitter data with other sensors in the environment and report it to the destruction center and related network controllers	System Check	Level 4
5	Collection of Data	Collection and visualization of vibration data through system via strong ground motion sensor	Scenario Based Quake	Level 4
6	Disaster Drill	Periodic exercise at least once a year	Visual Inspection	Level 4
7	Disaster Coordination	Having a disaster coordination center and to participate in AKOM meetings	Visual Inspection	Level 4
8	Gas Cutting at Threshold Boundaries	Gas can be cut from zone regulator when threshold value is reached	Visual Inspection	Level 3
9	Backup Communication	Providing 3G with data transmission of Strong Ground Motion (SGM) Sensors	Log Inspection	Level 3
10	Risk Map	Establishment of network risk map	System Check	Level 3

Table 4.15: (continued)

	ERRS Characteristics	Required information	Method	Level
11	Data Transfer	Sharing vibration data with the Kandilli Observatory	Log Inspection	Level 3
12	System Energy Redundancy	Detection and elimination of SGM failure and loss of contact	Visual Inspection	Level 3
13	Energy Backup	The energy reserve of the Coordination Center to be formed in case of disaster. (UPS-Generator)	Visual Inspection	Level 3
14	Number of Trained Staff	The number of trained personnel is sufficient	Certification Check	Level 2
15	Number of SGM Sensors	The number of SGM is sufficient	Visual Inspection	Level 3
16	Urgent Action Plan	A network-based (regional) emergency action plan exists	Planning Analysis	Level 2
17	Disaster Coordination Procedure Material	Disaster coordination procedures and staff task distribution. Provision of spare material stock according to the risks (probable need)	Planning Analysis	Level 2
18	AFAD Intervention Teams	Making of AFAD intervention teams	Planning Analysis	Level 2
19	Planning the System	Preparing budget and specifications for setting up the ERRS system	Process Analysis	Level 2

ERRS system has been evaluated according to these KPIs. Maturity level of ERRS is 9,3 out of 10 in the Istanbul. There are some improvable areas. This is only one element of the KPI list.

4.5.2 Warning Management System on Natural Gas Network

Warning Management System (WMS) provides crucial contribution to natural gas distribution network as a component of automation systems. There are many performance criteria of WMS such as duration of warning termination, event attachment etc. Performance criteria are presented in Table 4.16. We choose all key performance indicators for WMS in natural gas distribution. We determine level of these factors by investing legislation and specification about WMS.

Table 4.16: WMS Maturity Level - KPI

	WMS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Warning Link	In accordance with the notification, if necessary, the sub-structure to be able to transmit the notification to the emergency health, fire and security centers	System Check	Level 5
4	Transportation Optimization	Optimal assignment of personnel and vehicles to be delivered in lieu of notification	System Check	Level 4
5	Detection of the Area Without Gas	Notification of the estimated supply of gas to the region where the gas is not available in an emergency	System Check	Level 4
6	Warning Follow Up	Monitoring of notifications via mobile devices in the process of being seen, accepted, reached and terminated	Visual Inspection	Level 4
7	Transportation Warning Area	Remote control of reaching notices within 15 minutes which require urgent intervention	Visual Inspection	Level 4
8	Display of Required Information	Displaying the information (gas on / off, subscriber, contract, etc.) that will be required to finalize the notification through the system via the system	System Check	Level 3
9	Internal Information	Providing information and coordination to the identified persons and units in designated notification cases	System Check	Level 3
10	Natural gas infrastructure map	Field personnel can view the natural gas infrastructure map in the zone	System Check	Level 3
11	Viewing Home Project	Access to approved archive projects of network personnel	System Check	Level 3
12	Termination of Warning	Archiving of the finalization reports of incoming notifications and informing the notified	System Check	Level 3
13	Warning Road Information	Providing address and directions to incoming caller with mobile-integrated navigation device	System Check	Level 3
14	Archiving of Warning Records	Archiving of voice recordings of incoming notices, date and time of notification, names and duties of personnel and intervention teams, address and photographs of event reports and conclusion reports	Log Review	Level 3
15	Event Attachment	Linking incoming notices locally and linking followers	System Check	Level 3

Table 4.16: (continued)

	WMS Characteristics	Required information	Method	Level
16	Contact with the Warning Holder	Contact information can be viewed in the field so that the caller can be called if necessary	System Check	Level 2
17	Workload distribution of notifications	Provision of call dropping justice for the person recording the notification	System Check	Level 2
18	Warning Generation	Handling incoming notifications via ERP system integrated system and transferring them to field teams	System Check	Level 2
19	Warning Management	Classification of notifications (fire, smell, pipe damage, etc.) and training to prepare and implement the procedures to be applied on the intervention	Process Analysis	Level 2
20	Making of Teams	Ability to service the third workshop at the latest at notifications and intervene 7 days and 24 hours with the network personnel	Visual Inspection	Level 1
21	Establishment the System	Preparing budget and specifications for setting up the WMS	Process Analysis	Level 1

WMS system has been evaluated according to these KPIs. Maturity level of WMS is 7 out of 10 in the Istanbul. There are some improvable areas. These are top five elements of the KPI list.

4.6 Installation Management

Installation management on the natural gas network can be realized via three components. These are Geographical Information System (GIS), Digital Project Approve System (DPAS) - Digital Installation Control System (DICS), and SNERGY system.

4.6.1 GIS on Natural Gas Network

GIS (Geographical Information System) is an application, which provides information about location of natural gas pipeline networks, cadastral information, imaged based information, land information in natural gas distribution market. This table is a part of GIS questionnaire. A set of questions, which is about technical capability, are shown in Table 4.17. The presence of these technical specifications gives information to evaluate technical capability of GIS. Additionally, in this study, integrity of smart grids to each other, smart grid policy and collaboration of other infrastructures are controlled at GIS.

Table 4.17: GIS Maturity Level - KPI

	GIS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Network Analysis	Determining which valves should be closed in case of damage, and identifying the lines and buildings to be left without gas	System Check	Level 5
4	3D Map	Creation of 3D pipeline map	System Check	Level 4
5	Position of the Line	Determining coordinates with GPS info (ITRF coordinate system)	Visual Inspection	Level 4
6	Other Infrastructures	Distance of other infrastructures with the line (Electricity, Telephone, Water, Wastewater, etc.)	Visual Inspection	Level 4
7	Superstructure Positions	Determining distance with other service lines and buildings on the superstructure	Visual Inspection	Level 3
8	Valve Chambers on the Line	Viewing RMS-A, RMS-B, Skids, and customer stations	Visual Inspection	Level 3
9	Fittings on the Line	Viewing service boxes, and Welding points	Visual Inspection	Level 3
10	Line Information	Date of manufacture for the line, and the company manufacturing it	Visual Inspection	Level 3
11	Line Information	Viewing brand, model, and manufacturing date for the materials used in the line	Visual Inspection	Level 3
12	Building addresses	Determining IDs of the buildings according to the address details	System Check	Level 3
13	Image	Reflecting the satellite view to the software	Visual Inspection	Level 3
14	Address Details	Viewing District, Quarter, Street, Road, Door Number, and Routes	Visual Inspection	Level 2
15	Cadastral Data	Viewing square and map section	Visual Inspection	Level 2
16	Forest Boundaries	Viewing forest areas	Visual Inspection	Level 2
17	Line Information	Viewing type of line (steel line, pe line, service line), and the diameter	Visual Inspection	Level 1
18	Planning the System	Preparing budget and specifications for setting up the GIS system	Process Analysis	Level 1

GIS system has been evaluated according to these KPIs. Maturity level of GIS system is 8,9 out of 10 in the Istanbul. There are some improvable areas. These are top five element of the KPI list.

4.6.2 DPAS - DICS on Natural Gas Network

Digital Project Approve System (DPAS) - Digital Installation Control System (DICS) provides crucial contribution to natural gas distribution network as a component of automation systems. DPAS-DICS provide control and admission of the Natural Gas domestic installation projects and applications. The control of projects and application, which sent by certificated firms, is performed by basing on technical specification of IGDAS, standard of Natural Gas - Principles of projects and applications of installations in buildings, law of property ownership and Fire Cod. Performance criteria are presented in Table 4.18. We choose all key performance indicators for DPAS-DICS in natural gas distribution. We determine level of these factors by investing legislation and specification about for DPAS-DICS.

TABLE 4.18: DPAS-DICS Maturity Level - KPI

	DPAS-DICS Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Operation of the system without requiring to connect to the Internet (off-line)	System Check	Level 5
3	Digital Project Approval	An application ensuring inspection of natural gas domestic installations, and signing them electronically	System Check	Level 5
4	Digital Project Archive	Automatic archive of approved projects	System Check	Level 4
5	Data Transfer	Taking subscriber data over the server, processing them, and performing approval information with less than 0.1% error	Statistical Analysis	Level 4
6	Network Work Orders	Sending regulator assembly work orders to the relevant networks with less than 0.1% error over the automation system	Statistical Analysis	Level 3
7	Signature Security	Ensuring signature security of electronic signatures in digital projects with the help of registration by an accredited institution	Registration Check	Level 3
8	Transferring Project Data	Transfer of approved project data to digital gas delivery teams without any missing data	System Check	Level 3
9	Installation Check	Checking agreement and project data over the system, and creating an appointment	System Check	Level 3
10	Installation Check	Performing installation checks, and creating a work order to the Accrual Department for gas consumption monitoring of the subscriber	ERP Check	Level 2

Table 4.18: (continued)

	DPAS-DICS Characteristics	Required information	Method	Level
11	Installation Check	Checking the installation and informing to the system and the company why gas wasn't delivered to the subscriber who couldn't get approval for gas usage	System Check	Level 2
12	Installation Check	Accessing to the project archive during installation check	System Check	Level 2
13	Digital Project Software	An application ensuring performing technical drawings for natural gas domestic installations of DPAS-DICS software, and signing them	System Check	Level 1
14	Setting Up the System	Ensuring communication between DPAS-DICS systems with subscribers, accruals department, and relevant network over ERP	Process Analysis	Level 1
15	Planning the System	Preparing budget and specifications for setting up the DPAS-DICS system	Process Analysis	Level 1

DPAS - DICS system has been evaluated according to these KPIs. Maturity level of DPAS - DICS system is 8,6 out of 10 in the Istanbul. There are some improvable areas. These are top five element of the KPI list.

4.6.3 SNERGY on Natural Gas Network

Precise infrastructure design has a vital importance in modern metropolis. In this respect, Energy transmission and distribution networks are one of the most important components of energy supply. Appropriate network design is the most important condition for providing uninterrupted gas supply, which is one of the common values and targets of gas distribution companies. Network simulation and calculation programs and software realize this purpose. SNERGY system provides crucial contribution to natural gas distribution network as a component of automation systems. There are many performance criteria of SNERGY system such as duration of etc. Performance criteria are presented in Table 4.19. We choose all key performance indicators for SNERGY in natural gas distribution. We determine level of these factors by investing legislation and specification about for SNERGY.

Table 4.19: SNERGY Maturity Level - KPI

	SNERGY Characteristics	Required information	Method	Level
1	Improvement Activities	Improving the system by focusing on customers and stakeholder institutions	Process Analysis	Level 5
2	Cyber Security	Determining - compensating of system's inadequacy against cyber attack	System Check	Level 5
3	Gas Supply Priority	Designing the service network in such a way that the steel line design of the gas priority buildings is not a gas interruption	System Check	Level 4
4	Gas Supply Priority	Design of the line to provide gas to the building where continuous gas must be supplied in the gas shortage	System Check	Level 4
5	Emergency Analysis	Analysis of projects prepared for large-scale gas absence crises such as steel network damage or RMS failure	System Check	Level 4
6	Cost Reduction	Optimal design of service network design to minimize costs	System Check	Level 4
7	Service Network Design	Establishment of service network according to urban demand models	System Check	Level 3
8	Equipment Location Design	Designing the necessary installation equipment (RMS, zone regulator, Actuated Valve, etc.) according to regional requirements	System Check	Level 3
9	Risky Point Detection	The use of network data in the solution of risk points and the problem of gas supply problems	System Check	Level 3
10	Risky Point Detection	The use of network data in the solution of risk points and the problem of gas supply problems	System Check	Level 3
11	Network Optimization	Additional line and operation projects required for optimization	System Check	Level 2
12	Potential Evaluation	Assessment of potential of each building	System Check	Level 1
13	Planning the System	Preparing budget and specifications for setting up the SNERGY system	Process Analysis	Level 1

SNERGY system has been evaluated according to these KPIs. Maturity level of SNERGY system is 7 out of 10 in the Istanbul. There are some improvable areas. These are top four element of the KPI list.

Chapter 5 gives information about Results and Discussions of the study.

Chapter 5

Conclusion And Recommendations

The objective of this study is determining of maturity level of natural gas distribution companies and generating an action plan to raise maturity level of these companies. Within the scope of this study, the all necessary smart grid components, which are used in the natural gas distribution, are described by benchmarking of natural gas distribution company's field applications. These components are classified in six groups as follows:

(i) Disaster Management; ERRS and Warning Management System,

(ii) Pipeline Integrity Management; Risk Assessment System, Cathodic Protection System, and Pipeline Analysis Robot,

(iii) Installation Management; DPAS - DICS, GIS, and SNERGY,

(iv) Work Management; Workforce Management System, Building Energy Management System, and Vehicle Tracking System,

(v) Data Management; ERP, CRM, and Cyber Security System,

(vi) Flow Management; Gas Control Center, Electronic Bulletin Board System, Smart Meter and AVE systems.

We designated abilities of these systems by defining their (Key Performance Indicator) KPIs according to related legislations, specifications, and standards. These KPIs have been associated with five maturity levels. These KPIs should contain integrity of smart grids with each other, technical capability, policy and collaboration of other infrastructures with each smart grid component in next studies. Process performance is analyzed in statistical terms and is controlled throughout the life of processes. Thus, Importance weights of KPIs should be revised by smart grid experts each three years. Since

These KPIs can change depending on technological developments. These KPIs also have been associated with five maturity levels. These levels are categorized dependently the performance evaluation process which is mentioned previously. Moreover, the best gas distribution company based on the developed model is determined as well as weighting importance assessments of each system and management part have been determined by means of AHP analysis. The Company A has been designated as the best company with 78 points over 100. The ranking of the other companies is Company D, Company B, and Company C. Our calculation is presented in appendix as a summary because of the privacy in private companies.

Therefore, with the results presented in this study, smart grid maturity level of Istanbul has been used to examine in natural gas distribution. We have performed Gap analysis to show maturity level of all components. Figure 5.1 shows the result of this analysis.

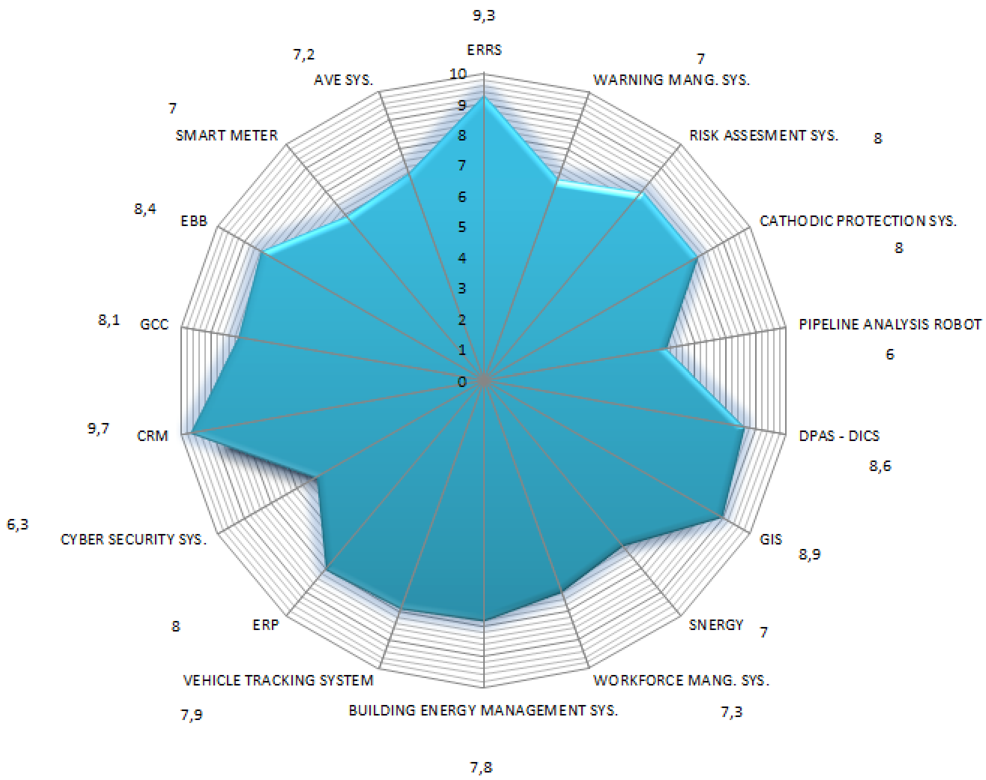

FIGURE 5.1: GAP Analysis of Smart Grid Component Maturity Level

The results of this study are explained as follows. In our sample study for Istanbul, the smart grid maturity level is found to be 78 out of 100 for the natural gas distribution. ERRS maturity level is found to be 9,3 out of 10. Warning Management System maturity level is found to be 7 out of 10. Thus, the Disaster Management maturity level is found to be 8 out of 10. There are some improvement areas. Risk Assessment System maturity level is found to be 8 out of 10. Cathodic Protection System maturity level is found to be 8 out of 10. Pipeline Analysis Robot maturity level is found to be 6 out of 10. Thus, Pipeline Integrity Management maturity level is found to be 7, out of 10. There are some improvement areas.

DPAS - DICS maturity level is found to be 8,6 out of 10. Geographic Information System maturity level is found to be 8,9 out of 10. SNERGY maturity level is found to be 7 out of 10. Thus, Installation Management maturity level is found to be 8,1 out of 10. There are some improvement areas. Workforce Management System maturity level is found to be 7,3 out of 10. Building Energy Management System maturity level is found to be 7,8 out of 10. Vehicle Tracking System maturity level is found to be 7,9 out of 10. Thus, Work Management maturity level is found to be 7,6 out of 10. There are some improvement areas.

ERP maturity level is found to be 8 out of 10. CRM maturity level is found to be 9,7 out of 10. Cyber Security System maturity level is found to be 6,3 out of 10. Thus, Data Management maturity level is found to be 8,2 out of 10. There are some improvement areas. Gas Control Center maturity level is found to be 8,1 out of 10. Electronic Bulletin Board System maturity level is found to be 8,4 out of 10. Smart Meter maturity level is found to be 7 out of 10. AVE system maturity level is found to be 7,2 out of 10. Flow Management maturity level is found to be 7,8 out of 10. There are some improvement areas.

According to results of the study, data management and cyber security are the most important fields in smart grid applications. Cyber security should be prioritized because of the huge effect on the automation system and business. Smart grid concept contains technology, innovation, information technology, hardware, and software. In this respect is a dynamic area. Thus its technological basis should be updated continuously.

Smart grid maturity level significantly affects efficiency of a firm directly. Efficiency in this subject is a criterion about profitability for gas distribution company. Every smart grid maturity level refers to more favorable asset management, service quality, efficient operation and sustainable natural gas supply. Additionally, raising the smart grid maturity level decreases the operational costs. Consequently smart gird maturity level is desired to be enhanced in all infrastructures.

In order to reduce energy consumption and ensure supply security, intelligent network applications are made randomly and unplanned due to lack of frame and road map. This study analyzes the existing networks and identifies the open areas for development and the steps for ensuring the optimum level. Smart grid market is rapidly developing and the sector requires guidance in the field of network modernization. Other result of benchmarking performed among distribution companies, is existence of unsuccessful investments in the market due to absence of roadmap.

In the future, the natural gas distribution company will be able to periodically check the intelligence of the grid with its own request and with the request of the market regulatory agencies. It will also speed up smart city design sector. All infrastructure companies will focus on similar intelligent network analysis and remediation efforts.

As a further study, infrastructure of natural gas distributors should be examined in terms of technical capability for building of smart cities. In future studies, the method presented in this study can be implemented in smart city projects. Additionally, integration of infrastructure companies, smart building projects, use of Internet of objects (IOT) technology, and use of machine-to-machine communication (M2M) technology are recommended to be added to this concept.

Appendix A

AHP calculation details

We have two goal in this study:

(1) to determine importance weights of smart grid components in natural gas distribution by means of AHP,

(2) to calculate importance weights of smart grid management parts in natural gas distribution by means of AHP,

Details of consistency calculations and pairwise comparison are presented following figures.

0,35

	PIM	AFET YÖNETİMİ	VERİ YÖNETİMİ	AKIŞ YÖNETİMİ	İŞ YÖNETİMİ	TESİSAT YÖNETİMİ
PIM	1	3	1	1	7	7
AFET YÖNETİMİ	0,333	1	0,333	1	5	3
VERİ YÖNETİMİ	1	3	1	1	7	5
AKIŞ YÖNETİMİ	1	1	1	1	5	3
İŞ YÖNETİMİ	0,142	0,2	0,142	0,2	1	0,333
TESİSAT YÖNETİMİ	0,142	0,333	0,2	0,333	3	1
TOTAL	3,617	8,533	3,675	4,533	28	19,333

COMPARISON

0,35

	PIM	AFET YÖNETİMİ	VERİ YÖNETİMİ	AKIŞ YÖNETİMİ	İŞ YÖNETİMİ	TESİSAT YÖNETİMİ
PIM	1	5	1	5	9	7
AFET YÖNETİMİ	0,2	1	0,333	3	5	3
VERİ YÖNETİMİ	1	3	1	3	5	3
AKIŞ YÖNETİMİ	0,2	3	0,333	1	5	7
İŞ YÖNETİMİ	0,111	0,2	0,2	0,2	1	0,333
TESİSAT YÖNETİMİ	0,142	0,333	0,333	0,142	3	1
TOTAL	2,653	12,533	3,199	12,342	28	21,333

The Analytic Hierarchy Process is a quantitative method for ordering and selecting decision alternatives according to multiple criteria.

FIGURE A.1: AHP calculation details-1

	PIM	AFET YÖNETİMİ	VERİ YÖNETİMİ	AKIŞ YÖNETİMİ	İŞ YÖNETİMİ	TESİSAT YÖNETİMİ	AVERAGE
PIM	0,276472215	0,351576233	0,272108844	0,220604456	0,25	0,362075208	0,288806159
AFET YÖNETİMİ	0,092065247	0,117192078	0,090612245	0,220604456	0,178571429	0,155175089	0,142370091
VERİ YÖNETİMİ	0,276472215	0,351576233	0,272108844	0,220604456	0,25	0,258625149	0,271564483
AKIŞ YÖNETİMİ	0,276472215	0,117192078	0,272108844	0,220604456	0,178571429	0,155175089	0,203354018
İŞ YÖNETİMİ	0,039259054	0,023438416	0,038639456	0,044120891	0,035714286	0,017224435	0,03306609
TESİSAT YÖNETİMİ	0,039259054	0,039024962	0,054421769	0,073461284	0,107142857	0,05172503	0,060839159
TOTAL	1	1	1	1	1	1	1

CONSISTENCY CALCULATIONS

	PIM	AFET YÖNETİMİ	VERİ YÖNETİMİ	AKIŞ YÖNETİMİ	İŞ YÖNETİMİ	TESİSAT YÖNETİMİ	AVERAGE
PIM	0,376931775	0,39894678	0,312597687	0,405120726	0,321428571	0,328130127	0,357192611
AFET YÖNETİMİ	0,075386355	0,079789356	0,10409503	0,243072436	0,178571429	0,140627197	0,136923634
VERİ YÖNETİMİ	0,376931775	0,239368068	0,312597687	0,243072436	0,178571429	0,140627197	0,248528099
AKIŞ YÖNETİMİ	0,075386355	0,239368068	0,10409503	0,081024145	0,178571429	0,328130127	0,167762526
İŞ YÖNETİMİ	0,041839427	0,015957871	0,062519537	0,016204829	0,035714286	0,015609619	0,031307595
TESİSAT YÖNETİMİ	0,053524312	0,026569856	0,10409503	0,011505429	0,107142857	0,046875732	0,058285536
TOTAL	1	1	1	1	1	1	1

FIGURE A.2: AHP calculation details-2

	DGAS&DPOS	SNERGY	GIS
DGAS&DPOS	1	1	0,333
SNERGY	1	1	0,333
GIS	3	3	1
TOTAL	5	5	1,666

	DGAS&DPOS	SNERGY	GIS	AVERAGE
DGAS&DPOS	0,2	0,2	0,199879952	0,199959984
SNERGY	0,2	0,2	0,199879952	0,199959984
GIS	0,6	0,6	0,600240096	0,600080032
TOTAL	1	1	1	1

	WFM	VTS	BEMS
WFM	1	7	5
VTS	0,14	1	0,333
BEMS	0,20	3	1
TOTAL	1,342857143	11	6,333

	WFM	VTS	BEMS	AVERAGE
WFM	0,744680851	0,636364	0,789515238	0,723519908
VTS	0,11	0,09	0,05	0,083291261
BEMS	0,14893617	0,272727	0,157903048	0,19318883
TOTAL	1	1	1	1

	ERP	CRM	CSS
ERP	1	5	1
CRM	0,2	1	0,142
CSS	1	7	1
TOTAL	2,2	13	2,142

	ERP	CRM	CSS	AVERAGE
ERP	0,454545455	0,384615	0,466853408	0,435338082
CRM	0,090909091	0,076923	0,066293184	0,078041784
CSS	0,454545455	0,538462	0,466853408	0,486620134
TOTAL	1	1	1	1

	SMART METER	FCC	EBT	AVE
SMART METER	1	0,2	0,333	3
FCC	5	1	5	5
EBT	3	0,2	1	3
AVE	0,333	0,2	0,333	1
TOTAL	9,333	1,6	6,666	12

	SMART METER	FCC	EBT	AVE	AVERAGE
SMART METER	0,107146684	0,125	0,049954995	0,25	0,13302542
FCC	0,535733419	0,625	0,750075008	0,416666667	0,581868773
EBT	0,321440051	0,125	0,150015002	0,25	0,211613763
AVE	0,035679846	0,125	0,049954995	0,083333333	0,073492044
TOTAL	1	1	1	1	1

Figure A.3: AHP calculation details-3

		Weight	Points out of 10
RISK MAGAMENT SYSTEM	0,098	9,8	8
CATHODIC PROTECTION SYSTEM	0,098	9,8	8
PIPELINE ANALYSIS ROBOT	0,098	9,8	6
ERRS	0,110	11,0	9,3
WMS	0,037	3,7	7
DPAS&DICS	0,016	1,6	8,6
SNERGY	0,016	1,6	7
GIS	0,048	4,8	8,9
WMS	0,027	2,7	7,3
VTS	0,003	0,3	7,9
BEMS	0,007	0,7	7,8
ERP	0,105	10,5	8
CRM	0,019	1,9	9,7
SMART METER	0,027	2,7	7
GCC	0,117	11,7	8,1
EBB	0,042	4,2	8,4
AVE	0,015	1,5	7,2
CSS	0,117	11,7	6,3
TOPLAM	1	100	774,8333964
		Total Points (Out of 100)	77,5

Figure A.4: AHP calculation details-4

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