RISK ASSESSMENT OF PETROLEUM TRANSPORTATION PIPELINE IN SOME TURKISH OIL FIELDS

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Approval of the Graduate School of Natural and Applied Sciences.

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I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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ABSTRACT

RISK ASSESSMENT OF PETROLEUM TRANSPORATION PIPELINE IN SOME TURKISH OIL FIELDS

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In this thesis, quantitative risk assessment study of several oil field transportation lines that belong to a private oil production company located in S. East Turkey has been conducted. In order to achieve this goal, first primary risk drivers were identified. Then relative ranking of all pipeline segments were conducted. Quantitative risk assessment was based on Monte Carlo simulations and a relative scoring index approach. In these simulations frequency of occurrence of pipeline failures for different oil field pipeline systems was used. Consequences of failures were also based on historical data gathered from the same oil fields. Results of corrosion rate calculations in oil and water pipeline systems were also reported.

Most significant failures are identified as corrosion, third party damage, mechanical failure, operational failure, weather effect and sabotage. It was suggested that in order to reduce corrosion rate, thin metal sheets must be inserted in pipelines. Aluminum sheets (anodes) must be used to reduce corrosion rate in water pipeline system. The required number of anodes was calculated as 266 for BE field water pipeline (the life of anode is 1.28 years), 959 for KA water pipelines system (the life of anode is 3.2 years.) and 992 for KW water pipelines (the life of anode is approximately 2 years). Furthermore high risk pipeline segments for further assessment were identified. As a result of Monte Carlo simulations, the highest risk was observed in return lines followed by flow lines, water lines and trunk lines. The most risky field was field BE for which the risk value in trunk lines were the highest followed by flow lines. Field SA was the second risky region for flow lines and it was followed by KU region. Field KA was forth-risky. Prioritization of maintenance activities was suggested and areas of missing or incomplete data were identified.

Keywords: risk assessment, quantitative risk analysis, corrosion, third party damage, mechanical and operational failure, Monte Carlo Simulation.

ÖZ

SEÇİLMİŞ TÜRK PETROL SAHALARINDAKİ PETROL BORU HATLARININ RİSK ANALİZİ

Öğütçü , Gökçen
Yüksek Lisans, Petrol ve Doğalgaz Mühendisliği Bölümü

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Bu tezde, Türkiye'nin güneydoğu bölgesinde özel bir petrol şirketine ait olan farklı petrol sahalarındaki petrol boru hatlarıyla ilgili olarak kantitatif risk analizi çalışması yapıldı. Bu amaca ulaşmak için, ilk olarak temel risk nedenleri belirlendi. Sonra, bütün boru hattı kısımlarına göreceli olarak değerler verildi. Kantitatif risk analizi Monte Carlo Simulasyonu, göreceli puanlama yöntemine bağlıdır. Bu simulasyonlarda, farklı petrol sahalarının boru hattı sistemi hatalarının oluşma olasılıkları kullanıldı. Bazı petrol sahaları için toplanılan tarihsel boru hattı verilerine bağlı olarak, hata sonuçları ayrıca kaydedilmiştir. Petrol ve su boru hatları korozyon hızı hesabı sonuçları da kaydedilmiştir.

En belirgin hatalar korozyon, üçüncü taraf hataları, mekanik hatalar,operasyon hataları ,havanın etkisi ve sabotaj olarak belirlendi. Korozyon hızını düşürmek için boruların içine ince metal tabakaların yerleştirilmesi önerildi. Su borularında korozyonu önlemek için aluminyum tabakaların (anot) kullanılması gerekli olduğu vurgulandı. BE sahası su hatları için gerekli anot sayısı 266 (anot süresi 1.28 yıl), KA sahası su boruları için 959 (anot süresi 3.2 yıl) ve KW sahası su hatları için 992 (anot süresi yaklaşık 2 yıl) olarak belirlendi. Monte Carlo benzetimleri sonucunda en yüksek riskin dönüş hatlarında oluştuğu ve akış hatları, su hatları ve ana hatlar tarafından takip edildiği görüldü. En yüksek riske sahip olan BE sahasında en riskli bölgelerin ana hatlar ve akış hatları olduğu gözlemlendi. SA sahası akış hatları ile ikinci yüksek riskli saha olarak bulundu. KU sahası ve KA sahaları sıralamada üçüncü ve dördüncü yüksek riskli saha olarak belirlendi. Ayrıca öncelikli bakım faaliyetleri önerildi ve gözden kaçan yerler veya eksik veriler belirlendi. Yüksek riskli bölgeler daha sonraki çalışmalar için tanımlandı.

Anahtar kelimeler: risk analizi, kantitatif risk analizi, korozyon, üçüncü taraf hataları, mekanik ve operasyonel hatalar, Monte Carlo Simulasyonu.

To My Family

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LIST OF SYMBOLS

a	Mean,min
b	Standard deviation, most likely, mode
c	Maximum
R	Risk
P	Probability
F	Frequency
Vcor	Corrosion rate in crude oil lines, mm/year
Re	Reynolds number
Yt	CO_2 mol fraction in gas phase at room temperature and pressure
P	Pressure, psi
T	Operating Temperature, K^0
I	Water Ionic strength, molar
U	Liquid flow rate,m/s
d	The hydraulic diameter, m
Vreact	The phase boundary reaction rate, mm/year
F_{pH}	pH correction factor
Fg	Fugacity of CO_2 gas @ specified temperature& pressure
SIc	Precipitation
CDF	Cumulative distribution function
H	Henry's Constant
Bo/d	Produced oil, bpd
QRA	Quantitative risk analysis
Bw/d	Produced water, bpd
K_1	First ionization constant of carbonic acid
fg	Fugacity of CO_2
p CO_2	Partial Pressure of CO_2, psi
Yg	Mol fraction of CO_2
DOE	Department of Energy
LHS	Latin Hypercube Sampling
LHC	Latin Hypercube
v	Kinematic viscosity, cp
D	Diffusion coefficient
V mass	Mass transfer rate through the boundary layer
pH_{act}	Actual pH of solution
pH_{sat}	$FeCO_3$ or Fe_3O_4 at saturation in solution

CHAPTER 1

INTRODUCTION

Today, oil and natural gas usage represents about 40% and 24% of world energy consumption respectively [5]. Petroleum and natural gas will still be the most important energy source in the near future. On the other hand, petroleum and natural gas reserves are not equally distributed all over the world. For example, although, Middle East and Asia have the largest petroleum reserves, Europe has poor petroleum and natural gas reserves. So in order to meet their energy demand, countries need to transfer energy resources from other countries, which have large petroleum and natural gas reservoirs. Petroleum and natural gas could be transported with ships, tankers or pipelines. If pipeline systems are compared with other alternatives, it is obvious that pipelines are the safest alternative because of lower oil spill rate and lower failure rate. As a result, the use of natural gas and petroleum pipeline network systems is increasing to meet energy demand of countries. On the other hand, pipeline systems are very expensive and also they are considered to operate for a long time securely. Because of these reasons, companies and countries have been implementing extra procedure to monitor safety management systems. All efforts are to reduce the frequency of accidents and failures. In order to tackle pipeline security and reduce failures, risk reduction methods have been developed.

All crude oil and natural gas transportation processes, regardless of their nature, involve an element of risk, defined as the probability of occurrence of an event, and the consequences of the event. Regardless of design criteria, pipelines may always have a certain level of risk due to the operating conditions, design, and environment. The concept of risk is not new. Its application has been extended from the stock market to maintenance and reliability programs for plants, equipment, and, ultimately, pipelines. The first documented industrial application of risk management occurred in the late 1980s since then, risk-based management (RBM) has grown rapidly to become a valuable tool for engineers, designers and operators. One of the greatest pitfalls of an RBM-type methodology for pipelines is the lack of accurate data to quantify risks. This lack of data is exacerbated by the fact that most lines operate safely in a number of conditions, and have low expected failure frequencies. Muhlbauer [2] proposed a commercially available pipeline risk management methodologies that relies on algorithm based risk estimation, aided by a semi-quantitative index measurement. More recently, a number of approaches that vary in their means of risk estimation, some in terms of qualitative versus quantitative approach; others by product transported have been proposed and developed some of which are proprietary in nature [3 – 6]. Even in a qualitative approach, some quantification is performed, since the scale for measurement tends to be less precise. In this study, quantitative risk assessment study of several oil field transportation lines located in S. East Turkey has been conducted using Monte Carlo simulations.

Field data are vital to evaluate risk factors. The failure analysis depends on historical field data. Such data could be obtained from maintenance records, construction documents, design documents, employee interviews, expert testimonies and inspection of facilities. Pipeline data must be composed of age of pipeline, pipeline material specifications, minimum depth cover, river, road crossing, coating type, welding requirements, minimum and maximum pressures and potential earth movement.

In this study, historical data, which includes the reason of failures and repair remarks 199 cases over 4 years, was grouped according to available information (location of failure, reason of failure, transported liquid type etc.) After that, failures and frequency of failure were identified. At this framework, risk was defined as product of probability of occurrence and frequency of failure [1]. Frequency of failure was calculated by dividing event number to length of pipelines times year. Probability of pipeline failures was calculated by normal and triangular distribution. In order to find maximum, minimum and most likely values of triangular distribution, relative risk scoring method was carried out. Relative risk scoring value was calculated based on repair cost obtained using typical repair costs valid in Turkey. Choosing triangular and normal distributions for each input variable conducted sensitivity analysis so that different scenarios were created in Monte Carlo Simulations. As a result, most risky pipeline segments and regions were identified.

CHAPTER 2

LITERATURE SURVEY

2.1. What Is Risk?

Risk is defined as the probability of an event that causes a loss and the magnitude of that loss [1]. Risk is also defined as potential variation in outcome. If prediction of outcome is not exact, uncertainty occurs. Risk consists of probability and frequency. Risk also includes uncertainty and loss.

2.1.1. Developing a Risk Assessment Model

Risk analysis (or risk assessment) estimates the probability of occurrence of an event. Risk assessment of petroleum pipeline consists of field data, the failure parameters, consequences and the output risk calculations. Figure 2.1 shows the risk assessment program procedure. While developing risk assessment model, risk reduction projects are also considered. Case studies must be done to evaluate risk consequences.

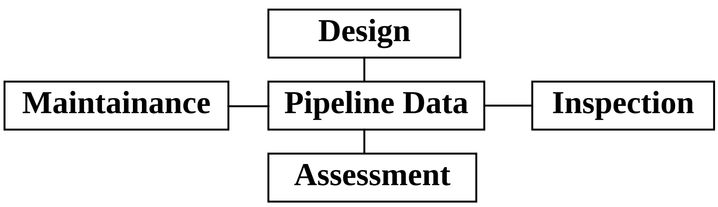

Figure 2.1. Risk Assessment Life Cycle [11]

Figure 2.2 indicates that risk assessment procedure, which was applied in this thesis. Risk analysis was started with data analysis, which is the most critical part of this study. This section was completed by pipeline sectioning procedure. Then, the best suitable risk analysis method was chosen as quantitative risk analysis model. Quantitative risk analysis model consists of risk factor determination and statistical analysis that is composed of choosing probability functions. Last part of the study gives sensitivity analysis conducted using Monte Carlo simulation.

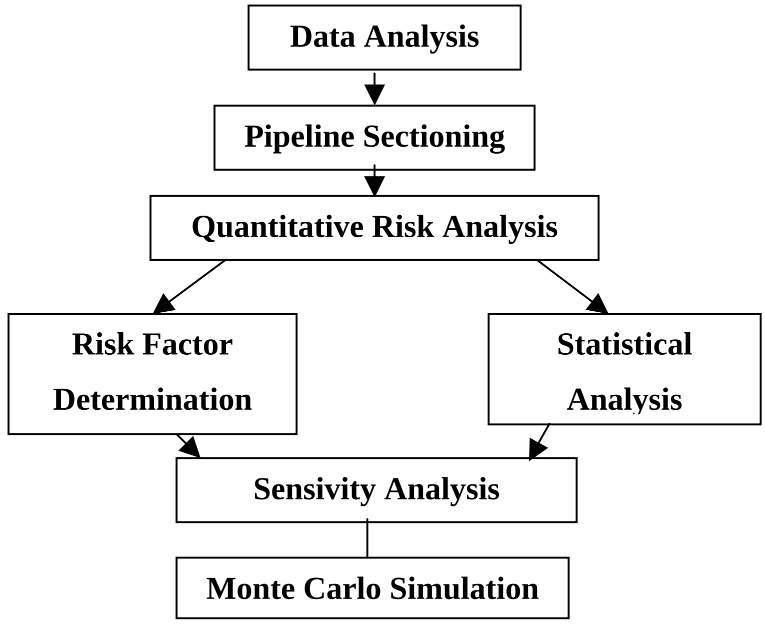

Figure 2.2. Risk Assessment Procedure

2.1.1.1. Pipeline Data Analysis

Risk assessment model must consider all failure data in the pipeline system. In order to develop an effective risk assessment model, data analysis must be carried out carefully because many questions can be answered by data analysis. Furthermore, relationship between all parameters must be identified. Pipeline physical condition and historical data must be checked.

Data can be provided from in line inspection tools, company's operation records depth of cover data, leak history, maintenance reports, cathotic protection data and pipeline repair data. Inline inspection tools or smart pigs are magnetic flux leakage tool, gauging tool, camera tools, and ultrasonic inspection tools [1]. These survey tools give information about change in pipeline wall thickness and pipeline abnormalities. Gauging tools are very useful to measure diameter of the pipe and change in diameter dents. Camera tool takes photos of the inside of the pipe when corrosion pits are located. Magnetic flux leakage tools, which contain permanent magnet, measure metal loss due to corrosion. The flux is contained in the pipe wall, as no defects exist. Ultrasonic inspection tool use a pulse echo techniques to measure metal loss caused by corrosion or damage.

2.1.1.2. Pipeline Inspection and Maintenance

Pipeline inspection provides pipeline integrity. Pipeline inspection is the most important parameter for pipeline integrity. The purpose of test and inspect the pipeline system is to ensure pipeline integrity. Pipeline inspection must be done frequently or defined periods. Pipeline inspection and testing provides to find defect or other abnormal condition in pipeline system so that it reduces possible risk factors. Inline inspection tools, smart pigs and also hydrostatic test are useful pipeline inspection methods. Smart pigs are electronic devices that travel inside the pipeline system and gives information about pipeline wall condition

Certain defects can be found by applying hydrostatic test. Hydrostatic test also gives information about pipeline ability at operating specified operating pressure. Hydrostatic testing is applied by filling pipeline with water and then, pressure is increased for a minimum of 4 hours. Hydrostatic test is higher than usually 1.25 times of maximum operating pressure (MOP) to allow for a safety margin.

2.2. Risk Evaluations

Risk evaluation is the judgment of the significance of the assessed risks and risk-benefit analysis [12]. Risk identification procedure is composed of source of risk identification, hazard identification, history matching (frequency, identification of critical factors, and probability of density function) and case study. Risk evaluation procedure also is included risk assessment application.

2.3. Risk Modeling

After evaluating the risk factors, risk model must be defined. It is important that the degree of risk is based on not only the probability of failure but also the outcome for each failure. So, an effective risk model must answer three important questions. These are:

1. How likely is it?
2. What can go wrong?
3. What is the impact?

In a conclusion, risk can be formulated as;

Risk = Frequency * Probability [2.3]

Equation 2.3.1 can be modified as follows;

$$R_{\text{(risk of crude oil pipeline/km yr)}} = P_{\text{(failure due to corrosion/km/yr)}} * \text{Frequency}_{\text{corrosion}} + P_{\text{(failure due to 3rd party /km/yr)}} * \text{Frequency}_{\text{3rd party}} + P_{\text{(failure due to mechanical failure /km/yr)}} * \text{Frequency}_{\text{mechanical failure}} + P_{\text{(failure due to operational failure /km/yr)}} * \text{Frequency}_{\text{operational failure}} + P_{\text{(failure due to weather effect /km/yr)}} * \text{Frequency}_{\text{weather effect}} \quad [2.3.1]$$

2.3.1. Frequency Analysis and Selection of Distribution Functions

Frequency depends on pipeline length, event number at a given time and length interval so that frequency can be calculated by;

Frequency, F, = number of event / (km * year) [2.3.1.1]

Historical data, which includes repair remarks, has been counted according to pipeline type for each field so that number of event was easily identified. Failure rates also were found in this calculation.

Selection of distribution function was carried out by U. S. Department of Energy's (DOE) risk analysis and decision-making software program.

2.3.1.1. DOE Risk Analysis and Decision Making Software

In this thesis, U.S. Department of Energy's (DOE) risk analysis and decision-making software (1997 version) have been used in order to find best distribution probability functions and to apply Monte Carlo simulation. This software is very helpful for exploration and production risk analysis and decision-making. The 1997 version of the software package consists of the following software:

1. Investment risk (Gambler's ruin) analysis
2. Monte Carlo simulation
3. Best fit for distribution functions
4. Sample and rank correlation
5. Enhanced oil recovery method screening
6. Artificial neural network

2.3.1.2. Best Fit for Distribution Functions

The DOE software program consists of sample data and probability density data. Sample data analysis is run to find the probability density distributions of physical measurements. Sample data uses statistical analysis on a set of measured or sampled data for a variable.

While determining probability distribution functions, it is better to overview some statistical concepts such as the average, variance, and standard deviation. Probability density data program provides the best fitted functions. The characteristics of probability such as median and mean are determined by probability density data part. Number of data points, maximum and minimum points were given and then, probability of density function was selected. Initial guesses for parameters were assumed as a, b and c. Then, distribution parameters were evaluated by the running program more than one. These parameters (a,b,c) are very helpful to calculate mean median and standard deviation of distribution function. Later, these parameters were used in Monte Carlo Application.

The program includes the following distribution functions that includes distribution parameters :

1. Beta Distribuiton Function (a, b)
2. Exponential Distribuiton Function (a)
3. Gamma Distribuiton Function (a, b)
4. Geometric Distribuiton Function (a, b)
5. Lognormal Distribuiton Function (a, b)
6. Normal Distribuiton Function (a, b)
7. Triangular Distribuiton Function (a, b, c)

The most suitable distribution functions were chosen as triangular and normal distribution functions.

2.3.1.3. Normal Distribution Functions

Normal distribution is observed as a bell-shaped curve. Density function of normal distribution is;

$$f(x) = \frac{1}{\sqrt{2\pi b^2}} \exp[-\frac{(x-a)^2}{2b^2}] \qquad [2.3.1.3.1]$$

Where: a and b is higher than 0 and -∞ < x > ∞

a is the mean and mode b^2 is variance.

2.3.1.4. Triangular Distribution Functions

Parameters of triangular distribution are a, b and c where a is the minimum value, b is the most likely value and c is the maximum value of triangular distribution. Density function of triangular distribution is given as:

$$f(x) = \frac{2(x-a)}{(b-a)(c-a)} \qquad \text{If } a \le x \le b \qquad [2.3.1.4.1]$$

$$f(x) = \frac{2(c-x)}{(c-a)(c-b)} \qquad \text{If } b < x \le c \qquad [2.3.1.4.2]$$

Cumulative distribution can be calculated by;

P (x) is 0 when $x < a$ and also if an ≤ x ≤ b P (x) is calculated by;

$$F(x) = \frac{(x-a)^2}{(b-a)(c-a)} \qquad [2.3.1.4.3]$$

In addition, if b < x ≤ c P (x) is calculated by

$$F(x) = 1 - \frac{(c-x)^2}{(c-a)(c-b)} \qquad [2.3.1.4.4]$$

P (x) is equal to 1 when c < x

Mean: $(a+ b+ c) / 3$ [2.3.1.4.5]

Mode: b

Variance: $$\frac{a^2 + b^2 + c^2 - ab - ac - bc}{18}$$ [2.3.1.4.6]

2.3.2. Quantitative Risk Analysis

Quantitative risk analysis is based on statistical calculations. Quantitative risk analysis applies probability distribution to model each uncertainty so that the effect of various uncertainties can be evaluated with possible outcome.

Sensitivity analysis is done by choosing different combinations for each input variables so that different scenarios are created by quantitative risk analysis with the application of Monte Carlo simulation.

2.3.3. Monte Carlo Simulation

In this study, risk evaluation was started with data analysis. First of all, statistical methods were performed to find defect populations. Furthermore, Monte Carlo simulation was applied. Monte Carlo (MC) simulation is very useful for computing the large numbers of the distributions. MC simulation provides to create probability distributions meanwhile input variables are assumed as independent parameters. This computational method provides distribution of the output and estimates the expectation of outcomes so that some characteristic of probability can be clarified such as median, mean. This type of measurement is very important to analyze central tendency and variation measurements. This technique involves the random sampling of each probability distribution within the model to produce hundreds or even thousands of scenarios. Each probability distribution is sampled in a manner that reproduces the distribution's shape. [18]
Monte Carlo includes expectations and input parameters.

In this study, corrosion, third party damage, mechanical and operational failure and weather effect was found as pipeline failure reasons. Each probability of these risk factors within the model was used in Monte Carlo simulation so that sensitivity analysis was completed.

CHAPTER 3

3.1. Corrosion

Corrosion is a risk factor for pipeline system because it causes leaks and also pipelines wall thickness reduction. Corrosion occurs due to tendency of metals to combine with oxygen, sulphur and other metals. Two different places on metals provide electric current due to different electrochemical potential.

Corrosion is electrochemical reaction and so, corrosion of steel pipelines can result from the flow of electrical current between areas of different electric potential.

Higher potential = anode (corroded), oxidation

Lower potential = cathode (no corroded), reduction

These reactions can be represented as,

Fe ----------> Fe^{++} + 2e-(Anodic reaction)

H_2CO_3 + e-----> HCO_3^- + H (Cathodic reaction)

The overall corrosion reaction can be represented as,

$Fe + 2H_2CO_3$ ---> $Fe^{++} + 2\ HCO_3- + H_2$

The corrosion rate between two electrodes depends on:

a) Soil resistivity: temperature, moisture content and the concentration of ionized salts affect negatively soil resistivity. When soil resistvity is low, conductivity of soil is high, so corrosion rate is high.
b) Separation between anode and cathode: corrosion rate is higher when distance between anode and cathode is lower.
c) Anode and cathode polarization
d) Relative surface areas of cathode and anode: the depth of corrosion on the anode affects negatively anode area. [1]

Material type and environment are very important for corrosion rate, so each type of environment condition, where pipeline system is passing, must be considered carefully. Corrosion rate can be reduced or prevented if a corrosive environment is recognized.

Corrosion can be discussed under three main topics;

- External Corrosion
- Atmospheric Corrosion
- Internal Corrosion

3.1.1.Atmospheric Corrosion

Atmospheric corrosion occurs when pipeline material reacts with atmosphere. As a result of this reaction oxidation of metal starts. Atmosphere type affects atmospheric corrosion. Chemical composition, humidity and temperature of air are vital variable for atmospheric corrosion. If the pipeline is isolated from outside external corrosion can be reduced. Coating can provide this. Coating type, coating application, inspection program are other important parameters to reduce atmospheric corrosion rate.

3.1.2. External Corrosion

External corrosion occurs outside of pipeline system. External corrosion is mostly related with cathotic protection, pipeline coating type, soil corrosivity and age of system. Soil behaves like electrolyte. Thus, soil resistivity and moisture affects corrosion current.

3.1.3. Internal Corrosion

Internal corrosion is a reaction between inside of pipeline wall and transported products. Internal corrosion depends on composition of petroleum.

Carbon dioxide and H_2S, which dissolve in water, corrodes steel.

$CO_2 + H_2O = H_2CO_3$ (Carbonic Acid)

$Fe^0 + H_2CO_3 = FeCO_3 + H_2$ (Iron Carbonate)

H_2S and acetic acid causes increase in corrosion rate. H_2S promotes corrosive environment in pipeline system. The action in steel is;

$Fe^0 + H_2S + \text{moisture} = FeS + H_2^0$

Hydrogen atoms tend to react with each other and to form hydrogen molecule. Hydrogen molecules provide extra pressure to the pipeline system. As a result of this extra pressure, yield strength and ductility of material changes and pipeline system can be damaged.

Oxygen leads to corrosion. In water injection systems, if oxygen is present in the system, which leads to an increase in corrosion rate. Internal corrosion rate also depends on pH value. If pH value in pipeline decreases, corrosion rate increases. Thus if bicarbonate rate is high, pH decreases and reverse trend is shown on corrosion rate. Parameter, which affects corrosion rate, is shown in Table 3.1. [3]

Table 3.1. Corrosion Parameters

Parameter	Effect
CO_2 Partial Pressure	CO_2 is an "acid gas" and results in a decreased pH which accelerates corrosion; it also facilitates formulation of protective carbonate film on steel at high temperature.
H_2S Partial Pressure	H_2S is an "acid gas" and results in a decreased pH which accelerates corrosion; protective sulphide

	films reduce CO_2 corrosion rate at low temperatures, but prevents carbonate film protection at high temperatures.
CO_2 / H_2S ratio	This partial pressure ratio indicates the predominant corrosion mechanism; values greater than 200 indicate CO_2 corrosion tendencies and those less than 200 indicate H_2S corrosion tendency.
Chloride	Found in formation water, chloride ions promote breakdown of normally protective films and promote localized versus general corrosion. Chloride can also affect solubility of inhibitions at high concentrations.
Bicarbonate	Found in formation water, bicarbonate ions increase solution pH and decrease corrosivity.
Temperature	Combines with other variables to determine stability of protective corrosion films; promotes increased aggressiveness of chlorides at high temperatures.
Velocity	In multiphase (oil water gas) systems, produce shear stress on metal surface that can remove protective corrosion films; various flow regimes can promote/limit effective inhibition.
Gas/oil ratio	Gas/oil ratio determines if oil or gas phases will dominate system; systems with low GOR tend to be less corrosive due to protection from oil phase.
Water content	In gas wells this is given a water/gas ratio and oil wells, it is referred to as water cut. Corrosivity decreases with decreasing amount of free water.
Dew Point	Above the dew point, water is only in the vapor phase, which greatly reduces corrosivity.
Oil type	The liquid hydrocarbon depending on its composition and gravity; may show varying degrees

of protectiveness and wettability on the steel surface; determines critical amount of water to produce corrosive conditions.

3.2. Corrosion Control

Electric current flows between anode and cathode, so if anodic and cathodic reaction is stopped, corrosion can be reduced. Corrosion can be reduced but cannot be stopped. If corrosion rate is known, corrosion control can be conducted easily. The rate of corrosion is controlled by safety precautions and environment considerations.

There are many ways to reduce corrosion [1]. These are;

1. Material selection,
2. Engineering design,
3. Inhibitors,
4. Coatings,
5. Cathotic protection.

3.2.1. Material Selection and Engineering Design

Pipeline design is vital to reduce pipeline risk. Material selection must be done correctly to reduce risk factors such as corrosion. Parameters like weather condition, soil type, etc must be considered when material selection application continues. Metals are selected at the framework of corrosion environment and physical requirements, so identification of soil type also reduces corrosion effect.

Furthermore, stream and road crossing is the most critical locations in pipeline system while design pipeline system and also laying stress calculations, buckling and collapse resistance, pump and compressor horsepower must be done before construction of pipelines.

3.2.2. Inhibitors

Inhibitors are organic or inorganic chemicals, which are applied to reduce or prevent corrosion in the petroleum production systems. Inhibitors form a film on the metal surface so that it provides to raise metal resistance. Meanwhile, efficiency of inhibitors depends on concentration of inhibitors, contact time.

3.2.3. Pipeline Coating

Coatings prevent the metals form corrosive environment. Coatings isolate metal from environment so that corrosion current is eliminated. Pipeline coatings can be discussed under two main topics. One of them is organic coating and the other one is inorganic coating.

Organic coatings are paints and bituminous coating
Inorganic coatings are polietilen and PVC

High softening paints coal tar and asphalt enamels, coal tar enamels (in water lines), cold applied tapes and hot applied plastic base coatings, polyethylene, asphalt mastics are also used as coating.

A coal tar enamel coating is mostly applied at tank bottom. Cold applied tapes and hot applied tapes are used in the joints.

The quality of the coating, the coating application, coating thickness, effectiveness of inspection programs are important parameter for the effectiveness of coating system.

3.2.4. Cathodic Protection

Cathodic protection systems are based on electric current. Corrosion current occurs because of electrochemical potential differences between two different metals when they installed in the same electrolyte. A current must be provided between the metal structure and the new anode. This new anode causes to current flow in the opposite direction. It is important that cathotic voltage must be at least 850 MV according to NACE standard. [1].

850 MV is between the structure and $Cu/CuSO_4$ reference electrode. There are two types of protection [1].

a) Galvanic Cathodic Protection: In a cathotic system more active metal are installed in pipeline system and more active metal behaves as anode. In fact, metals, which have higher electrical potential, have higher tendency to corrode so that electrical current is made to flow between the pipe and the anodes though the soil. The pipeline becomes the cathode of the system and its corrosion is decreased. This method is also called as **sacrificial cathodic protection.** In conclusion, the more active metals are corroded and less active metals are protected from corrosion. Metals like magnesium, zinc or aluminum are generally used as sacrificial anodes. Sacrificial cathodic protection is applied in low resistivity environment. Although it is easy to install the system, coating must support this system and also, too many anodes are needed. Figure 3.1 shows sacrificial anode.

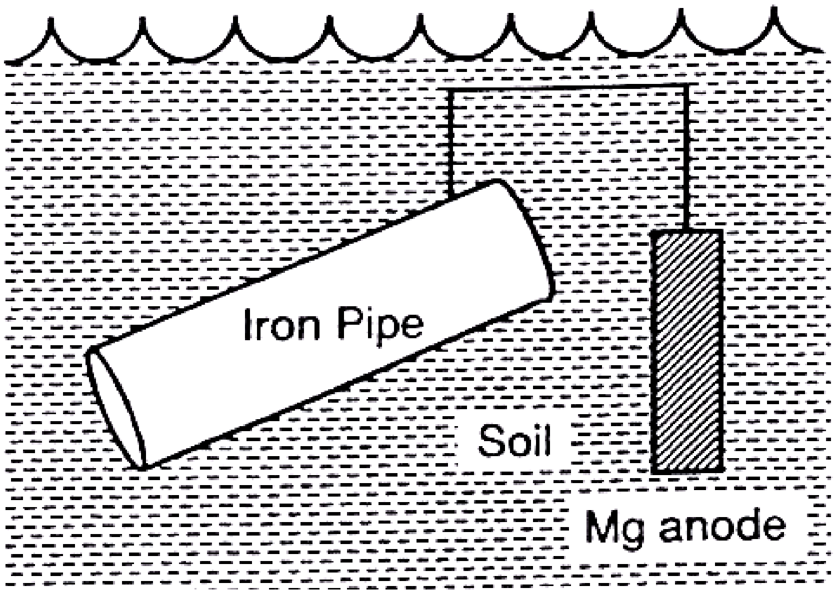

Figure 3.1. Sacrificial Anode [20]

b) Impressed Cathodic Protection: Impressed Cathodic Protection can be provided by applying Direct current (DC) current to the system. DC flows from installed anode to the structure. This method is called impressed current cathotic protection. Generators, battery, solar cell is used as power supply in the circuit. The rectifier supplies electron to the system. This causes to change iron form anode to cathode. Impressed cathotic protection is applied in high resistivity environment. It is difficult to install the system but it is useful all kinds of system. It means that it can be installed in bad coating conditions. In addition, unlike Galvanic cathodic protection, small amount of anodes is needed.

Measurement of cathodic protection voltage potentials help to identify the accuracy of cathodic protection. In general, a copper-copper sulphate accepted a reference electrode for cathodic protection pipe to soil voltage readings. It is -0.85 volts at the pipe to electrolyte boundary. In cathodic protection potentials, the low readings show coating problems or other problems in corrosion prevention systems. Figure 3.2 refers to impressed current diagram.

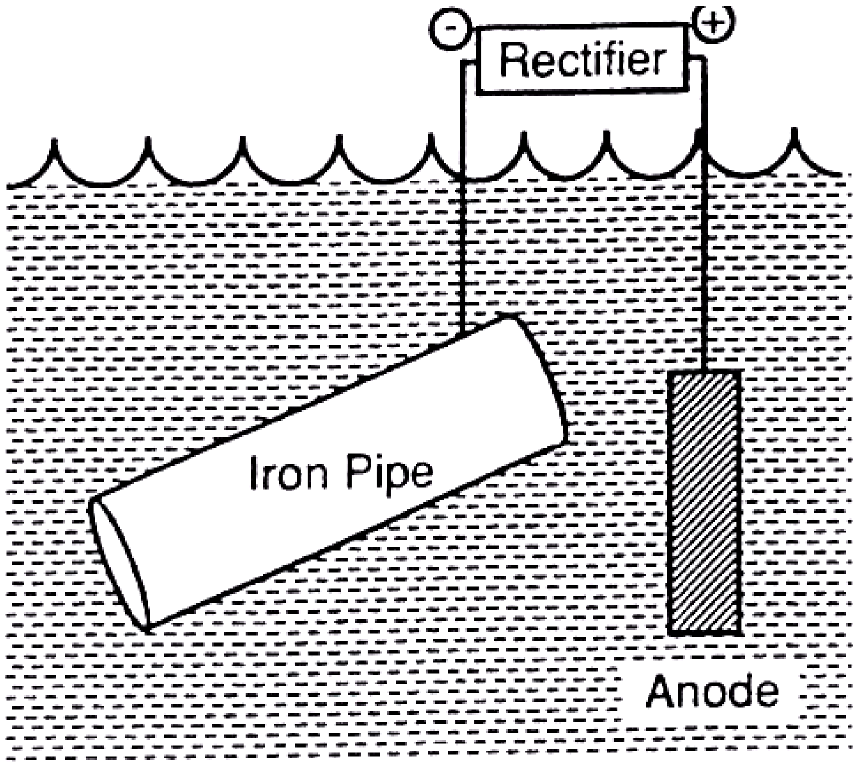

Figure 3.2. Impressed Current Diagram [20]

3.3. Estimation of Corrosion Rate

In order to estimate operation life of pipeline and also risk factors, corrosion rate must be calculated. When corrosion rate of system is known, it is easy to control corrosion rate and also protect the pipeline, in case of estimation of corrosion risk in the pipeline system, corrosion rate was clarified.

3.3.1. Corrosion Rate Calculations in Crude Oil Pipeline

In this pipeline system internal corrosion was observed and this result was also supported by companies repair reports. Shape of corrosion crack was helpful to identify internal corrosion.

CO_2, O_2, H_2S, and SO_2 cause internal corrosion. On the other hand, it is assumed that if there is no O_2 entrance in the system and also, if O_2 is lower than

20 ppm, corrosivity due to O_2 can be neglected [7]. Likewise, if SO_2 is lower 50 ppm, corrosivity of SO_2 can be neglected [7]. Thus, in such cases only CO_2 corrosivity needs to be estimated. However, while calculating of CO_2 corrosivity, SO_2 amount effect in the system has to be considered using Oddo Thomson and de Waard Lotz method.

In order to calculate corrosion rate some assumptions must be made for analyzing corrosion. These are;

Oddo Thomson and De Waard and Lotz formula is

$$Vcor = \frac{1}{\frac{1}{cVmass} + \frac{1}{Vreact}} \qquad [3.3.1.1]$$

Vmass is the mass transfer rate though the boundary layer and V react is the phase boundary reaction rate.

$$c = Re^2 + 2.62 \times 10^6 \qquad [3.3.1.2]$$

c is the constant, which depends on square of Re number.

$$\text{Log (V react)} = 5.8 - (1710/T) + 0{,}67\log(P_{CO2}) \qquad [3.3.1.3]$$

V react is the phase boundary reaction rate.

F_{pH} is pH correction factor, whose effect must be considered for corrosion calculation because higher pH value means lower corrosion rate in the system.

$$\log F_{pH} = 0{,}32\,(pH_{sat} - pH_{act}) \qquad [3.3.1.4]$$

In addition, pH_{sat} shows saturation of $FeCO_3$ or Fe_3O_4 in the solution. It is important that higher pH value means lower corrosion rate, so it must be considered. pH depends on corrosion product, so De Waard Lotz uses correction factors in order to pH physical and chemical effects in the system [6]. pH_{sat} is also found from;

$pH_{sat} = 5{,}4 - 0{,}66 \log (fg * P(B)_{CO2})$ [3.3.1.5]

pH correction factor can be found form ;

$\log F_{pH} = 0{,}32 \, (pH_{sat} - pH_{act})$ [3.3.1.6]

pH_{sat} is also found from;

Where pH act = measured pH value

In order to calculate CO_2 corrosion rate, partial pressure of CO_2 must be considered. Partial pressure of it can be calculated form

$(P_{CO2}) = (CO_2 \text{ mol percent}) * (\text{Total Gas Pressure})$ [3.3.1.7]

Concentration of CO_2 can be calculated by;

$(CO_2) = H^* (P_{CO2})$ [3.3.1.8]

H shows Henry Constant and it is calculated by

$\text{LogH} = 2.238 + 6{,}348E^{-3}(T) - 9{,}972E^{-6}(T^2) + 1{,}234E^{-5}(P) + 6{,}58E^{-2}(I^{0,5}) - 3{,}3E^{-2}(I) + 4{,}79E^{-2}(I^{1,5}) + 1{,}596\,E^{-4}(T)(I^{0,5})$ [3.3.1.9]

T, F^0, is temperature of system and P, psi, is the pressure of the system I refers to ionic strength of water and Ionic strength can be calculated from;

$I = \frac{1}{2} [(Ca)*4 + (Mg)*4 + (Fe)*4 + CIx1 + (SO_4)*4 + (HCO_3)*1]$ [3.3.1.10]

In order to find partial pressure of CO_2 mole fraction of it must be estimated. ($CO_{2)}$ mole fraction, Yg, can be calculated by;

$$Y_g = \frac{Yt}{1 + \frac{Pfg(5xbw/d + 10xbo/d)10^{-5}}{(T+460)*MMcfd}} \qquad [3.3.1.11]$$

Yt refers to (CO_2) mole fraction on the surface condition and it is calculated by

$$Yt = ([HCO_3]10^{-pH}) /(H)(K_1)(f_g) \qquad [3.3.1.12]$$

K_1 refers to first ionization constant of carbonic acid and it is calculated by

$$\log K_1=6,331-8,278E^{-4}(T)+7,142E^{-6}(T^2)-2,564E^{-5}(P)-0,491E^{-2}(I^{0,5})+0,379(I)-6,506E^{-2}(I^{1,5})-1,458E^{-3}(T)(I^{0,5}) \qquad [3.3.1.13]$$

F^0, is temperature of system and P, psi, is the pressure of the system I refers to ionic strength of water and Ionic strength. In Equation 3.3.1.14 refers to fugacity and

Fugacity is found by Oddo Tomson Equation [8];

$$fg= \exp [(-7,66*10^{-3} + 8* 10\text{-}4\ T^{0,5} - 2,11*10^{-5}\ T)P^{0,5} + (-2,77* 10^{-4} + 3,72 * 10^{-5} T^{0,5} - 5,7*10^{-7}\ T)P + (4,4*10^{-6} - 2,96*10^{-7}\ T^{0,5} + 5,1*10^{-9}\ T)P^{1,5}] \qquad [3.3.1.14]$$

CO_2 forms HCO_3 and H^-. These structures react with Fe and steel. As a result, carbonate base corrosion products occur, so a carbonate scale and calcite scale must be considered duration of corrosion rate calculation. A calcite and carbonate scales protect pipelines and led to reduce corrosion rate because they form like protective layer in pipeline surface. Fcalcite shows calcite scale factor and Fscale represents carbonate scale factor. In order to identify protective layer, Fcalcite and Fscale must be calculated. In order to calculate Fcalcite, saturation index value (SIc) must be found. SIc represents calcite saturation index. If SIc is lower than about 0.4, then Fcalcite is considered as 1. It means that no calcite layer assumption can be done. On the other hand, If SIc value is between 0.4 and –0.4 equation 3.3.1.17 have to be used to find calcite scale factor. When SIc is higher than 0.4, Fcalcite is considered as 0 because if it is higher than 0.4, it is not considered as a corrosion problem but rather a precipitation problem in the pipeline system.

SIc can be found using the following formulae;

$$SIc = \log [(Ca^{2+}(HCO_3)] + pH - 2,53 + 8,943 * 10^{-3} T + 1,886*10^{-6} T^2 - 4,855*10^{-5} P - 1,47 I^{0,5} + 3,16 I + 5,73*10^{-2} I^{1,5} + 1,297 *10^{-3} T I^{0,5} \quad [3.3.1.15]$$

$$\text{Log F scale} = 2400/T(K^0) - 0,6 \log (fg\ P(B)_{CO2}) - 6,7$$

with a maximum F scale of 1 [3.3.1.16]

$$\text{F calcite } 1 - [(SIc + 0,4) / 0,8] \quad [3.3.1.17]$$

According to de Waard and Lotz [8], the cVmass can be neglected at high flow rates. Thus, only V react is considered in this thesis. On the other hand, it can be found by ;

$$\text{V mass} = 0,0,23 \frac{D^{0,7} U^{0,8}}{v^{0,5} d^{0,2}} [H_2CO_3] \quad [3.3.1.18]$$

Where;

V mass = the transfer rate at boundary layer

v = the kinematic viscosity, m^2/sec

D = the diffusion coefficient

U = the liquid flow rate, m/s
d = the hydraulic diameter, m

On the other hand, metal loss due to corrosion can be considered because corrosion caused to decrease failure pressure in pipelines.

3.3.2. Corrosion Rate Calculation in Water Pipeline

There are three main water pipelines in pipeline system of petroleum companies. In order to estimate corrosion of water pipeline systems, formation water resistivity analysis results must be collected. Calman graph is then used to determine corrosion current. Calman graph shows resistivity versus cathotic protection current. Cathotic protection current must be equal to corrosion current to control corrosion current. Formation water resistivity was collected from the petroleum field remarks so that corrosion rates are easily evaluated. In this study, cathodic protection current is assumed to be equal to corrosion current. Figure 3.3 shows Calman Graph.

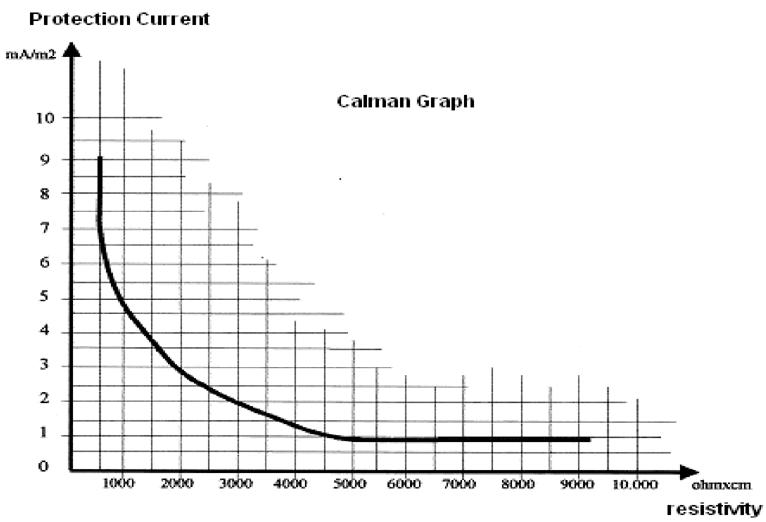

Figure 3.3. Calman Graph

After determination of corrosion current, metal loss due to corrosion must be found. In order to identify metal loss, Faraday's Law can be used. A relationship between the magnitude of electrical charge and the quantity of matter that reached at the electrode interface can be explained by Faraday's Law. [20]

According to Faraday's Law, the quantity of reactant is always taken in electrochemical equivalents. So, when atomic weight Peq is divided to electrons number, n, which is in the reaction, the equivalent weight can be found. [20]

$$Peq = \text{atomic weight}/n \quad [3.3.2.1]$$

Ampere-hours can be calculated by;

$$1\ Ah = Peq / 26.8 \quad [3.3.2.2]$$

Finally, the weight P produced by I, ampere can be evaluated by;

$$P = (Peq * I * t) / 26.8 \quad [3.3.2.3]$$

CHAPTER 4

4.1. Operational Failure

Operational failures consist of human error; pump overpressure, backfill or coating condition. Technical capacity, effective organization and effective communication between departments help to reduce risk probability in pipeline system.

4.2. Mechanical Failure

Construction faults and material faults are considered as mechanical failure. Material failures such as dent, weld, gasket failures and construction failures are considered in mechanical failure. Pipeline pressure capacity is very important to continue operations without any mechanical failure; thickness, material type, and pipeline diameter are vital parameters for pipeline pressure capacity. The pipeline wall thickness is designed according to operating stress, surge pressure, external pressure. Internal pressure level, external pressure and longitudinal stress have to be calculated. If pressure loading in pipeline is known, mechanical failure can be identified. In order to find the behavior of defects internal, external pressure can be calculated by using Barlow equations. [13] So that possible crack growth can be found and also possible risks can be identified.

4.3. Third Party Failure

Road crossing, sabotage, vandalism, farming are considered in third party damage in pipeline systems.

Sabotage and thefts are the most frequent events, which were discussed as third party failure.

CHAPTER 5

STATEMENT OF THE PROBLEM

The aim of this thesis is to identify risk factors in some Turkish petroleum field pipelines. Furthermore, this thesis also focuses on identification of relationship between all parameters that leads to pipeline failures. Identification of risk factors causes to increase system efficiency and safety of pipeline systems.

There are many methods and techniques to reduce or eliminate risk factors in pipeline systems. In this study, quantitative risk assessment method, which depends on statistical calculations, will be applied to clarify risk factors. In order to define most risky region in pipelines, sensitivity analysis will be carried out with application of Monte Carlo Simulation so that different scenarios with different outcomes will be discussed. DOE software program will be used to apply Monte Carlo calculations.

CHAPTER 6

METHODOLOGY

Risk assessment was started to collect field data with repair remarks. Missing data were decided and collected from company's field engineers and General Directorate of Petroleum Affair's statistical database. Data was then grouped according to pipeline types and petroleum fields. Then failure identification was completed based on failure basis. In order to carry out frequency analysis, events were grouped as field's basis, segmentation basis and failure basis. Segmentation procedure was carried out according to company's pipeline system.

Data from a petroleum production company located in S. East Turkey was used. In order to evaluate risk factor and increase data analysis accuracy, pipeline system must be divided in small parts, which is called as pipeline sectioning. In a typical field arrangement, produced crude oil is gathered to manifold. Crude oil then flows to block stations in the petroleum fields. Pipeline system includes five-block stations. A typical block station is composed of a dehydration unit, test unit and storage tanks. Storage, dehydration, test and drainage processes are applied in these block stations. Dehydration unit contains a separator to separate oil, gas, and water. After separation process, produced water is re-injected into the reservoir to maintain reservoir pressure at desired level by water injection pipelines. All produced crude oil is finally collected in P block station via block stations. Flow lines connect production wells to manifolds, and return lines link manifolds to block stations. Trunk lines are pump-station lines.

Finally, all petroleum pipelines connect to a block station.

The lines are further classified as water and oil lines for each petroleum field. Figure 6.1. represents company's pipeline system. "H" shows manifolds in pipeline system. Nine oil fields are then grouped as shown below;

- Crude oil return line,
- Crude oil trunk line,
- Crude oil flow line,
- Water line.

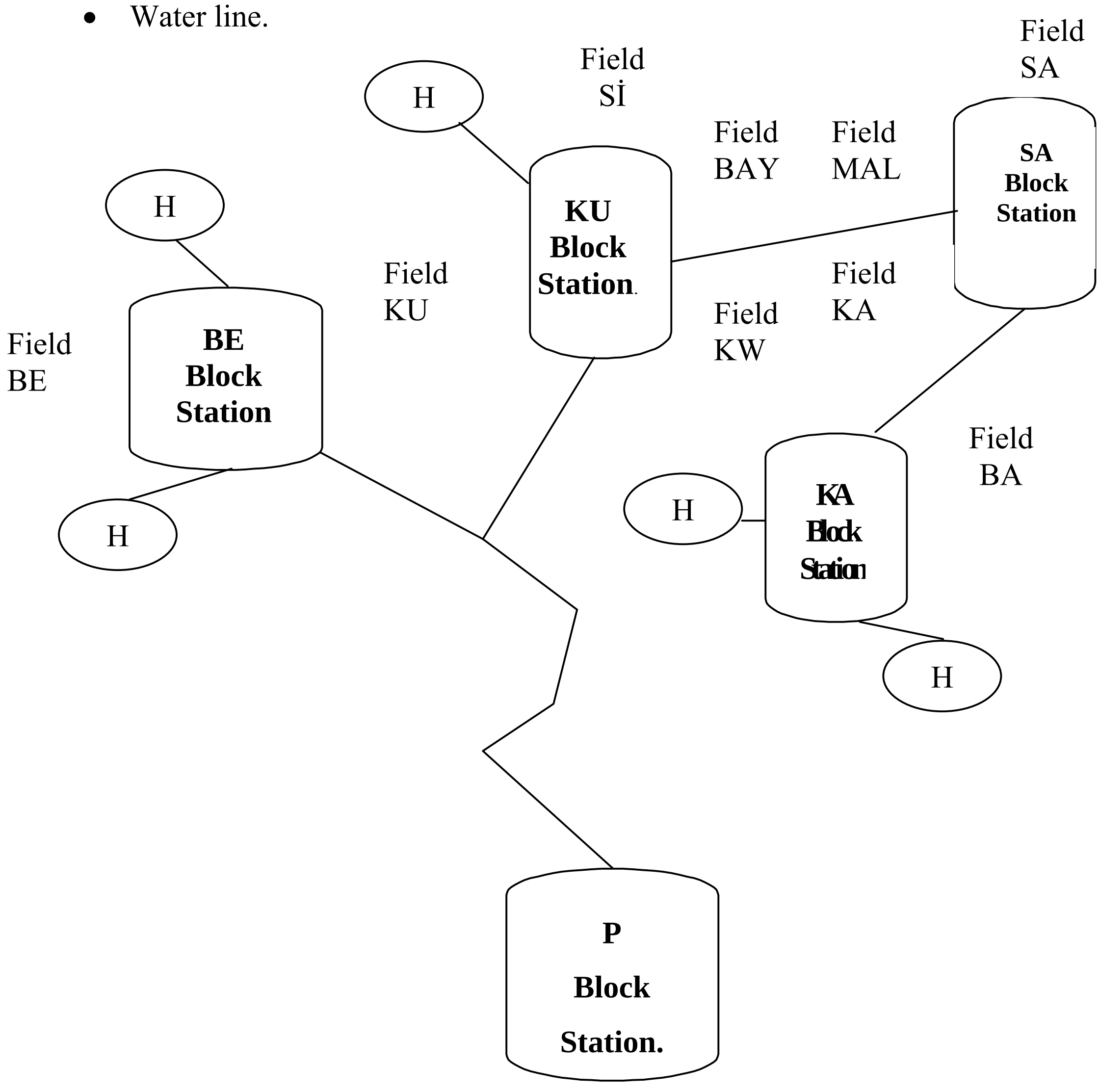

Figure 6.1. A schematic drawing of company's pipeline system.

Corrosion was found as the major risk factor in the pipeline system, so corrosion rate was calculated so that operation life of pipeline system can be defined. In order to find the effect of corrosion on the system, corrosion rate was calculated both crude oil lines and water lines. Two different methods were applied to find corrosion rate for crude oil lines and water lines at the framework of available data and the suitable methods were chosen according to field data, so two different methods were used for waterlines and crude oil lines. Since the company allowed us to use water resistivity values, only Calman Graph method was available to find corrosion current in water pipelines. Thus, corrosion current was calculated from Calman graphs [22] and life of pipelines was assumed to be equal to one-year due to high corrosion rate. It is assumed that cathotic protection current, which is found from Calman Graph, is equal to corrosion current. In crude oil pipelines, Oddo Thomson and De Waard and Lotz method [8] was used because of available field data.

In this thesis, sensitivity analysis was performed on the model to determine how much the risk might vary with Monte Carlo simulation. As it mentioned before, risk is defined as frequency and probability of risk factors. Probability of risk factors was found by using relative risk scoring calculation, which was conducted by using consequences of failure analysis and the probability of density function which has to be either selected as triangular or normal functions. Different scenarios were created for quantitative risk analysis with the application of Monte Carlo Simulation Relative risk score values were assumed as mean of probability for normal distribution and most likely value for triangular distribution. Pipeline failure rate probability was calculated by using normal distribution function and risk probability of fields was calculated by using triangular distribution function. Most likely value of –0.01 was accepted as minimum value for all systems. In addition, most likely value of +0.01 was assumed as maximum value for all pipelines.

These probability distribution functions were applied to each risk factor for every production field the company owns so that probability of risk factors was calculated. Sensitivity analysis was done by Monte Carlo simulation that was carried out by using DOE software program. Most risky regions and the most risky pipelines were defined.

CHAPTER 7

RESULTS AND DISCUSSION

In this thesis, risk factors were grouped as corrosion, third party, mechanical and operational failure, weathering effect based on historical data. Table 7.1 represents historical field data, which was not grouped and arranged. F/L indicates flow lines. Figure 7.1 indicates risk factors in the pipeline system based on arranged field data.

Table 7.1. Same Example of Historical Field Data

Date	**Facility**	**Reason**	**Remark**
20.11.1999	BEY-34 F/L 4"	Corrosion	Clamp installed
27.11.1999	BEY-07 4" F/L	Corrosion	Clamp installed
11.05.2000	BEY 37 4" F/L	Corrosion	Clamp installation

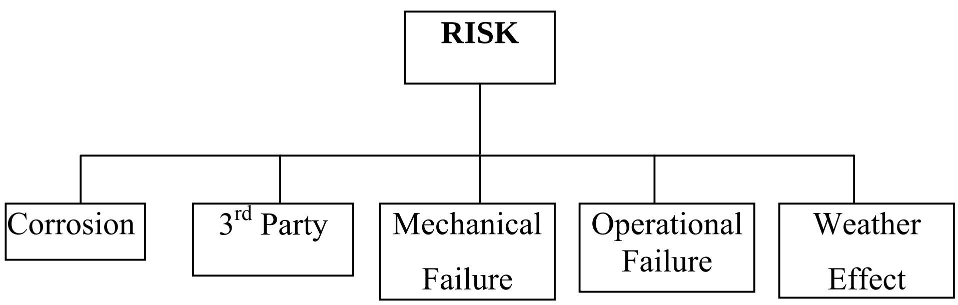

Figure 7.1. Risk Factors in the Pipeline System.

CONCAWE is European oil company organization that studies on environment, health and safety. DOT is Department of transport in USA [10]. In this study observations are compared with CONCAWE statistics and DOT statistics (Table 7.2). It is obvious that corrosion is the biggest problem for the pipeline systems considered. It is much higher than other statistics results. On the other hand, 3 rd party damage effects, mechanical failure and operational failure were less frequent. There has been one operational failure due to manager fault for four years. Note that weathering effect was included in "other" reasons. It is obvious that weather in S East Turkey is pretty harsh especially during winter. Weather effect includes temperature and climate change in petroleum fields. Table 7.2 shows risk factor percentage in the pipeline systems. [15,16]

Table 7.2. Comparison of Failure Data

Cause of Accident	**DOT (%)**	**CONCAWE (%)**	**This Study (%)**
Corrosion	33	30	78.26
Third parties	34	33	6.2
Mechanical Failure	18	25	4.97
Operational Failure	2,5	7	0,01
Other	8	1	10.56 *

(*) Refers to weather effect in this thesis.

7.1. Calculation of Corrosion Rate

In the first stage of this study, corrosion is risk factor for most pipeline systems because it causes leaks and also results in reduced pipeline wall thickness.

In order to control or reduce corrosion, corrosion rate must be calculated. Corrosion rate was calculated for crude oil pipelines and water pipelines.

Internal corrosion was the main factor as observed in repair reports. Note that internal corrosion occurs due to tendency of metals to combine with oxygen, sulphur and other metals. Carbon dioxide and H_2S, which dissolve in water, corrodes steel.

In this thesis, corrosion was found the most frequent event in the system. So parameters, which affects corrosion rate, were determined and collected from company monthly activity reports. These are;

- Lithology of formation
- Water and crude oil production
- Sulphur content of crude oil
- API
- Formation water analyses results (includes Ca, Mg, Na, K, Fe, Ba, Sr, NH_4, Cl^-, SO_4, HCO_3 and S^{-2})
- Formation water resistivity.
- Temperature and pressure values.
- pH values

Table 7.3. gives reservoir parameters and also produced crude oil and water amount. These data were collected from General Directorate of Petroleum Affairs December 2003 statistics. Since all petroleum reservoirs are carbonate no conclusive result can be obtained from the lithology analysis. Oddo Thomson and De Waard and Lotz methods calculated corrosion rate in petroleum pipelines. This calculation procedure was used based on collected parameters. Since mineral deposition reduces corrosion rate calcite scale saturation index (SIc) was calculated. If SIc values are very high, precipitation of carbonate-based products may occur. Table 7.4 indicates formation water analyses results, which were used in calculations. Water analyses result came from company’s field laboratory.

Table 7.3. Petroleum Field Parameters. [23]

Region	Watercut %	Sulphur Content in Oil ppm	API	Temp. ^{0}F	Salinity ppm	Water Resistivity ohm-m	Oil Rate bbl/d
BA	94	0,6	29,7	156	25000	12	1127
BAY	89	0,69	33,3	180	3300	67	341
BE	95	0,97	33,2	137	25000	14	1999
KA	28	0,9	34,7	185	23000	35	1902
KW	96	0,87	34,7	136	15000	22	1991
KU	93	0,51	31,4	130	20000	18	1079
MAL	94	0,69	33,9	126	20000	85	559
Sİ	92	0,63	31,1	130	20000	18	225
SA	97	0,66	34,4	180	8000	40	411

Table 7.4. Formation Water Analyses Results.

PARAMETERS	FIELDS		
(ppm)	KA	MAL	BE
Ca^{++}	1716	723	455
Mg^{++}	630	431.5	220.3
Na^{+}	14350	3174	1982
K^{+}	341.1	109	88.27
Fe^{++}	0.61	0.3361	0.5146
Ba^{++}	0.50	21.78	0.41
Sr^{++}	67.53	54	40.37
NH_4^{++}	0.00209	0.0063	0.0075
Cl^{-}	24839	7112	4069
SO_4^{-}	984	-	466
HCO_3^{-}	443.22	350.86	477.69
S_2^{-}	0	0	1.07

Table 7.5 presents corrosion rate calculation results for several fields

considered for this study.

Table 7.5 Corrosion Rate in Crude Oil Pipelines

FIELDS	Vreact (mm/year)	SIc
KA	6,25	360,87
MAL	6,99	316,16
BE	6,91	305,77

If corrosion rate is compared between these fields, it can be seen that field MAL has the highest corrosion rate. This may be because it has one of the highest water production rates and it has lower precipitation rate. Precipitation helps to reduce corrosion rate. Although, in field KA sulphur amount is very high, corrosion rate is lower than the other fields' corrosion rates. This may be due to the low water production and high precipitation rate. Corrosion rate in field BE is very high due to high CO_2 partial pressure and low precipitation rate. Besides, pH values, temperature, pressure are also very important parameter for corrosion rate but in those fields these parameters are very close to each other so relationship between these parameters with corrosion rate was not found or it can not be concluded truly.

In this study, there are three main water pipelines. These are field KA, KW and field BE. In order to estimate corrosion in water pipes, firstly resistivity of water information was collected and then, Calman graph was used to determine corrosion current in the system. Calman graph is plot of protection (mA/m^2) current versus resistivity graph (ohm*cm)). Life of pipelines was assumed as one year [22]. Water resistivity values were then inserted to graph and corresponding protection current was easily found from graph.

It was assumed that in order to protect pipeline from corrosion, protection current must be at least equal to corrosion rate, so corrosion rate was assumed to be equal to protection current. After calculation of corrosion current, weight loss was calculated by using Faraday's Law. The quantity of matter that reached at electrode interface was calculated. Then, corrosion rate was calculated by dividing weight loss to density of pipeline material. Diameters of water pipelines were considered while calculating of metal loss. Finally the required number of anode to protect pipelines was calculated [20].

It is found that corrosion rate in water lines is much higher than crude oil corrosion rate. Crude oil forms a protective layer, while it flows. This causes decreased corrosion rate in crude oil pipelines. This may be one of the reasons of the observed low rate of corrosion. When formation water resistivity is low, corrosion current is high. Thus, in this study field KA has the highest resistivity with the lowest corrosion rate and field BE has the highest corrosion rate with lowest resistivity.

On the other hand, in order to reduce corrosion rate, thin metal sheets can be inserted in pipelines. Aluminum sheets (anodes) can be used to reduce corrosion rate in water pipeline system. The required number of anodes was calculated as 266 for BE field water pipeline (the life of anode is 1.28 years), 959 for KA water pipelines system (the life of anode is 3.2 years.) and 992 for KW water pipelines (the life of anode is approximately 2 years) by using Akat Engineering cathodic protection TR software program. Table 7.6 shows water corrosion rate results.

Table 7.6.Corrosion Rate in Water Pipelines

FIELDS	I (mA/m^2)	Corrosion Rate (mm/month)
BE	266	1,007
KA	114	0,431
KW	175	0,662

7.2 Determination of Failure Rate

In order to calculate total failure rate in fields and also for each type of pipelines, historical data were arranged based on pipeline types for each petroleum fields. Total numbers of events over four years were determined. Each pipeline length was found from company pipeline map. Then, failure rates were calculated by Equation 2.3. In addition failure rates were calculated based on pipeline types. Table 7.7. shows all failure rates according to fields and type of pipelines. Table 7.8. indicates failure rates, which are classified according to pipeline type. It can be easily seen that field KU and MAL has the biggest failure rates at return lines. In addition to this KU has the biggest failure rate at flow lines and trunk lines. There are three main water pipelines in company's system and the highest failure rate in return lines belongs to field KA. Flow lines have the biggest failure rate followed by return lines (Table 7.8.).

Table 7.7. Total Failure Rates For Each Fields

FIELDS	FAILURE RATE (Failure/km/year)			
	Return Lines	**Flow Lines**	**Trunk Lines**	**Water Lines**
MAL	0,877			
BE	0,297	0,56		0,22
BA	0,38		0,06	
SI	0,58			
SA	0,108	0,097	0,006	
KW	0,118			0,25
KA	0,093			0,33
KU	2,25	2,79	0,108	
BAY	0.0097			

Table 7.8. Failure Rate for Each Type of Pipelines

Failure Rates (Failure/km/year)	Pipelines
0.228	Return Lines
0.564	Flow Lines
0.218	Water Lines
0.128	Trunk Lines

Table 7.9 shows failure data classified using the aforementioned sectioning classification. Majority of failures is due to corrosion, followed by weathering effects, mechanical failure, 3rd party damages and sabotage.

Table 7.9.Failure Data for Sectioned Pipe System.

Corrosion			
78.26%	**ID, inch**	**Length,km**	**Failure**
Return Line (oil)	2.875-12	82.219	66
Flow Line	4	5.154	10
Trunk line	4-8	74	16
Water Line	4-12	17.125	34
3 rd Party			
3.1%	**ID, inch**	**Length,km**	**Failure**
Return Line (oil)	3-4	1.2	3
Flow Line			
Trunk line	8	30	1
Water Line	6	1	1
Sabotage			
3.1%	**ID, inch**	**Length,km**	**Failure**
Return Line (oil)	6-8	6.355	3
Flow Line			
Trunk line	8	2	2
Water Line			
Mechanical Failure			
4.97%	**ID, inch**	**Length,km**	**Failure**
Return Line (oil)	4	1.8	3
Flow Line	2.875-4	7.6	3
Trunk line	8	1	1
Water Line	12	12	1
Weather Effect			
10.56%	**ID, inch**	**Length,km**	**Failure**
Return Line (oil)	4	6.375	14
Flow Line	2.875-4	0.168	2
Trunk line			
Water Line	12	12	1

7.3 Relative Risk Scoring

Relative risk scoring was used to quantify consequences of failure as a result of corrosion, third party, operational failure, mechanical failure and weather effects. Repair cost analysis was conducted. Relative risk scoring method was very helpful to identify probability of risk factors in this thesis.

Four major operations were carried out as a result of a failure: welding, clamp installation, gasket installation and line change. The cost of repair including the labor and spare parts used during the operations is calculated for each year during the analysis period. A relative scoring index from 0 to 1 is used to quantify the consequences. Consequence of failure calculations were utilized to identify risks scores in this study. Thus, historical data arrangement was classified based on company repair remarks for each field's risk factors with pipeline type. Typical repair remarks are clamp installation, pipeline installation, welding and gasket change. Cost analysis was carried out based on three important factors: cost of equipment, loss of revenue and duration. Duration of identified failure and number of events were determined. After this process, clamp costs, gasket costs, welding electrode cost over four years were searched.

Communication with three different welding experts provided welding costs. Average of three welding experts costs were used in calculations. Maximum and minimum required welding electrodes were determined to repair leaks in the pipelines. Welding cost of equipment was not included to calculation because it had completed rate of return before this calculation so it was not true to include equipment cost to calculations.

Pipeline change cost was based on Borusan Company pipeline costs averaged over four years. (dollars/length). Pipeline change length was collected from repair remarks and cost of pipeline was easily clarified. Labor cost for pipeline change was not included in calculations because company has used its personnel and there has not been an extra payment for personnel.

Relative risk scoring index was determined by dividing each repair cost to the total cost. Table 7.10 presents relative risk score values for each risk factor. It can be seen that corrosion has the highest relative risk score index and also the most important risk factor for this pipeline system. It is followed by weather effect. Third party damage has a significant effect for the system. Mechanical effect is not more effective when compared to other risk factors. Operational failure risk score value was much lower than 0.01, so it was ignored.

Table 7.10 Relative Risk Score Values Based on Risk Factors

RISK FACTORS	RELATIVE RISK SCORE VALUES
Corrosion	0,85
Weather effect	0,067
Mechanical failure	0,016
Third Party	0,065

Table 7.11 shows relative risk score values based on pipeline types in the system. In this table RL shows return line, FL indicates flow lines, TL refers to trunk lines and water lines are mentioned as WL. Return lines have the highest relative risk score index and water lines follow them.

Table 7.11 Relative Risk Score Values Based on Pipeline Type.

RELATIVE RISK SCORE VALUE			
RL	**FL**	**TL**	**WL**
0,50	0,074	0,0036	0,42

Table 7.12 shows total number of clamp installation operations for all petroleum fields considered in this study. It is obvious that clamp installation due to corrosion is much higher than the other risk factors in the pipeline system. Field BE has the highest clamp repair remarks because of higher corrosion rate in both crude oil and water pipelines.

On the other hand, clamp installation is higher in return lines compared with other pipelines. The same situation can be seen in weathering effects. In addition, return line clamp installation in mechanical failure and third party damage is bigger than other type of pipelines. Corrosion rate in water lines is higher than that of crude oil lines, so repair cost and relative risk score index are higher than that of crude oil lines.

Table 7.12. Number of Clamp Installation for Each Field with Pipeline Type.

	CORROSION				**THIRD PARTY**				**MECHANICAL FAILURE**				**WEATHER EFFECT**			
Clamp	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**
BA	4					2										
BE	19	6	1	24					1				2			
MAL	7								1							
KU	8	1											3			
SA	5	1			1								1			
Sİ	2															
KW	12	2														
KA	10			5									1			
BAY	2	1														
Total	**69**	**11**	**1**	**29**	**1**	**2**	**0**	**0**	**2**	**0**	**0**	**0**	**7**	**0**	**0**	**0**

Table 7.13 gives the line installations for all fields. Since line changes are costly compared to clamp installations, the number of line changes is small. Thus the company prefers to use clamps whenever it is feasible and prefers to change the line only if the line could not be repaired. Nevertheless, the line changes due to corrosion are still more frequent compared to other failure reasons. Field BE has the highest line installation frequency.

Table 7.13. Number of Line Installation for Each Field with Pipeline Type

	CORROSION				THIRD PARTY				MECHANICAL FAILURE				WEATHER EFFECT			
Line inst.	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**
BA					1											
BE				3					1				2		2	
MAL																
KU																1
SA																
Sİ	1															
KW	1															
KA				2												
BAY																
Total	**2**	**0**	**0**	**5**	**1**	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**2**	**0**	**2**	**1**

Gasket changes mostly occurred in return lines due to weather effect (Table 7.14). In addition, mechanical failure is the second important failure reason for return lines' change of gasket. Field KU has the highest gasket change number. As can be seen from the table the gasket changes are even less than the line changes. It is possible that the gasket lives are relatively long and/or gasket selection process has been conducted properly.

Table 7.14 Number of Gasket Change for Each Field with Pipeline Type.

CORROSION					THIRD PARTY				MECHANICAL FAILURE				WEATHER EFFECT			
Gasket Change	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**
BA													1			
BE																
MAL																
KU													4			
SA																
Sİ																
KW																
KA																
BAY																
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**0**	**0**	**0**

Welding operation is another repair type that could be used. If the line could not be repaired by clamp installation and if the line is in relatively good conditions then the line is cut and the faulty section is removed. Then the pipeline is welded. Thus in terms of cost, welding is somewhat more expensive compared to clamp installation, but cheaper than the line change.

For all the fields most of the welding operations were conducted in water lines and return lines (Table 7.15). Field KA has the highest welding operation rate.

Table 7.15. Number of Welding for Each Field with Pipeline Type.

CORROSION					THIRD PARTY				MECHANICAL FAILURE				WEATHER EFFECT			
Welded	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**
B																
BE	1												1	1		
MAL																
KU																
SA																
Sİ																
KW	1															
KA				1	1			1								
BY					1								1			
Total	**2**	**0**	**0**	**1**	**2**	**0**	**0**	**1**	**0**	**0**	**0**	**0**	**2**	**1**	**0**	**0**

Using the above data (i.e. all consequence of failure calculations), relative risk scoring values, which can be seen in table 7.16, were calculated. As a summary, the highest risk was observed in return lines due to corrosion and the most frequent repair was clamp installation in the pipeline system. Field BE has the highest clamp installation rate, line change rate and welding and thus have the highest risk. The most frequent gasket change was seen in KU field. Repair operations were mostly due to corrosion. As a conclusion one could say clamp installation costs were higher than the other costs.

7.16. Relative Risk Scoring Values of All Fields

RELATIVE RISK SCORE VALUE																
CORROSION					THIRD PARTY				MECHANICAL FAILURE				WEATHER EFFECT			
Fields	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**TL**	**WL**	**RL**	**FL**	**T/L**	**WL**
B	0,003					0,17							0,17			
BE	0,105	0,03	0,004	0,48	0,06				0,34				0,16	0,01		
MAL	0,031								0,31							
KU	0,046	0,01											0,34			
SA	0,023	0,01			0,08								0,08			
Sİ	0,01															
KW	0,08	0,01		4E-03									0,01			
KA	0,061			9E-04	0,51			0,01	0				0,15	0,08		
BY	0,01	0,01							0,03							
Total	**0.37**	**0,07**	**0,004**	**0,49**	**0.65**	**0,17**	**0**	**0,01**	**0.68**	**0**	**0**	**0**	**0,91**	**0,09**	**0**	**0**

7.4. Sensitivity Analysis with Monte Carlo Simulation

Sensitivity analysis was applied with Monte Carlo Simulation. DOE software program was very helpful to carry out Monte Carlo Simulation. First of all, sensitivity analysis was carried out by quantitative risk analysis with the application of Monte Carlo Simulation, so possible scenarios were considered. Risk defined by Equation 2.1 and modified to the pipeline system by Equation 2.2 was used in DOE software program. Failure frequencies were calculated and the main problem was the determination of probability values of risk factors. Relative risk scoring values were very helpful for the calculation of probability of risk factors. Normal distribution and triangular distribution functions were applied to find probability of failures.

Normal distribution function was applied to return line, trunk line, and water line and flow line based on risk score value because number of data was more than 30 to carry out normal distribution calculations. Standard deviation was found and relative risk score values were assumed as mean of probability for normal distribution. These parameters were installed to software program. On the other hand, while calculating probability of failure at the framework of petroleum field, triangular distribution function was applied. Relative risk scores were assumed as most likely value and most likely –0.01 was accepted as minimum value for system. In addition, most likely +0.01 was assumed as maximum value of the system.

Then, DOE software program was carried out for 3000 scenarios. Number of random variables was taken as 9. Random sampling was applied. Then, program was run to find the most effective parameter and also the most risky region in the system. Figure 7.2 represents Monte Carlo simulation results, CDF shows cumulative distribution function.

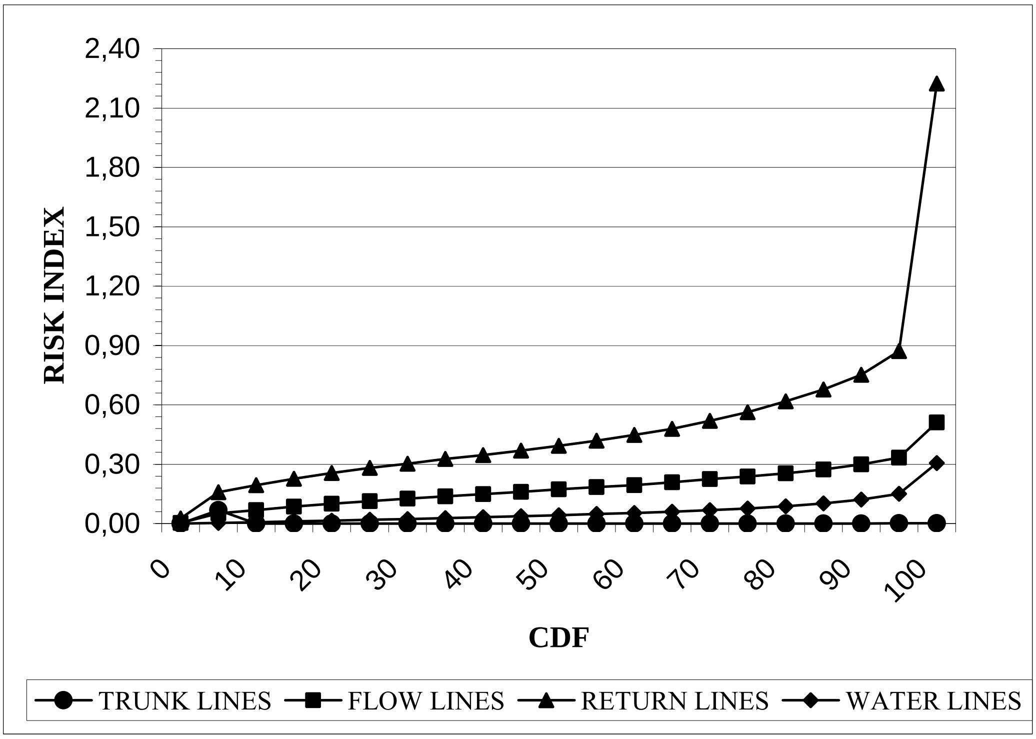

Figure 7.2. Monte Carlo Simulation Results

As a result of Monte Carlo simulation, the highest risk factor was found in return lines. Second one was flow line. Water lines were followed by trunk lines. The most risky field was field BE for which the risk value in trunk lines were the highest followed by flow lines. Field SA is the second risky region for flow lines and it is followed by KU region. Field KA is forth-risky region for the flow lines and other regions have the same risk value in flow lines. In trunk lines, except field BE, the other regions have the same risk value. Field SA is the most risky region for return lines and BE is the second risky region for return lines. It is followed by field KU and filed Sİ. The other fields have the same risk value. In waterlines, KW field is the most risky region and it is followed by KA and the least risky region is BE waterlines. This may be because of lower frequency rate. Other small water lines have the same risk value. Results of Monte Carlo simulations are represented as tables in Appendix A. In these tables 10%, 50% and 90% probability of risk occurrence can be compared.

CHAPTER 8

CONCLUSION

Today, security of supply in the energy sector is the most critical subject all over the world as mentioned above, so all efforts is to reduce possible accident in pipelines. In this study, risk assessment in some Turkish oil field pipelines have been carried out. In conclusion,

- Pipeline sectioning is very helpful to group or arrange data correctly and also, pipeline-sectioning increases risk assessment accuracy.
- Clamp installation rate is much higher than other repair methods. This may be lower cost of clamp installation or company's policy. Clamp installation is mostly observed in return lines. Corrosion is the main reason for clamp installation. Field BE has the highest clamp repair remarks and also highest line change rate because of higher corrosion rate in both crude oil and water pipelines.
- Gasket change was mostly seen because of weathering effect. Mechanical failure is the second biggest reason for gasket change. Gasket change is highest in return lines due to weathering effect. It is mostly seen in field KU.
- Corrosion rate in water lines is higher than that of crude oil lines,

so repair cost and relative risk index are higher than that of crude oil lines. Crude oil forms films around the pipe walls during flow, so it can help to protect pipeline from corrosion.

- Welding operation was seen mostly in water lines and return lines.
- Higher precipitation rate decreases corrosion rate. Although Corrosion rate in field KA is the lower than field MAL and field BE, precipitation rate is highest in field KA.
- Low formation water resistivity in waterlines results in high corrosion rate. Although Field BE water resistivity value is lower than field KA and field KW, it has the highest corrosion rate. Field KA has the highest water resistivity with lowest corrosion rate.
- Thin metal sheet (Al) or cathodic protection can be useful to protect pipelines from corrosion. The required number of anodes is equal to 266 for BE field water pipeline. The life of these anodes is taken as 1.28 years. 959 anodes is necessary for KA water pipelines system based on 3.2 years of anode life. 992 anodes are necessary for KW water pipelines with approximately 2 years of anode life.
- Weather effect is the second biggest risk factor and it is followed by third party damage. Mechanical failure is fourth important risk factor in the system. The least important failure reason is operational failure.
- Corrosion has the highest relative risk index. Weathering effect and third party risk scores are very close to each other. Mechanical failure is lower than other risk factors.
- Return lines have the highest relative risk index value. Risk in flow lines is lower than return lines and water lines. On the other hand, trunk lines have the lowest risk scoring value.
- The most risky trunk lines are in field BE. The other fields have

relative risk indices much lower than that of BE.

- The most risky return lines were found in field SA. Field BE is the second risky region. Filed KU return lines are the third risky return lines. Field Sİ follows field KU and the other fields. The other fields are less risky than these fields.
- The highest risk results for flow lines were found in Field BE. Field SA has one of the highest risk results. KU has the third highest risk factor. KA risk results are lower than that of field KU. Sİ field follows field KU. Other fields have the same risk results in flow lines.
- KA water line is one of the most risky lines. Field BE water line is the second and field BE is the third one.
- Cathodic protection or use of coupons can be very helpful to identify corrosion risk in the pipeline system. In addition, Aluminum sheets (anodes) can be useful to reduce corrosion rate in water pipeline system.

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APPENDIX A

TABLES

This appendix will contain tables of Monte Carlo simulation results

Table A.1- Field KW Monte Carlo Simulation Results

Property	TL	FL	RL	WL
Min	1,00E-04	2,00E-04	2,63E-04	3,11E-02
Max	5,00E-04	6,00E-04	5,01E-02	3,65E-03
Mean Value	3,00E-04	4,00E-04	1,42E-02	0,00E+00
Median	3,00E-04	4,00E-04	1,29E-02	2,99E+03
Avg.Dev.	1,67E-04	1,67E-04	6,72E-03	5,76E-03
Variance	2,83E-07	2,83E-08	7,16E-05	4,66E-05
Skewness	1,28E-05	1,32E-05	8,67E-01	8,91E-01
Kurtosis	-1,929	-1.929	8,05E-01	0,08837

Table A.2- Field KW Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	2,20E-04	8009	2,75E-03	28	-6,65E-03	7.925
1,90E-04	3992	2,60E-04	3992	7,73E-03	45	-2,78E-03	60,89
1,20E-04	500	3,00E-04	500	1,27E-02	47	1,09E-03	57,03
2,40E-04	0	3,40E-04	0	0	36	4,96E-03	33,68
2,80E-04	0	3,80E-04	0	2,27E-02	24	8,83E-03	33,94
3,20E-04	0	4,20E-04	0	0	11	1,27E-02	24,29
3,60E-04	0	4,60E-04	0	0	5.891	1,66E-02	12,84
4,00E-04	500	5,00E-04	500	0	2.611	2,04E-02	4.996
4,40E-04	4000	5,40E-04	4000	0	1.205	2,43E-02	2,24
4,80E-04	8001	5,80E-04	8001	0	1	2,82E-02	0,603

Table A.3- Field KW Cumulative Distribution Results

Cumulative Distribution				
(%)	Trunk Line	Flow Line	Return Line	Water Lines
0	1,00E-04	2,00E-04	2,63E-03	-8,59E+03
5	1,05E-04	2,05E-04	2,84E-03	-4,16E-03
10	1,11E-04	2,11E-04	4,32E-03	-3,17E-03
15	1,16E-04	2,16E-04	5,49E-03	-2,47E-03
20	1,22E-04	2,25E-04	6,59E-03	-1,95E-03
25	1,29E-04	2,29E-04	7,79E-03	-1,51E-03
30	1,40E-04	2,31E-04	8,85E-03	-1,66E-03
35	1,45E-04	2,45E-04	9,88E-03	-3,18E+03
40	1,55E-04	2,55E-04	1,09E-02	-4,21E-03
45	1,68E-04	2,68E-04	1,19E-02	-6,88E-03
50	1,98E-04	2,98E-04	1,29E-02	2,97E-03
55	4,32E-04	5,32E-04	1,42E-02	2,47E-03
60	4,45E-04	5,45E-04	1,52E-02	4,15E-03
65	4,55E-04	5,55E-04	1,64E-02	5,63E-03
70	4,64E-04	5,63E-04	1,78E-02	7,00E-03
75	4,70E-04	5,71E-04	1,92E-02	8,47E-03
80	4,84E-04	5,77E-04	2,08E-02	1,00E-02
85	4,90E-04	5,84E-04	2,27E-02	1,15E-02
90	4,95E-04	5,89E-04	2,55E-02	1,35E-02
95	5,00E-04	5,95E-04	3,02E-02	1,68E-02
100	5,10E-04	6,00E-04	0	3,01E-02

Table A.4- Field BA Monte Carlo Simulation Results

Property	Trunk Line	Flow Line	Return Line	Water Lines
Min	1,00E-04	1,00E-04	2,62E-03	1,00E-04
Max	5,00E-04	5,00E-04	0	5,00E-04
Mean Value	3,00E-04	3,00E-04	0,05376	3,00E-04
Median	3,00E-04	3,00E-04	4,51E-02	3,00E-04
Avg.Dev.	1,67E-04	1,67E-04	2,63E-02	1,67E-04
Variance	2,83E-07	2,83E-07	1,10E-03	2,83E-07
Skewness	1,28E-05	1,28E-05	1.109	1,28E-05
Kurtosis	-1,929	-1,929	1.015	-1,929

Table A.5- Field BA Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	1,20E-04	8009	1,25E-02	7.198	1,20E-04	8009
1,90E-04	3992	1,90E-04	3992	3,22E-02	16	1,90E-04	3992
1,20E-04	500	1,20E-04	500	5,19E-02	11	1,20E-04	500
2,40E-04	0	2,40E-04	0	0	6.826	2,40E-04	0
2,80E-04	0	2,80E-04	0	9,14E-02	4.765	2,80E-04	0
3,20E-04	0	3,20E-04	0	0	2.636	3,20E-04	0
3,60E-04	0	3,60E-04	0	0	1.419	3,60E-04	0
4,00E-04	500	4,00E-04	500	0	1	4,00E-04	500
4,40E-04	4000	4,40E-04	4000	0	0	4,40E-04	4000
4,80E-04	8001	4,80E-04	8001	0	0	4,80E-04	8001

Table A.6- Field BA Cumulative Distribution Results

Cumulative Distribution				
(%)	**Trunk Line**	**Flow Line**	**Return Line**	**Water Lines**
0	1,00E-04	1,00E-04	2,60E-02	1,00E-04
5	1,05E-04	1,05E-04	1,41E-02	1,05E-04
10	1,11E-04	1,11E-04	1,94E-02	1,11E-04
15	1,16E-04	1,16E-04	2,29E-02	1,16E-04
20	1,22E-04	1,22E-04	2,59E-02	1,22E-04
25	1,29E-04	1,29E-04	2,88E-02	1,29E-04
30	1,40E-04	1,40E-04	3,16E-02	1,40E-04
35	1,45E-04	1,45E-04	3,47E-02	1,45E-04
40	1,55E-04	1,55E-04	3,78E-02	1,55E-04
45	1,68E-04	1,68E-04	4,14E-02	1,68E-04
50	1,98E-04	1,98E-04	4,51E-02	1,98E-04
55	4,32E-04	4,32E-04	4,92E-02	4,32E-04
60	4,45E-04	4,45E-04	5,37E-02	4,45E-04
65	4,55E-04	4,55E-04	5,93E-02	4,55E-04
70	4,64E-04	4,64E-04	6,50E-02	4,64E-04
75	4,70E-04	4,70E-04	7,15E-02	4,70E-04
80	4,84E-04	4,84E-04	7,53E-02	4,84E-04
85	4,90E-04	4,90E-04	8,01E-01	4,90E-04
90	4,95E-04	4,95E-04	8,89E-01	4,95E-04
95	5,00E-04	5,00E-04	1,01E-01	5,00E-04
100	5,10E-04	5,10E-04	0	5,10E-04

Table A.7- Field MAL Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	1,00E-04	1,00E-04	6,36E-04	1,00E-04
Max	5,00E-04	5,00E-04	0.183	5,00E-04
Mean Value	3,00E-04	3,00E-04	0,02596	3,00E-04
Median	3,00E-04	3,00E-04	2,60E-02	3,00E-04
Avg.Dev.	1,67E-04	1,67E-04	2,45E-02	1,67E-04
Variance	2,83E-07	2,83E-07	9,81E-04	2,83E-07
Skewness	1,28E-05	1,28E-05	1.442	1,28E-05
Kurtosis	-1,929	-1,929	1.778	-1,929

Table A.8- Field MAL Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	1,20E-04	8009	8,95E-03	19	1,20E-04	8009
1,90E-04	3992	1,90E-04	3992	2,68E-02	16	1,90E-04	3992
1,20E-04	500	1,20E-04	500	4,47E-02	6.775	1,20E-04	500
2,40E-04	0	2,40E-04	0	0	4.893	2,40E-04	0
2,80E-04	0	2,80E-04	0	8,04E-02	3.661	2,80E-04	0
3,20E-04	0	3,20E-04	0	0	2	3,20E-04	0
3,60E-04	0	3,60E-04	0	0	1.239	3,60E-04	0
4,00E-04	500	4,00E-04	500	0	0	4,00E-04	500
4,40E-04	4000	4,40E-04	4000	0	0	4,40E-04	4000
4,80E-04	8001	4,80E-04	8001	0	0	4,80E-04	8001

Table A.9- Field MAL Cumulative Distribution Results

Cumulative Distribution				
(%)	Trunk Line	Flow Line	Return Line	Water Lines
0	1,00E-04	1,00E-04	6,36E-03	1,00E-04
5	1,05E-04	1,05E-04	1,43E-02	1,05E-04
10	1,11E-04	1,11E-04	8,96E-02	1,11E-04
15	1,16E-04	1,16E-04	1,12E-02	1,16E-04
20	1,22E-04	1,22E-04	1,31E-02	1,22E-04
25	1,29E-04	1,29E-04	1,51E-02	1,29E-04
30	1,40E-04	1,40E-04	1,61E-02	1,40E-04
35	1,45E-04	1,45E-04	1,88E-02	1,45E-04
40	1,55E-04	1,55E-04	2,09E-02	1,55E-04
45	1,68E-04	1,68E-04	2,34E-02	1,68E-04
50	1,98E-04	1,98E-04	2,60E-02	1,98E-04
55	4,32E-04	4,32E-04	2,89E-02	4,32E-04
60	4,45E-04	4,45E-04	3,29E-02	4,45E-04
65	4,55E-04	4,55E-04	3,28E-02	4,55E-04
70	4,64E-04	4,64E-04	4,47E-02	4,64E-04
75	4,70E-04	4,70E-04	5,23E-02	4,70E-04
80	4,84E-04	4,84E-04	6,20E-02	4,84E-04
85	4,90E-04	4,90E-04	7,17E-02	4,90E-04
90	4,95E-04	4,95E-04	8,44E-02	4,95E-04
95	5,00E-04	5,00E-04	1,03E-01	5,00E-04
100	5,10E-04	5,10E-04	0	5,10E-04

Table A.10- Field BAY Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	1,00E-04	2,00E-04	0,002448	1,00E-04
Max	5,00E-04	6,00E-04	0.01164	5,00E-04
Mean Value	3,00E-04	4,00E-04	0.001901	3,00E-04
Median	3,00E-04	3,39E-04	8,86E-04	3,00E-04
Avg.Dev.	1,67E-04	1,67E-04	0.002142	1,67E-04
Variance	2,83E-07	2,83E-08	6,44E-06	2,83E-07
Skewness	1,28E-05	1,32E-05	0.8512	1,28E-05
Kurtosis	-1,929	-1,929	0	-1,929

Table A.11- Field BAY Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	2,20E-04	8009	-1,74E-03	37.78	1,20E-04	8009
1,90E-04	3992	2,60E-04	3992	-3,35E-04	243	1,90E-04	3992
1,20E-04	500	3,00E-04	500	2,48E-03	126.8	1,20E-04	500
2,40E-04	0	3,40E-04	0	0	90.85	2,40E-04	0
2,80E-04	0	3,80E-04	0	5,30E-03	92.04	2,80E-04	0
3,20E-04	0	4,20E-04	0	0	67.67	3,20E-04	0
3,60E-04	0	4,60E-04	0	0	33.36	3,60E-04	0
4,00E-04	500	5,00E-04	500	0	5.206	4,00E-04	500
4,40E-04	4000	5,40E-04	4000	0.01094	1.656	4,40E-04	4000
4,80E-04	8001	5,80E-04	8001	-	-	4,80E-04	8001

Table A.12- Field BAY Cumulative Distribution Results

Cumulative Distribution				
(%)	**Trunk Line**	**Flow Line**	**Return Line**	**Water Lines**
0	1,00E-04	2,00E-04	-2,45E-04	1,00E-04
5	1,05E-04	2,50E-04	-1,04E-04	1,05E-04
10	1,11E-04	2,11E-04	-6,64E-04	1,11E-04
15	1,16E-04	2,16E-04	-4,27E-04	1,16E-04
20	1,22E-04	2,23E-04	-2,40E-04	1,22E-04
25	1,29E-04	2,29E-04	-7,32E-05	1,29E-04
30	1,40E-04	2,37E-04	1,00E-04	1,40E-04
35	1,45E-04	2,45E-04	2,41E-04	1,45E-04
40	1,55E-04	2,55E-04	3,94E-04	1,55E-04
45	1,68E-04	2,68E-04	5,70E-04	1,68E-04
50	1,98E-04	2,98E-04	8,86E-04	1,98E-04
55	4,32E-04	5,32E-04	1,15E-02	4,32E-04
60	4,45E-04	5,45E-04	2,13E-03	4,45E-04
65	4,55E-04	5,55E-04	2,65E-03	4,55E-04
70	4,64E-04	5,63E-04	2,65E-03	4,64E-04
75	4,70E-04	5,71E-04	3,20E-04	4,70E-04
80	4,84E-04	5,84E-04	4,28E-04	4,84E-04
85	4,90E-04	5,84E-04	4,86E-03	4,90E-04
90	4,95E-04	5,89E-04	5,61E-03	4,95E-04
95	5,00E-04	5,89E-04	6,74E-03	5,00E-04
100	5,10E-04	6,00E-04	0	5,10E-04

Table A.13- Field Sİ Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	1,00E-04	1,00E-04	-0,01756	1,00E-04
Max	5,00E-04	5,00E-04	0.05963	5,00E-04
Mean Value	3,00E-04	3,00E-04	0.06903	3,00E-04
Median	3,00E-04	3,00E-04	2,99E-04	3,00E-04
Avg.Dev.	1,67E-04	1,67E-04	0.1141E-3	1,67E-04
Variance	2,83E-07	2,83E-07	0.1834E-3	2,83E-07
Skewness	1,28E-05	1,28E-05	0.8986	1,28E-05
Kurtosis	-1,929	-1,929	0.115	-1,929

Table A.14- Field Sİ Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	1,20E-04	8009	-0,0137	3.627	1,20E-04	8009
1,90E-04	3992	1,90E-04	3992	-5,99E-04	39.34	1,90E-04	3992
1,20E-04	500	1,20E-04	500	0.1785E-2	38.137	1,20E-04	500
2,40E-04	0	2,40E-04	0	0.9454E-2	16.97	2,40E-04	0
2,80E-04	0	2,80E-04	0	0.01717	38.155	2,80E-04	0
3,20E-04	0	3,20E-04	0	0.02489	41.609	3,20E-04	0
3,60E-04	0	3,60E-04	0	0.03261	6.434	3,60E-04	0
4,00E-04	500	4,00E-04	500	0.04038	2.504	4,00E-04	500
4,40E-04	4000	4,40E-04	4000	0.04805	1.123	4,40E-04	4000
4,80E-04	8001	4,80E-04	8001	0.05577	0.3023	4,80E-04	8001

Table A.15- Field Sİ Cumulative Distribution Results

Cumulative Distribution				
(%)	**Trunk Line**	**Flow Line**	**Return Line**	**Water Lines**
0	1,00E-04	1,00E-04	-0,01756	1,00E-04
5	1,05E-04	1,05E-04	-0,008574	1,05E-04
10	1,11E-04	1,11E-04	-0,006568	1,11E-04
15	1,16E-04	1,16E-04	-0,05206	1,16E-04
20	1,22E-04	1,22E-04	-0,004148	1,22E-04
25	1,29E-04	1,29E-04	-0,003288	1,29E-04
30	1,40E-04	1,40E-04	-0,002593	1,40E-04
35	1,45E-04	1,45E-04	-0,001904	1,45E-04
40	1,55E-04	1,55E-04	-0,00118	1,55E-04
45	1,68E-04	1,68E-04	-0,004228	1,68E-04
50	1,98E-04	1,98E-04	0,002915	1,98E-04
55	4,32E-04	4,32E-04	0,004573	4,32E-04
60	4,45E-04	4,45E-04	0.007875	4,45E-04
65	4,55E-04	4,55E-04	0.01081	4,55E-04
70	4,64E-04	4,64E-04	0.01353	4,64E-04
75	4,70E-04	4,70E-04	0.01647	4,70E-04
80	4,84E-04	4,84E-04	0.01951	4,84E-04
85	4,90E-04	4,90E-04	0.02252	4,90E-04
90	4,95E-04	4,95E-04	0.02651	4,95E-04
95	5,00E-04	5,00E-04	0.03305	5,00E-04
100	5,10E-04	5,10E-04	0.5963	5,10E-04

Table A.16- Field SA Monte Carlo Simulation Results

Property	**Trunk Lines**	**Flow Lines**	**Return Lines**	**Water Lines**
Min	1,00E-04	-0,003524	0.2647E-3	1,00E-04
Max	5,00E-04	0.01584	0.02043	5,00E-04
Mean Value	3,00E-04	0.003255	0.004729	3,00E-04
Median	3,00E-04	0.001725	0.003269	3,00E-04
Avg.Dev.	1,67E-04	0.003528	0.002956	1,67E-04
Variance	2,83E-07	0.1588E-4	0.1336E-4	2,83E-07
Skewness	1,28E-05	0.5355	1.248	1,28E-05
Kurtosis	-1,929	-0,8413	1.054	-1,929

Table A.17- Field SA Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	-0,002556	22.55	0.001273	154.9	0,00012	8009
1,90E-04	3992	-6,19E-04	157.5	0.003289	144.3	0,00019	3.992
1,20E-04	500	0.001381	87.95	0.005305	57.04	0,00012	500
2,40E-04	0	0.003255	38.38	0.007321	52.25	0,00024	0
2,80E-04	0	0.005192	64.2	0.009337	40.51	0,00028	0
3,20E-04	0	0.007128	74.52	0.01135	23.49	0,00032	0
3,60E-04	0	0.009065	44.75	0.01337	13.39	0,00036	0
4,00E-04	500	0.011	17.13	0.01539	1.448	0,0004	500
4,40E-04	4000	0.01294	6.712	0.0174	2.149	0,00044	4000
4,80E-04	8001	0.01488	2.065	0.01942	1.488	0,00048	8001

Table A.18- Field SA Cumulative Distribution Results

Cumulative Distribution				
(%)	Trunk Line	Flow Line	Return Line	Water Lines
0	1,00E-04	0.002849	0.02588	1,00E-04
5	1,05E-04	0.05166	0.1592	1,05E-04
10	1,11E-04	0.06864	0.1941	1,11E-04
15	1,16E-04	0.08573	0.2259	1,16E-04
20	1,22E-04	0.101	0.2551	1,22E-04
25	1,29E-04	0.1125	0.2808	1,29E-04
30	1,40E-04	0.1264	0.3029	1,40E-04
35	1,45E-04	0.1374	0.3268	1,45E-04
40	1,55E-04	0.1492	0.3456	1,55E-04
45	1,68E-04	0.16	0., 3689	1,68E-04
50	1,98E-04	0.1725	0.3937	1,98E-04
55	4,32E-04	0.1836	0.4191	4,32E-04
60	4,45E-04	0.1944	0.4472	4,45E-04
65	4,55E-04	0.2093	0.4780	4,55E-04
70	4,64E-04	0.225	0.5192	4,64E-04
75	4,70E-04	0.2376	0.5626	4,70E-04
80	4,84E-04	0.2534	0.6183	4,84E-04
85	4,90E-04	0.2734	0.6783	4,90E-04
90	4,95E-04	0.2998	0.7520	4,95E-04
95	5,00E-04	0.3336	0.8725	5,00E-04
100	5,10E-04	0.5108	2.224	5,10E-04

Table A.19- Field KU Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	1,00E-04	-0,8096	3,43E-03	1,00E-04
Max	5,00E-04	0.371	0,9758	5,00E-04
Mean Value	3,00E-04	0.07839	0,2271	3,00E-04
Median	3,00E-04	0.05808	0.2106	3,00E-04
Avg.Dev.	1,67E-04	0.06437	0.9473	1,67E-04
Variance	2,83E-07	0.005925	0.01442	2,83E-07
Skewness	1,28E-05	0.7784	0.8727	1,28E-05
Kurtosis	-1,929	0.06437	1.253	-1,929

Table A.20- Field KU Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	-0,05836	0.2876	0.05205	1.388	0,00012	8009
1,90E-04	3992	-1,32E-01	4	0.1493	3.267	0,00019	3.992
1,20E-04	500	0.03203	6.542	0.2485	3.017	0,00012	500
2,40E-04	0	0.07723	3.805	0.3438	1.615	0,00024	0
2,80E-04	0	0.1224	3.061	0.441	0.7336	0,00028	0
3,20E-04	0	0.1676	2.456	0.5382	0.1680	0,00032	0
3,60E-04	0	0.2128	1.298	0.6355	0.06513	0,00036	0
4,00E-04	500	0.2580	0.5531	0.7327	0.024	0,0004	500
4,40E-04	4000	0.3032	0.1991	0.83	0.006586	0,00044	4000
4,80E-04	8001	0.3484	0.08112	0.9272	0.003428	0,00048	8001

Table A.21- Field KU Cumulative Distribution Results

Cumulative Distribution				
(%)	Trunk Line	Flow Line	Return Line	Water Lines
0	1,00E-04	0.08096	3,43E-03	1,00E-04
5	1,05E-04	0.01711	0.06264	1,05E-04
10	1,11E-04	0.005142	0.08726	1,11E-04
15	1,16E-04	0.004881	0.1051	1,16E-04
20	1,22E-04	0.01175	0.1226	1,22E-04
25	1,29E-04	0.01841	0.1375	1,29E-04
30	1,40E-04	0.02602	0.1543	1,40E-04
35	1,45E-04	0.03301	0.1674	1,45E-04
40	1,55E-04	0.04048	0.1809	1,55E-04
45	1,68E-04	0.04884	0.1966	1,68E-04
50	1,98E-04	0.05796	0.2105	1,98E-04
55	4,32E-04	0.06968	0.2244	4,32E-04
60	4,45E-04	0.08271	0.2417	4,45E-04
65	4,55E-04	0.09895	0.2583	4,55E-04
70	4,64E-04	0.1149	0.2741	4,64E-04
75	4,70E-04	0.1302	0.2982	4,70E-04
80	4,84E-04	0.1478	0.3247	4,84E-04
85	4,90E-04	0.1672	0.3528	4,90E-04
90	4,95E-04	0.1885	0.3885	4,95E-04
95	5,00E-04	0.2238	0.4427	5,00E-04
100	5,10E-04	0.371	0.9758	5,10E-04

Table A.22- Field BE Monte Carlo Simulation Results

Property	TL	FL	RL	WL
Min	1,73E-04	-2,49E-02	0,01279	5,66E-04
Max	1,34E-03	3,64E+03	2,25E+00	3,06E-01
Mean Value	6,68E-04	4,57E-01	3,23E-01	8,19E-02
Median	6,63E-04	3,40E-01	2,58E-01	7,48E-02
Avg.Dev.	1,66E-04	3,13E-01	1,83E-01	4,13E-02
Variance	4,26E-08	1,71E-01	5,81E-02	2,76E-03
Skewness	1,19E-01	1,69E+03	1,16E+04	8,13E-01
Kurtosis	-0,2137	4.132	3,98E+03	0,6575

Table A.23- Field BE Probability Density Distribution

Probability Density Distribution							
Trunk line		Flow Line		Return Line		Water Line	
Mid Point	Pdf.	Mid Point	Pdf.	Mid Point	Pdf.	Mid Point	Pdf.
2,31E-04	311,4	1,57E-01	1.372	1,25E-01	2.043	1,58E-02	5.808
3,48E-04	562,8	5,24E-01	0,7719	3,48E-01	1.419	4,64E-02	7.337
4,64E-04	1260	8,89E-01	0,3428	5,72E-01	1	7,69E-02	7.085
5,81E-05	1777	1,26E+03	0,1546	1	0	1,07E-01	5.819
6,98E-04	1825	1,62E+03	0,05546	1,02E+03	0	1,38E-01	3.537
8,14E-04	1451	1,99E+03	0,02093	1.243	0	1,69E-01	1.671
5,31E-04	854,1	2,36E+03	0,006364	1.467	0	1,99E-01	0,8843
1,05E-03	374,2	2,72E+03	0,003637	2	0	2,30E-01	0
1,16E-03	111,4	3,09E+03	0,000909	1.914	0	2,60E-01	0,1747
1,28E-03	42,85	3,45E+03	0,000909	2.138	0	2,91E-01	0

Table A.24- Field BE Cumulative Distribution Results

Cumulative Distribution				
(%)	Trunk Line	Flow Line	Return Line	Water Lines
0	1,73E-04	-2,49E-02	1,28E-02	5,66E-04
5	3,23E-04	3,51E-01	6,37E-02	1,05E-04
10	4,04E-04	6,41E-01	8,85E-02	1,95E-04
15	4,53E-04	9,12E-02	1,08E-01	2,66E-04
20	4,88E-04	1,23E-01	1,27E-01	3,45E-04
25	5,24E-04	1,55E-01	1,48E-01	4,15E-04
30	5,53E-04	1,87E-01	1,67E-01	4,83E-04
35	5,86E-04	2,17E-01	1,90E-01	4,83E-04
40	6,09E-04	2,59E-01	2,11E-01	5,47E-04
45	6,36E-04	2,97E-01	2,34E-01	6,15E-04
50	6,63E-04	3,39E-01	2,58E-01	6,79E-04
55	6,53E-04	3,82E-01	2,84E-01	7,48E-04
60	7,14E-03	4,33E-01	3,12E-01	8,17E-04
65	7,76E-04	4,92E-01	3,44E-01	8,88E-04
70	8,08E-04	5,60E-01	3,90E-01	1,05E-04
75	8,45E-04	6,43E-01	4,33E-01	1,14E-04
80	8,85E-04	7,31E-01	4,90E-01	1,24E-04
85	9,40E-04	8,70E-01	5,58E-01	1,35E-04
90	1,02E-04	1	6,53E-01	1,52E-04
95	1,34E-04	1	7,88E-01	1,79E-04
100	1,50E-04	4	2	3,06E-04

Table A.25-Field KA Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	1,00E-04	1,13E-05	0,0004837	-2,44E-02
Max	5,00E-04	3,76E-03	3,82E-02	2,61E-02
Mean Value	3,00E-04	1,30E-03	1,17E-02	4,92E-04
Median	3,00E-04	1,22E-03	1,07E-02	4,04E-04
Avg.Dev.	1,67E-04	5,51E-04	4,91E-02	7,19E-03
Variance	2,83E-07	4,56E-07	3,91E-05	7,26E-05
Skewness	1,28E-05	4,86E-01	9,49E-01	-3,70E-02
Kurtosis	-1,929	0	9,72E-01	-0,62257

Table A.26- Field KA Probability Density Distribution

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
1,20E-04	8009	1,99E-04	184,1	2,37E-03	22	-2,19E-02	1
1,90E-04	3992	5,73E-04	451,9	6,15E-03	62	-1,68E-01	5,61
1,20E-04	500	9,48E-04	569,3	9,92E-03	67	-4,78E-02	20,13
2,40E-04	0	1,32E-03	499,1	0	53	-6,73E-03	39,34
2,80E-04	0	1,70E-02	450,1	1,75E-02	31	-1,68E-03	34,98
3,20E-04	0	2,07E-02	280,2	0	16	-3,36E-03	37,95
3,60E-04	0	2,45E-03	138,8	0	8.215	8,42E-03	37,36
4,00E-04	500	2,82E-03	65,83	0	4.329	1,35E-02	16
4,40E-04	4000	3,20E-03	18,68	0	1.502	1,85E-02	4,62
4,80E-04	8001	-	-	0	1	2,36E-02	1.056

Table A.27-Field KA Cumulative Distribution Results

Cumulative Distribution				
(%)	**Trunk Line**	**Flow Line**	**Return Line**	**Water Lines**
0	1,00E-04	1,13E-04	4,86E-03	-2,44E-02
5	1,05E-04	3,10E-04	3,53E-03	-1,30E-02
10	1,11E-04	4,63E-04	4,66E-03	-1,07E-02
15	1,16E-04	5,76E-04	5,51E-03	-8,79E-03
20	1,22E-04	6,81E-04	6,23E-03	-7,39E-03
25	1,29E-04	6,81E-04	7,04E-03	-6,12E-03
30	1,40E-04	7,80E-04	7,78E-03	-4,90E-03
35	1,45E-04	8,68E-04	8,52E-03	-3,79E-03
40	1,55E-04	9,55E-04	9,12E-03	-2,53E-03
45	1,68E-04	1,04E-04	9,81E-03	-1,19E-03
50	1,98E-04	1,22E-03	1,07E-03	3,96E-03
55	4,32E-04	1,33E-03	1,16E-02	2,23E-03
60	4,45E-04	1,43E-03	1,23E-02	3,48E-03
65	4,55E-04	1,54E-03	1,31E-02	4,66E-03
70	4,64E-04	1,64E-03	1,41E-02	5,86E-03
75	4,70E-04	1,74E-03	1,52E-02	7,10E-03
80	4,84E-04	1,86E-03	1,65E-02	8,38E-03
85	4,90E-04	2,01E-03	1,80E-02	9,50E-03
90	4,95E-04	2,20E-03	2,00E-02	1,13E-02
95	5,00E-04	2,53E-03	2,28E-02	1,41E-02
100	5,10E-04	3,76E-03	0	2,60E-02

Table A.28- Field Pipelines Monte Carlo Simulation Results

Property	Trunk Lines	Flow Lines	Return Lines	Water Lines
Min	0.3E-4	0.2849E-2	0.02588	0.00002579
Max	0.001077	0.5108	2.224	0.3064
Mean Value	0.0005318	0.1794	0.4423	0.05457
Median	0.005117	0.1725	0.3938	0.042
Avg.Dev.	0.0001242	0.07064	0.1769	0.03627
Variance	0.2268E-7	0.007584	0.05277	0.002227
Skewness	0.6637	0.4614	1.283	1.429
Kurtosis	-0,5577	-0,1494	3.048	2.399

Table A.29- Field Pipelines Probability Density Distribution Results

Probability Density Distribution							
Trunk line		**Flow Line**		**Return Line**		**Water Line**	
Mid Point	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**	**Mid Point**	**Pdf.**
0.3390E-3	2138	0.02824	1.096	0.3556	2.046	0.01534	12,616
0.4166E-3	2486	0.0794	3	0.5754	1.025	0.04598	8.854
0.4943E-3	2481	0.1298	4.226	0.7952	0.4731	0.07662	5.223
0.5719E-3	2142	0.1806	4.148	1.015	0.135	0.1073	2.829
0.6496E-3	1593	0.2314	3	1.235	0.024	0.1379	1.599
0.7772E-3	1026	0.2822	2.028	1.455	0.0166	0.1685	0.9139
0.8049E-3	571	.03838	0.439	1.674	0.0060	0.1992	0.3155
0.8825E-3	274.7	0.4346	0.105	1.894	0.0015	0.2298	0.1741
0.9602E-3	107.3	0.4854	0.039	2.114	0.0015	0.2604	0.1088

Table A.30- Field Pipelines Cumulative Distribution Results

Cumulative Distribution				
(%)	**Trunk Line**	**Flow Line**	**Return Line**	**Water Lines**
0	0.3002E-3	0.002849	0.02588	0.2579E-4
5	0.06864	0.05166	0.1592	0.00338
10	0.3488E-3	0.06864	0.1941	0.007047
15	0.3708E-3	0.08573	0.2259	0.01134
20	0.3919E-3	0.101	0.2551	0.01497
25	0.4123E-3	0.1125	0.2808	0.01923
30	0.4322E-3	0.1264	0.3029	0.02345
35	0.4519E-3	0.1374	0.3268	0.02768
40	0.4717E-3	0.1492	0.3456	0.03184
45	0.4914E-3	0.16	0.,3689	0.03647
50	0.5116E-3	0.1725	0.3937	0.042
55	0.5323E-3	0.1836	0.4191	0.04804
60	0.5540E-3	0.1944	0.4472	0.0536
65	0.5768E-3	0.2093	0.4780	0.06046
70	0.6034E-3	0.225	0.5192	0.06737
75	0.6283E-3	0.2376	0.5626	0.0758
80	0.6586E-3	0.2534	0.6183	0.08735
85	0.6947E-3	0.2734	0.6783	0.102
90	0.7406E-3	0.2998	0.7520	0.1208
95	0.8093E-3	0.3336	0.8725	0.1503
100	0.1077E-2	0.5108	2.224	0.3064

Table A.31- Comparison of Risk in Water Lines for Each Field, Monte Carlo Results

FIELDS	10%	50%	90%
KW	-3.17E-03	2.97E-03	1.35E-02
BA	1.11E-04	1.98E-04	4.95E-04
MAL	1.11E-04	1.98E-04	4.95E-04
BAY	1.11E-04	1.98E-04	4.95E-04
Sİ	1.11E-04	1.98E-04	4.95E-04
SA	1.11E-04	1.98E-04	4.95E-04
KU	1.11E-04	1.98E-04	4.95E-04
BE	1.95E-04	6.79E-04	1.52E-04
KA	-1.07E-02	3.96E-03	1.13E-02

Table A.32- Comparison of Risk in Flow Lines for Each Field Monte Carlo Results

FIELDS	10%	50%	90%
KW	2.11E-04	2.97E-03	5.89E-04
BA	1.11E-04	1.98E-04	4.95E-04
MAL	1.11E-04	1.98E-04	4.95E-04
BAY	2.11E-04	2.98E-04	5.89E-04
Sİ	2.11E-04	2.98E-04	4.95E-04
SA	0.06864	0.1725	0.2998
KU	0.005142	0.05796	0.1885
BE	0.641	0.0339	1
KA	4.63E-04	1.22E-03	2.2E-03

Table A.33- Comparison of Risk in Return Lines for Each Field Monte Carlo Results

FIELDS	10%	50%	90%
KW	4.32E-03	1.29E-02	2.55E-02
BA	1.94E-02	4.51E-02	8.89E-01
MAL	8.96E-02	2.6E-02	8.44E-02
BAY	-6.64E-04	8.86E-04	5.61E-03
Sİ	6.56E-04	2.91E-04	0.026
SA	0.1941	0.3937	0.752
KU	0.08726	0.2105	0.3885
BE	8.85E-02	0.0258	2
KA	4.66E-03	1.7E-03	2E-02

Table A.34- Comparison of Trunk lines For Each Field Monte Carlo Results

FIELDS	10%	50%	90%
KW	1.11E-04	1.98E-04	4.95E-04
BA	1.11E-04	1.98E-04	4.95E-04
MAL	1.11E-04	1.98E-04	4.95E-04
BAY	1.11E-04	1.98E-04	4.95E-04
Sİ	1.11E-04	1.98E-04	4.95E-04
SA	1.11E-04	1.98E-04	4.95E-04
KU	1.11E-04	1.98E-04	4.95E-04
BE	4.04E-04	6.63E-04	1.02E-04
KA	1.11E-04	1.98E-04	4.95E-04