Risk analysis for construction and operation of gas pipeline projects in Pakistan

Abstract

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Looking its high energy demand, Pakistan is planning to import natural gas through pipelines from neighboring countries. For fully utilizing the imported gas, providing it to end customers, the infrastructure of gas pipeline is being developed. Therefore a huge investment is being carried out in this sector. During the last 10 years the network of main and distribution gas pipeline was expanded by 85%[6]. But the geological and geographical conditions of Pakistan are complex for the construction. On one side there are glaciers and high mountains, other side there is desert and plan of river Indus with extensive network of wide rivers and canals. There is always risk of earthquake, landslides and floods. Instable Government policies, high rate of inflation, rapid change in material prices are important risk factors. Looking the current geopolitics situation there is a persistent threat of war and terrorism in the country. All these factors make the situation very complex in quantifying the risk factors especially when the project is gas pipeline in which the impact factor of risk exponentially rise in case of risk occurrence. Moreover, due to the absence of modern project or risk management techniques and methodologies the projects are usually not completed in their planned time or budget. Effort has been made here to quantify the associated risks of gas pipeline project on the basis of historical data. The research will be helpful to separate the most important risks from the minor ones for the construction of any sort of pipeline project in the northern areas of Pakistan.

Introduction

Geological and geographical conditions of Pakistan are very complex. The Pakistan can be divided in three geographical zones: Northern Part, Plan of river Indus and the Baluchistan Plato. Almost 50 % of the total area of Pakistan is mountainous. The northern areas are having different chains of mountains coming from china and India (Himalaya, Korakurram) which meet with the mountain chains coming from Iran and Afghanistan (Koh Salman, Hindukush)in the northern areas of Pakistan [8]. There is also an extensive net work of wide rivers and canals in Pakistan. Figure 1 shows the GIS map of Pakistan showing topography and other important features of the region. The two continental plates i.e. Indian and Eurasian meet in Pakistan which highly effect the geodynamics of the region, due to that frequently earthquake of high intensity occurs in the regions e.g 8^{th} October, 2005 earthquake in which almost 86000 people were died and millions became homeless [10]. In summer temperature ranges between 45-50^{o}C due to that glaciers melt and melted water goes to the Indus water system. The monsoon rains which occurs during June to August raise the river flows to high extend and ultimately floods occurs. The statistics shows that big floods in the history occurred in summer. Considering geopolitics of the regions there is a persistent threat of terrorism and war. Probability of was and its effects are rising as the tension between America and Iran is increasing. The economic instability has added the problem due to that there is frequent change in economic parameters. All these are in fact potential risks for any construction project especially oil and gas pipelines in which risk are multiplied many fold and there is exponential rise in damage in case of occurrence of one or

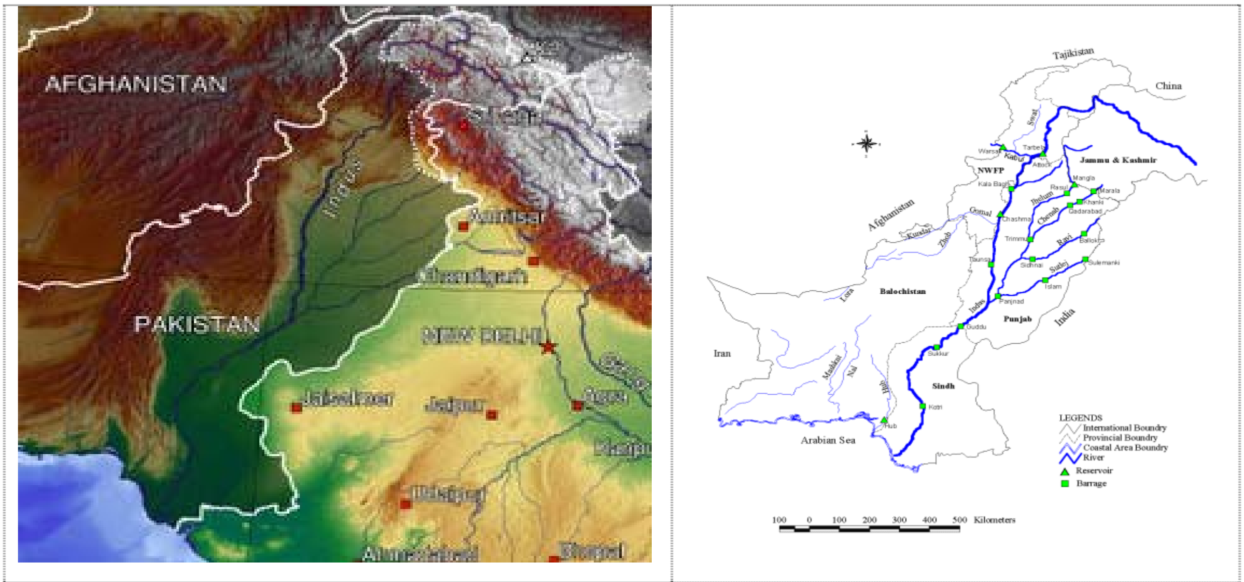

Figure 1.GIS map of Pakistan showing important geological and geographical features of the country

more risks resulting huge human and environmental losses.

Looking the high demand of energy sources, Pakistan is planning to import natural gas from neighboring country. Option of Turkmenistan, Iran and Qatar are available for gas import but Iran being at the top due to many reasons (Figure 2). Besides the investment of 4 billions dollars on the project Pakistan is also expending infrastructure for fully utilizing the imported gas. Therefore a huge construction is being carried out in this sector in Pakistan. During the last 10 years the network of main and distribution gas pipeline was expanded by 85%. Project Rawat-Muree gas pipeline, which is the latest project carried out in Pakistan in this sector was selected as the case study (completed in Nov 2006). It was the first time in the history of construction in Pakistan when the pipeline was laid on such a high altitude of 7000 feet. The project was not completed with in budget and time, therefore complete risk analysis is made. The results and recommendation can further be used in the construction of pipeline projects in Pakistan and especially in Northern and western Areas.

Figure 2. The routes of future gas pipeline project in the region.

In that context, it is necessary to identify, categorize, analyze, and manage risks in projects. Risks may be classified in a number of ways. Considering project life cycle of gas pipeline project in Pakistan we can mainly categorize risk in two ways.

- Risks during Construction
- Risk during Exploitation

On the basis of risk identification we can divide the risks into Risk Breakdown Structure (RBS) as shown in the figure 3.

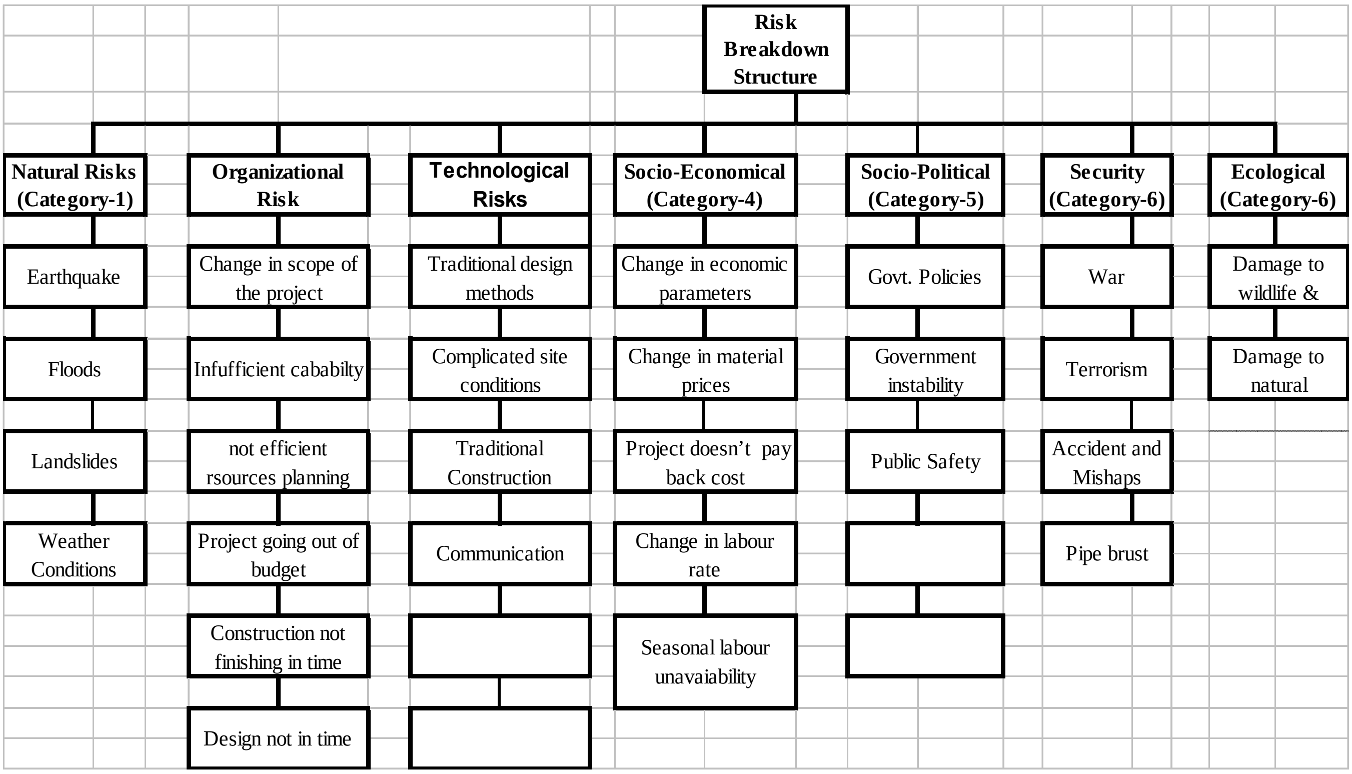

Figure 3. Risk Breakdown Structure of potential risks in gas pipeline construction sector

RBS make things more simple in visualizing the process of Risk assessment or analysis.
Once risks have been identified, they must then be assessed as to their potential severity of loss and to the probability of occurrence. Risk assessment/analysis is primarily a systematic and comprehensive methodology to evaluate risks associated with a complex engineered technological entity. Risk assessment is defined as a feasible detrimental outcome of an activity or action. Risk assessment process required two items

a. The magnitude (Impact) of the possible adverse consequence (risk), and
b. The likelihood (probability) of occurrence of each consequence.

Consequences are expressed numerically and their likelihoods of occurrence are expressed as probabilities or frequencies (i.e., the number of occurrences or the probability of occurrence per unit time). The total risk is the sum of the products of the consequences multiplied by their probabilities.

The fundamental difficulty in risk assessment is determining the rate of occurrence since statistical information is not available on all kinds of past incidents.

Furthermore, evaluating the severity of the consequences (impact) is often quite difficult for immaterial assets. Asset valuation is another question that needs to be addressed. Thus, best educated opinions and available statistics are the primary sources of information. Nevertheless, risk assessment should produce such information for the management of the organization that the primary risks are easy to understand and that the risk management decisions may be prioritized. Thus, there have been several theories and attempts to quantify risks. Numerous different risk formulae exist, but perhaps the most widely accepted formula for risk quantification is:

Rate of occurrence multiplied by the **impact of the event** equals **risk**

Risk Assessment usually answers three basic questions:

1. What can go wrong with the studied technological entity, or what are the initiating events that lead to adverse consequence(s)?
2. What and how severe are the potential adverse consequences that the technological entity may be eventually subjected to as a result of the occurrence of the initiator?
3. How likely to occur are these undesirable consequences, or what are their probabilities or frequencies?

The frequency of occurrence (probability) and impact factor of an event given by PMI can be utilized for risk analyses but they are more generalized and need expert judgment to utilized them. They can produce misleading results for the risk which have probability of occurrence very closer to each other. i.e difficult to chose value of probability 45-60% . In that way we can supersede some risks to the other. They can be used safely when the risks identified are less and risk management is not one of the first priorities. Risk impact factor defined by PMI are 0,1 to 0,9 depending upon the type and impact of event to the project. For risk modeling we need more precise value to risk. Therefore we need to pick independent event and required to gather historical data regarding to that risk. This historical data can be processes to obtain some information in the form of probability and impact of risk. Project Management Institute (PMI) defines Probability (rate of occurrence) and Impact of event are shown in Table 1;

Probability	Impact
90 % = very high chance 75% = High chance 60 = Greater chance 45% = Possible 30% = likely 15% = unlikely	0,9- when maximum impact on scope, time and cost 0,6-High impact on scope, medium impact on time and lesser impact on cost 0,3- High impact on time, medium impact on scope and lesser impact on cost 0,1-when high impact on cost of the project, medium impact on time and lesser impact on scope.

Table 1. Standard values of frequency of occurrence and Impact factors [12]

Statistical processing of historical data

In Pakistan, two continental plats i.e Indian and Eurasian meet together whish result in geodynamics activity in the region (figure 4). The phenomenon is much complex and intricate. History of earth quake occurrence reveals that that there had been sever earth quake in Pakistan in the past e.g 1935, 1940,1998,2005. For calculation purposes the data from Mangla seismology station, located in north areas has been utilized for further processing, which shows that the lesser is the intensity of earth quake more is the frequency of occurrence. For gas pipeline construction we are interested to know the possibility of earthquake occurrence in northern areas more than 3 rector scale (RS) intensity. 3 RS has been chosen because of the reason that at this intensity there may be not physical failure or rupture in the structures or pipelines but that vibration may cause a residual stress or strain in the pipeline or this may cause other incidents like Landslides.

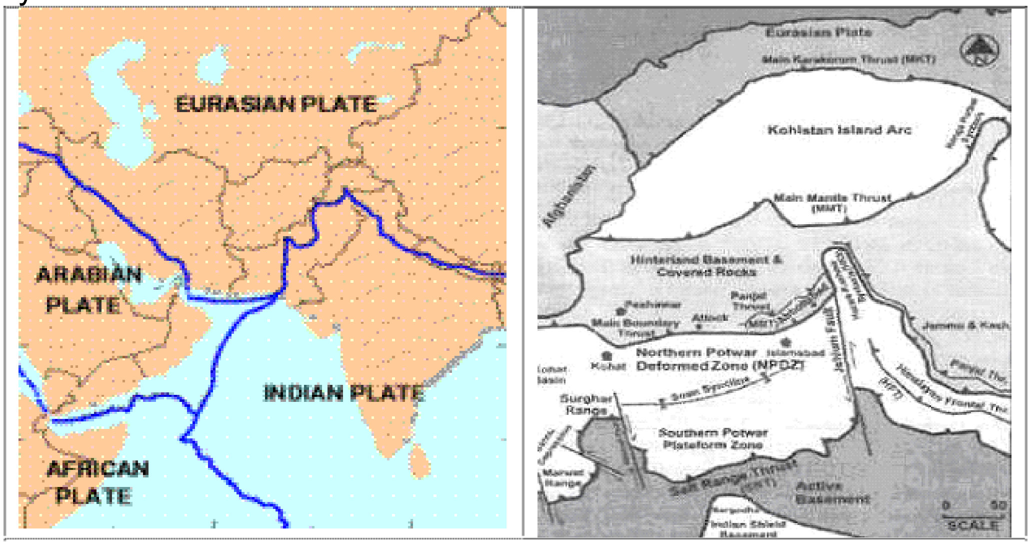

Figure 4. Characteristics of tectonic plates of northern area [10]

MAGNITUDE FREQUENCY DATA
Northern Area (Jhelam Zone) 1960-2005*

Magnitude	Cumulative Number Of Seismic Events > given Magnitude	Cumulative Number Of Seismic Events/Year (45 yrs period)	Magnitude	Cumulative Number Of Seismic Events > given Magnitude	Cumulative Number Of Seismic Events/Year (45 yrs period)
0,5	985	21,889	3,1	256	5,689
0,6	984	21,867	3,2	224	4,978
0,7	982	21,822	3,3	199	4,422
0,8	976	21,689	3,4	172	3,822
0,9	971	21,578	3,5	153	3,400
1	957	21,267	3,6	137	3,044
1,1	950	21,111	3,7	119	2,644
1,2	940	20,889	3,8	103	2,289
1,3	926	20,578	3,9	88	1,956
1,4	914	20,311	4	81	1,800
1,5	898	19,956	4,1	71	1,578
1,6	876	19,467	4,2	62	1,378
1,7	852	18,933	4,3	52	1,156
1,8	819	18,200	4,4	45	1,000
1,9	780	17,333	4,5	40	0,889
2	731	16,244	4,6	31	0,689
2,1	662	14,711	4,7	24	0,533
2,2	620	13,778	4,8	17	0,378
2,3	571	12,689	4,9	16	0,356
2,4	528	11,733	5	11	0,244
2,5	488	10,844	5,1	8	0,178
2,6	451	10,022	5,2	6	0,133
2,7	406	9,022	5,3	4	0,089
2,8	365	8,111	5,4	2	0,044
2,9	317	7,044	5,5	1	0,022
3	284	6,311	5,6	-	

Table 2. Historical earthquake data from 1960-2005, Northern Zone, Pakistan [10]

Using exponential distribution methods for probability calculation we get the probability of earthquake occurrence more than 3 RS as;

$$\mathrm{E}[X] = \frac{1}{\lambda}. \qquad \mathrm{Var}[X] = \frac{1}{\lambda^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\text{(Eq-1.1)}$$

$\lambda = 1 / 2.7 = 0.37$

$$P\,(X>3) = \int_3^{\infty} \lambda e^{-\lambda x} = [-e^{-\lambda x}]_3^{\infty} = e^{-0.37x3} = 32.95\%$$

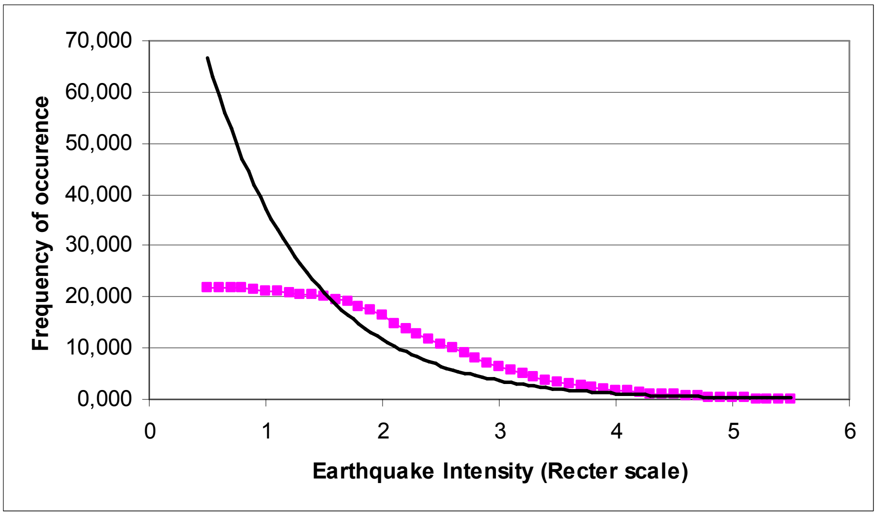

Figure 5. Graphical representation of earthquake data

Flood is an important factor in defining and analyzing risk in Pakistan. history prevails that a lot of historic floods occurred in Pakistan during last 50 years but still so far no strategy has been prepared to cater the flood. This factor is very important for pipeline construction and exploitation in the northern region due to some dominant floods occurrence in that regions in the past few years. Typical topography, steep slopes, high rainfall in a specific period (June-August) and high temperature are the dominating factors for intensifying the affects of floods.

Year	Loss (Billion $)	Loss of people (Number)	Effected Areas (KM^2)
1950	9.08	2,910	7,000
1955	7.04	679	8,000
1956	5.92	160	29,065
1973	5.52	747	16,200
1975	12.72	126	13,645
1976	64.84	425	32,000
1978	41.44	393	11,952
1981	--	82	--
1982	--	350	--
1988	15.96	508	4,400
1992	56.00	1,008	15,140
1995	7.00	591	6,518
2001	10.3	231	9,850
2005	20.0	520	5,691

Table 3. Flood History in Pakistan [2]

The flow histogram ten years from 1990-2001 (figure -6) shows that the river flow increase 10 times in the peak flood season. Flow is minimum in winter and maximum in summer. A normal curve can be made based on the formula. The normal distribution method is used for probability calculation of occurring flow more than 400MAF.

$$f(x;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) = \frac{1}{\sigma}\varphi\left(\frac{x-\mu}{\sigma}\right), \qquad \text{..........Eq-1.2}$$

$$\varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-x^2/2} \qquad \text{..Eq1-.3}$$

$$Z = \frac{X-\mu}{\sigma} \qquad \text{...Eq-1.4}$$

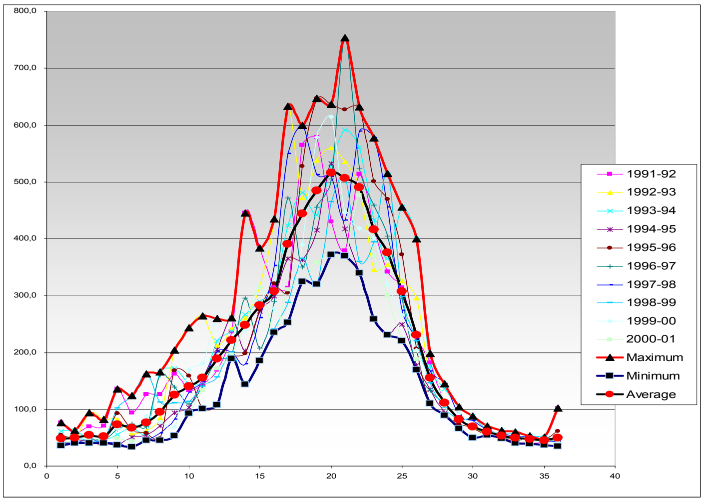

Figure 6. Graphical representation of flood data 1990-2001

On the basis of historical data the probability of river flow more than 400 (MAF) said to be flood is the sum of river flow at Terbela and Magla dam. Therefore, for the equation 1.4 X=350, mean (nu) = 196, standard deviation = 109 we calculate z, the area under the normal curve from normal probability tables. The probability of occurrence of flood more than 400 (MAF) discharge comes out to be 18,44%. Similarly other risks are quantified and noted in risk register on the basis of that further risk analysis is made.

Similarly processing the historical data for each identified risk was processed (Figure 7) and noted in risk register for further analysis (Table-4).

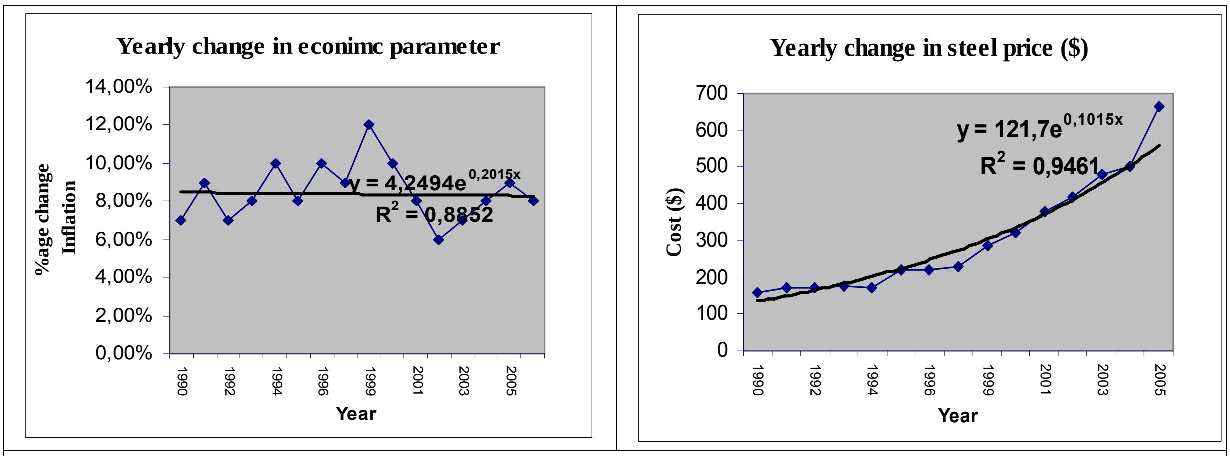

Figure 7. Change in economic parameters and material prices.

For analyzing security risks, It is required to study the previous terrorist attacks on the pipelines in that particular region. In the northern and east northern part the intensity of terrorism on pipelines are lesser than the west and south west region. (province of Balouchistan). Balouchistan has borders with Iran and Afghanistan.

History prevails that in last five years the total attacks made on the pipelines were 213(Figure-8). Only in the year 2005 the total no of attacks were 102. As major gas resources are located at Sui town in Balouchistan meeting almost 75 percent of gas demand in Pakistan therefore major transmission pipelines are running from Sui. Due to the internal political situation in this province gas exploitation or pipeline construction will always be in risk in this region. Unfortunately all the future mega pipeline projects are either running through this province or ending in this province at the newly developed city of Gawader.
Factors considering terrorism risk on pipeline construction and exploitation.

1. Total terrorism attacks with in the 100 km range of the project.
2. Internal situation of country, internal politics and polices in the region.

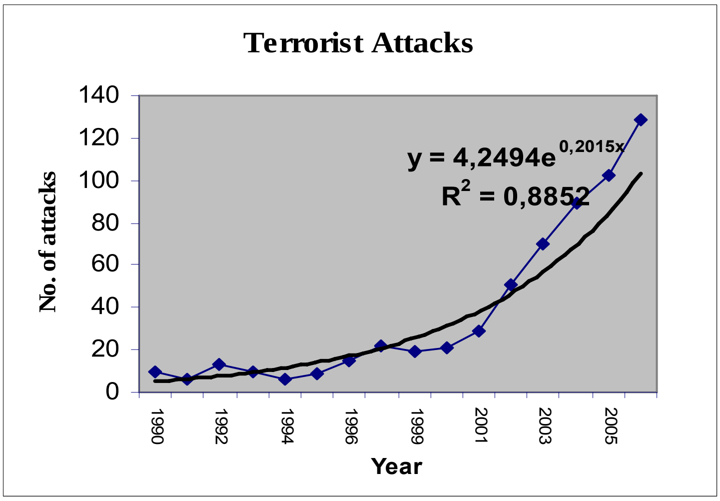

Figure 8. Graphical representation of terrorist attacks trend line.

The risks related to organizational relationships may appear to be unnecessary but are quite real. Strained relationships may develop between various organizations involved in the design/construct process. When problems occur, discussions often center on responsibilities rather than project needs at a time when the focus should be on solving the problems. Cooperation and communication between the parties are discouraged for fear of the effects of impending litigation. This barrier to communication results from the ill-conceived notion that uncertainties resulting from technological problems can be eliminated by appropriate contract terms. The net result has been an increase in the costs of constructed facilities.

The risks related to technological problems are familiar to the design/construct professions which have some degree of control over this category. However, because of rapid advances in new technologies which present new problems to designers and constructors, technological risk has become greater in many instances. Certain design assumptions which have served the professions well in the past may become obsolete in dealing with new types of facilities which may have greater complexity or scale or both. Site conditions, particularly subsurface conditions which always present some degree of uncertainty, can create an even greater degree of uncertainty for facilities with heretofore unknown characteristics during operation. Because construction procedures may not have been fully anticipated, the design may have to be modified after construction has begun. An example of facilities which have encountered such uncertainty is the nuclear power plant, and many owners, designers and contractors have suffered for undertaking such projects.The environmental protection movement in Pakistan has contributed to the uncertainty for construction because of the inability to know what will be required and how long it will take to obtain approval from the regulatory agencies. This delay in approval practically influence on total costs of the project. Public safety regulations have similar effects, which have been most noticeable in the energy field involving nuclear power plants, oil and gas pipelines and coal mining. The situation constantly change guidelines for engineers, constructors and owners, as projects move through the stages of planning to construction due to the change in govt. policies. These moving targets add a significant new dimension of uncertainty which can make it virtually impossible to schedule and complete work at budgeted cost.

Risk Identification		Risk Register									
		Risk Analysis			Strategy for negative risks			Decision			
Cat. Risk	Risk	Possibility (P)	Impact (I)	Risk Score (RS)	Avoid	Transfer	Mitigate	Passive	Active		
1	Earthquake	32,95%	0,9	29,65%			✓				
1	Floods	18,44%	0,9	16,59%			✓				
1	Landslides	21,1 %	0,3	6,33%			✓				
1	Unexpected weather conditions	25,72%	0,6	15,42%			✓				
2	Change in scope	11,9 %	0,6	7,14 %			✓				
2	Insufficient technology	15%	0,3	4,5%		✓					
2	Construction not finished in time	29,65%	0,3	8,89 %		✓					
2	Availability of Finances	10.1 %	0,9	9,09%	✓						
2	Ineffective resource planning	30,1%	0,3	9,03 %		✓					
2	Project not finishing within budget	13,12%	0,6	7,87 %		✓					
3	Design not in time	15,8 %	0,3	4,75 %		✓					
3	Unexpected obstacles on site	18,8 %	0,3	5,64 %			✓				
5	Unstable Govt. policies	25,9 %	0,6	15,4 %	✓						
5	Public Safety in danger	9,1 %	0,9	8,19%			✓				
5	Change in economic parameter	29,1%	0,9	26,19%			✓				
4	Change in material price	32,63%	0,3	9,78%		✓					
4	Project doesn't pay back its cost	9,8%	0,6	5,88%			✓				
6	War	14,9 %	0,9	13,5%	✓						
6	Terrorism	21,2%	0,9	13,5%		✓					
7	Damage to Environment and wild life	9,75%	0,6	5,85 %		✓					
7	Damage to natural resources	30%	0,3	9,0 %		✓					
7	Accident or pipe blast	11,9 %	0,9	10,71%		✓					

Table 4. Formulation of Risk Register.

Risks quantified in Risk Register are plotted on graph with ascending order. Any other method can be used for further identification of critical risk. Pareto analysis has been used (20%-80% rule) to separate the most critical risks from the minor many.

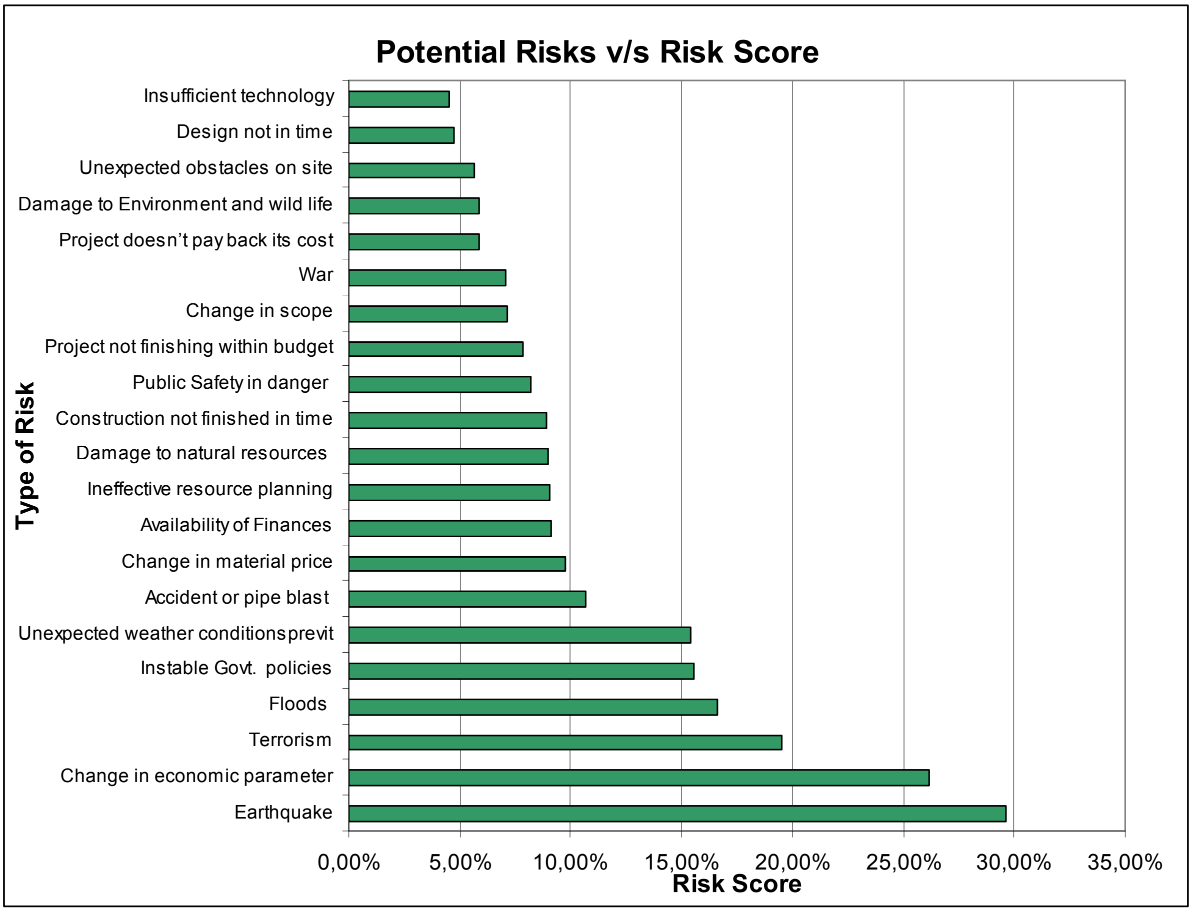

Figure 9. Plotting of risks on the basis of Risk score.

Results and Recommendation.

1. Looking the risk scores, the most critical risks come out to be Earthquake, change in economic parameters, terrorism and floods during construction and operation of gas pipelines.

2. The secondary risks like change in material prices, construction not finished in time or budget can be reduced or transferred to the other party or organization by contract.

3. Organizational or technological risk like insufficient resource planning or project management, change in scope etc can be eliminated by improving the process or application of new technologies available in this field. New state of the art technologies are helpful in managing change at any stage of the project.

4. Earthquake risks during construction phase depends on the length of execution of project and only impact on the construction cost of the project. As the duration of the execution increases probability of occurrence of risk also increase. However, in operation phase this risk must be eliminated by practicing design based on earthquake/horizontal forces.

5. Historical data of river flows shows that the flood has probability of 95% of occurrence between June to August. This risk can be minimized during construction phase by rearranging the construction schedule. Other risks like landslides are associated with floods, rain fall or earthquakes.

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