Measuring the Benefit of the Investment in Pipeline Safety Using Fuzzy Risk Assessment

$$B_m = \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{k=1}^{Q} P(\theta_i \parallel failure)\cdot L_{jk}\cdot P(\beta_k \parallel \theta_i)\cdot \Delta R_{ijk} - C_m$$

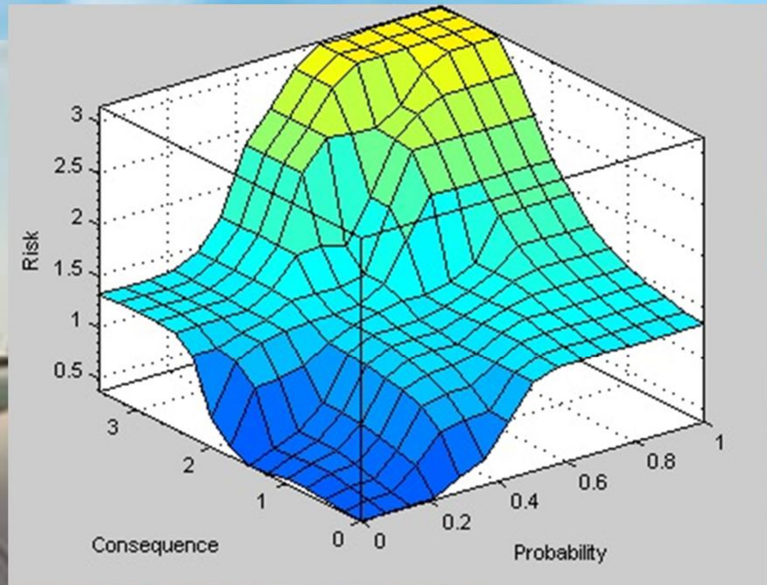

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Image source: http://www.ecopetrol.com.co/especiales/Informe_Gestion_Empresarial_y_Finanzas_2009/finan-expansion.htm

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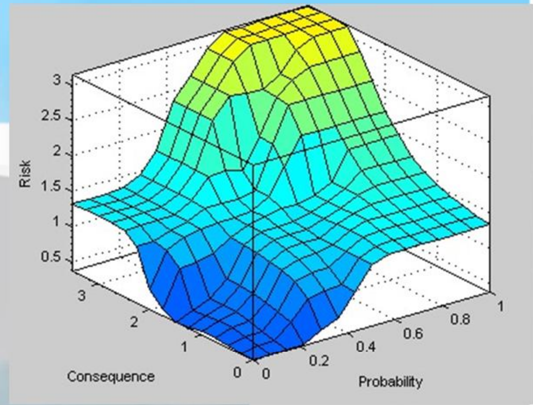

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1. Introduction

1.1 Background and Significance of the Research

- Oil & Gas represent the significant amount of 62% of the total world energy supply (IEA, 2013).
- Pipelines represent the most important asset used through all supply chain.
- Total of more than 1.9 millions of kilometers worldwide (CIA World Factbook, 2008).

Image source: http://www.gazprom.com/about/production/transportation/

Photo source: http://abclocal.go.com/kgo/story?id=8368158

- 8 People Killed and 58 Injured
- 38 Homes destroyed and 70 damaged
- Caused due to inadequate pipeline safety management

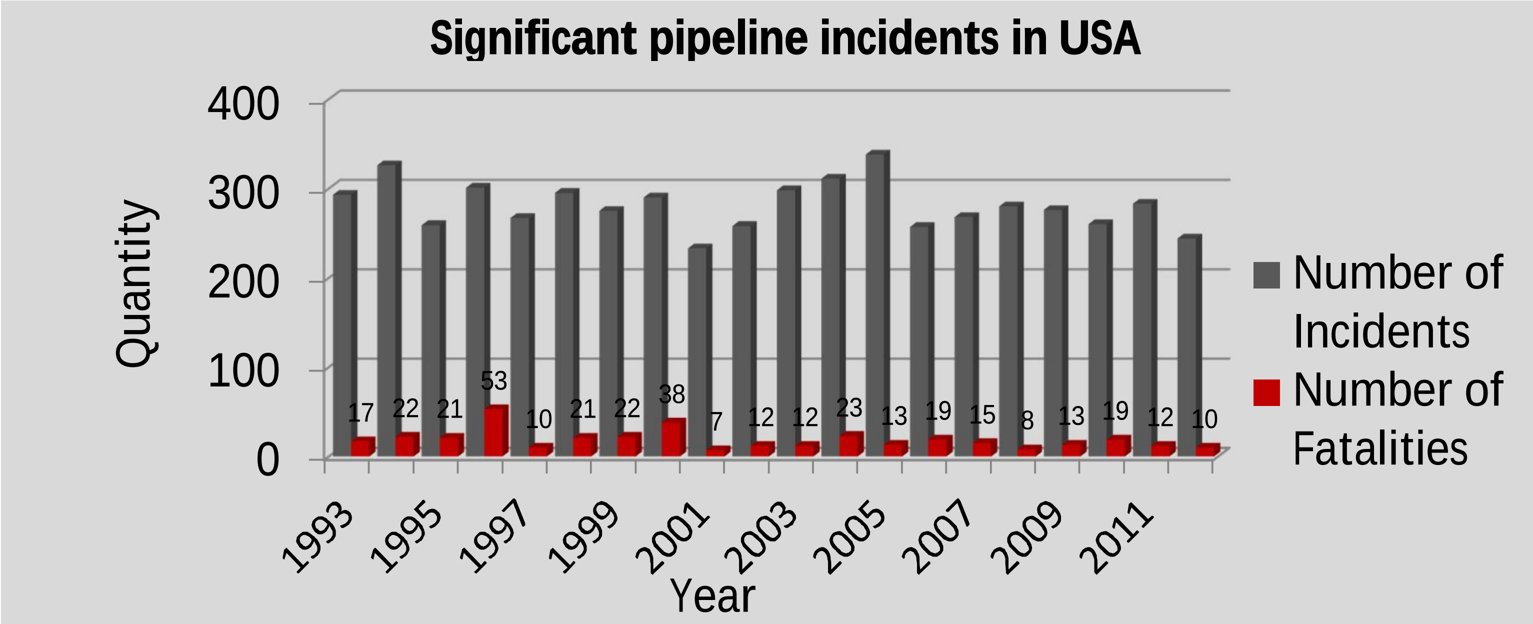
(U.S. National Transportation Safety Board, 2011)

hoto Source: http://online.wsj.com/news/articles/SB10001424127887323394504578610161692919702

1. Introduction

1.1 Background and Significance of the Research (Cont.)

- San Bruno ,CA. Natural gas pipeline explosion on September, 2010.



Only in the U.S., according to PHMSA (2013), for the last two decades:

- Significant incidents in pipelines were 5,612
- Number of fatalities of 367
- Property damage of 6.6 billion dollars and 2.3 mill. of spilled barrels

1. Introduction

1.1 Background and Significance of the Research (Cont.)

Current situation:

- Aging of the pipelines
- Changing the public awareness about risk
- Emphasis on public health and safety
- And increasing requirements set by regulating bodies (Lutchman R, 2006).

The pipeline operators must re-build their risk assessment and decision making methodologies to show benefits of safety!

Photo sources: http://www.esquire.com/blogs/politics/xl-keystone-pipeline-protest-6546942 and http://www.downwindersatrisk.org/2014/02/either-way-is-keystone-decision-really-game-over/keystone-pipeline-protest/.

1. Introduction

1.2 Problem Statement

- Pipeline operators are unable to justify the expenditure in safety as an investment with a quantifiable return.
- Because most decision frameworks for invest in pipeline safety are developed for initial risk prioritization (Stewart, 2009).
- Those frameworks are developed under a considerable amount of uncertainty derived from subjective judgement or lack of information.

1. Introduction

1.3 Research Questions

- How the pipeline operators can evaluate the benefit of investment in safety measures in quantitative terms of risk mitigation?

- How could be improved the precision of the risk assessment values under the common amounts of uncertainty caused by the lack of information and subjective judgment?

* Photo source: http://www.marksmithinspectionservices.com/apps/photos/photo?photoid=87846310, http://business.financialpost.com/2013/03/02/pipelines-in-canada-sophisticated-arteries/?__lsa=e46a-2597

1. Introduction

1.4 Objectives of the research

This study aims to:

- 1. Establish a methodology to evaluate the benefit of the investment in pipeline safety measures in quantitative terms of risk mitigation.

- 2. Provide a framework to estimate the value of the pipeline risk using the probability theory of the Fuzzy logic to deal with the uncertainty of the data.

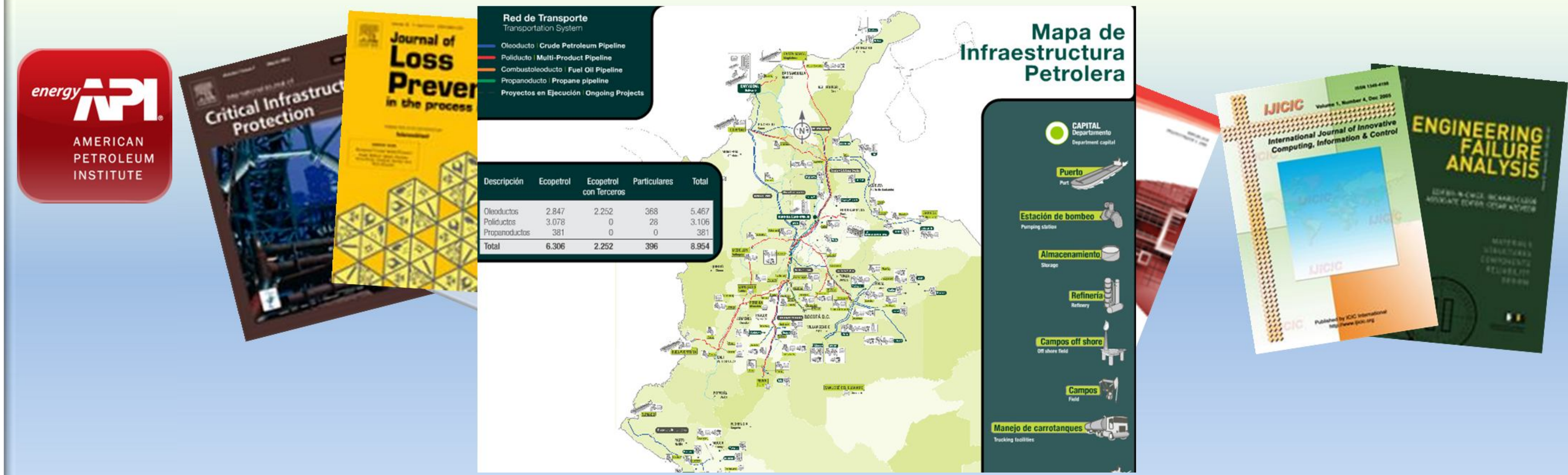
- 3. Integrate the techniques of fuzzy risk assessment and cost benefit analysis to improve the decision making process in the pipelines safety management.

Image source: http://www.tinawilliamsdesigns.com/tag/objectives/

2. Method and Key Concepts

2.1 Research Method

- Desktop Research using the most relevant and updated sources in the field of safety management, asset management and Risk & Reliability.



- Case study for the application of the methodology proposed.

Images source: http://350.org/big-oil-messes-and-announces-keystone-xl-victory-realizing-they-lost/--http://www.journals.elsevier.com/--http://www.ijicic.org/--http://www.emeraldinsight.com/-journals.htm?issn=0265-671X---http://www.speciation.net/Database/Journals/Journal-of-Hazardous-Materials-;i588---http://www.speciation.net/Database/Journals/Journal-of-Hazardous-Material

2. Method and Key Concepts

2.2 Key Concepts

Net Benefit: Evaluating various investment alternatives, a firm tends to consider the surplus of the expected revenue (Benefits) and its expenditure (Costs). (Boardman et al, 2006).

$$NB = \sum_{i=1}^{N} B_i - C_i$$

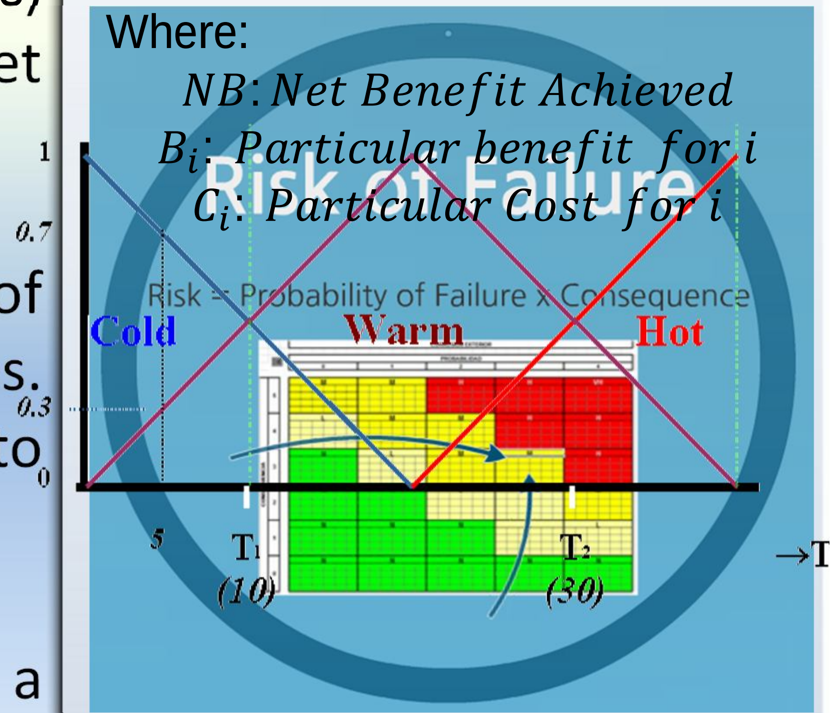
Where:

$NB: Net\ Benefit\ Achieved$

$B_i: Particular\ benefit\ for\ i$

$C_i: Particular\ Cost\ for\ i$

Risk: A combination of the probability of an event and its consequences. Consequences can range from positive to negative (IRM, 2010).

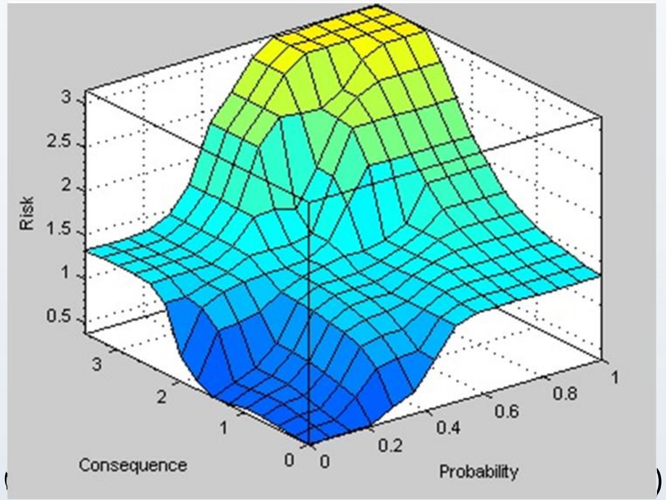


Fuzzy Sets: A class of objects with a continuum of grades of membership (Zadeh, 1965).

Image source: http://sci2s.ugr.es/keel/links.php

3. Results

3.1 Fuzzy Risk Assessment



*Risk Matrix developed using fuzzy risk assessment

- Risk assessment involves complex models to determine probabilities and consequences of failure.
- Models with large amount of variables and lack of information.
- Fuzzy logic establishes a link between deterministic and human conceptualization values.

3. Results

3.1 Fuzzy Risk Assessment (Cont.)

- The process of Fuzzy Risk Assessment is described as follows:

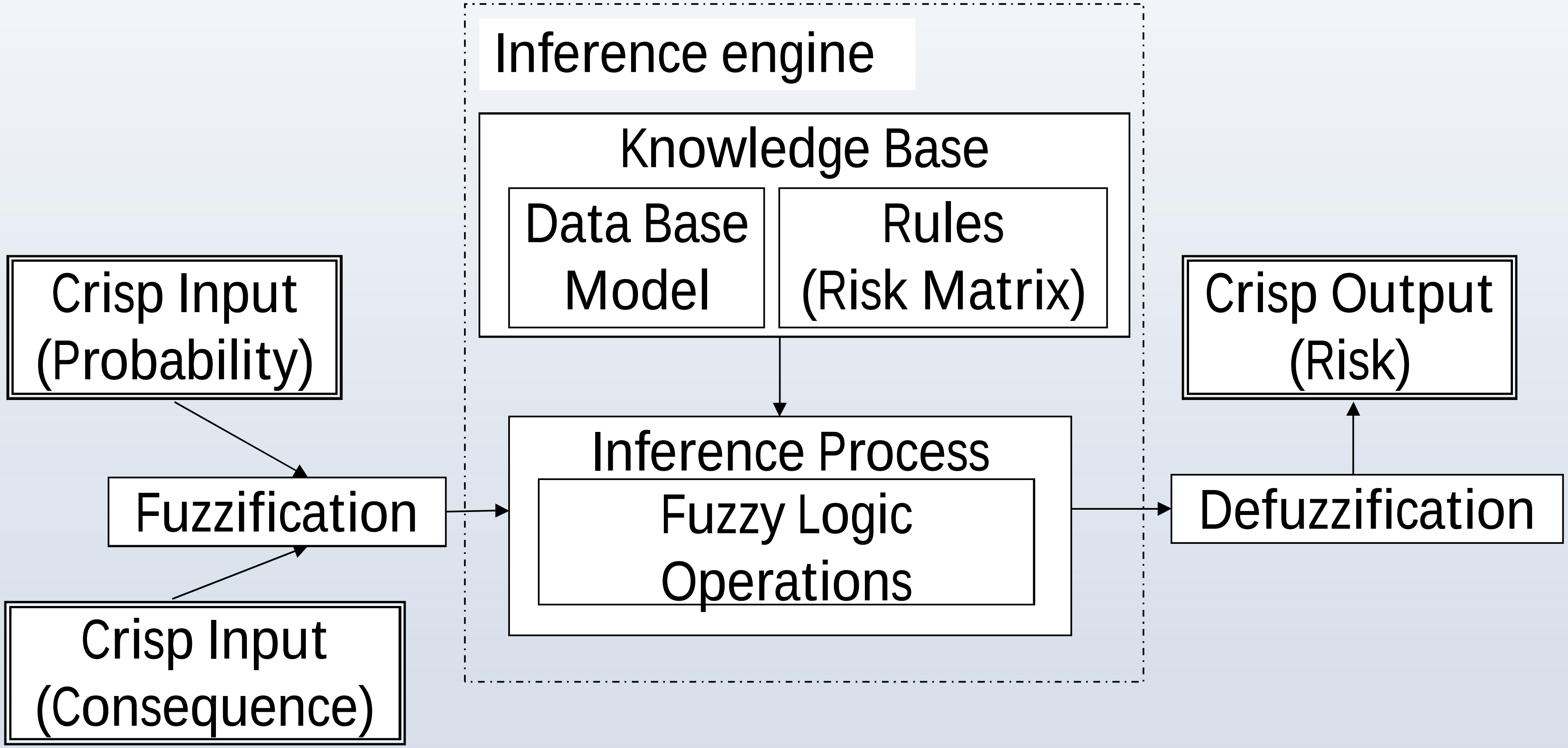


Figure of the structure of fuzzy inference system to estimate risks.

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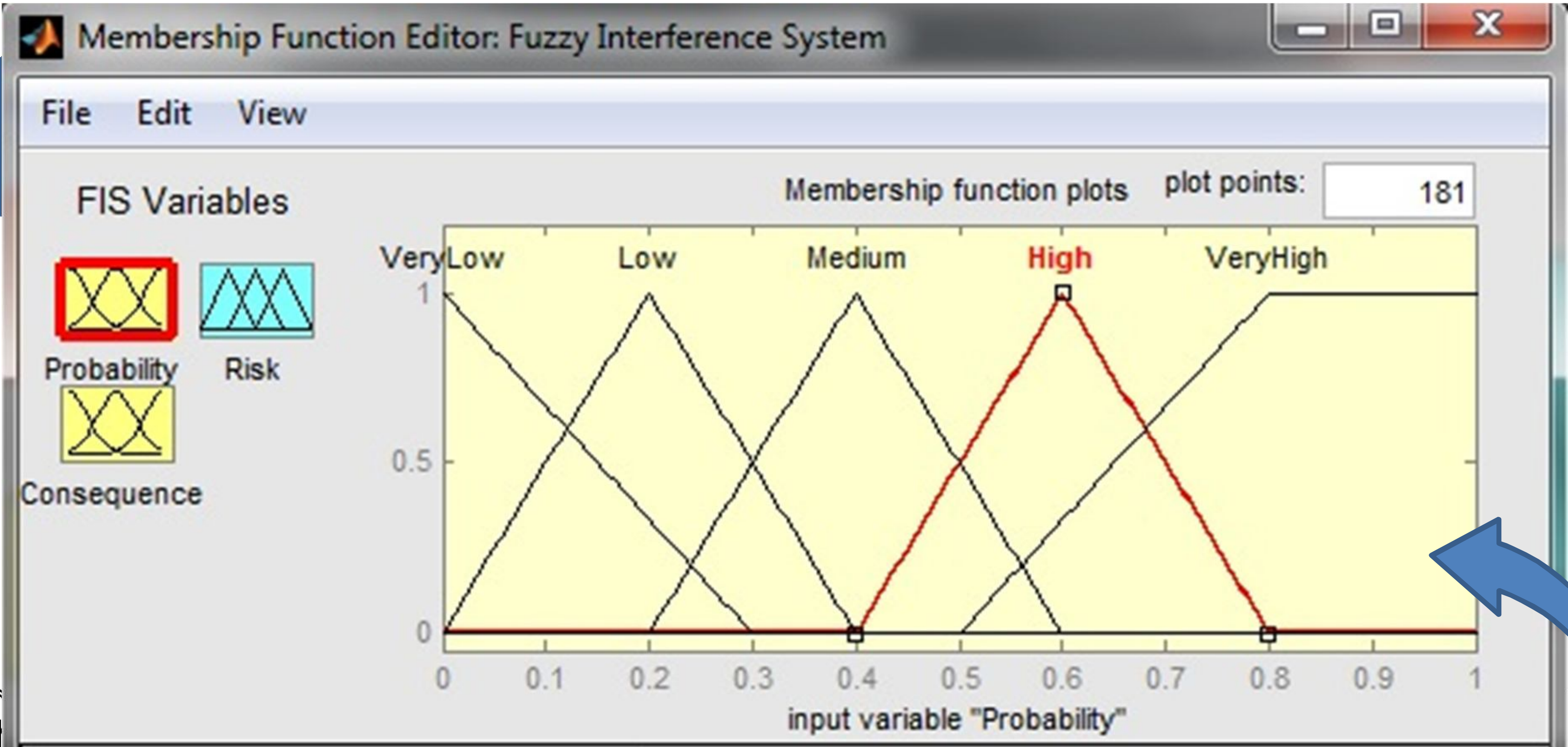

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Table 5 Probability ratings for crisp and fuzzy values

Threat (θ_i)	Linguistic term	Probability crisp rating	Probability fuzzy rating
Third Party / Mechanical - Damage	Very High	0.80	$0.5 < \theta_{TPD} \leq 0.8$
	High	0.60	$0.4 \leq \theta_{TPD} < 0.8$
	Medium	0.40	$0.2 \leq \theta_{TPD} \leq 0.6$
	Low	0.20	$0 \leq \theta_{TPD} \leq 0.4$
	Very Low	0.00	$0 \leq \theta_{TPD} < 0.3$
External Corrosion	Very High	0.80	$0.5 < \theta_{EC} \leq 0.8$
	High	0.60	$0.4 \leq \theta_{EC} < 0.8$
	Medium	0.40	$0.2 \leq \theta_{EC} \leq 0.6$
	Low	0.20	$0 \leq \theta_{EC} \leq 0.4$

*Source: Jamshidi et al. (2012)

*Matlab FIS Editor

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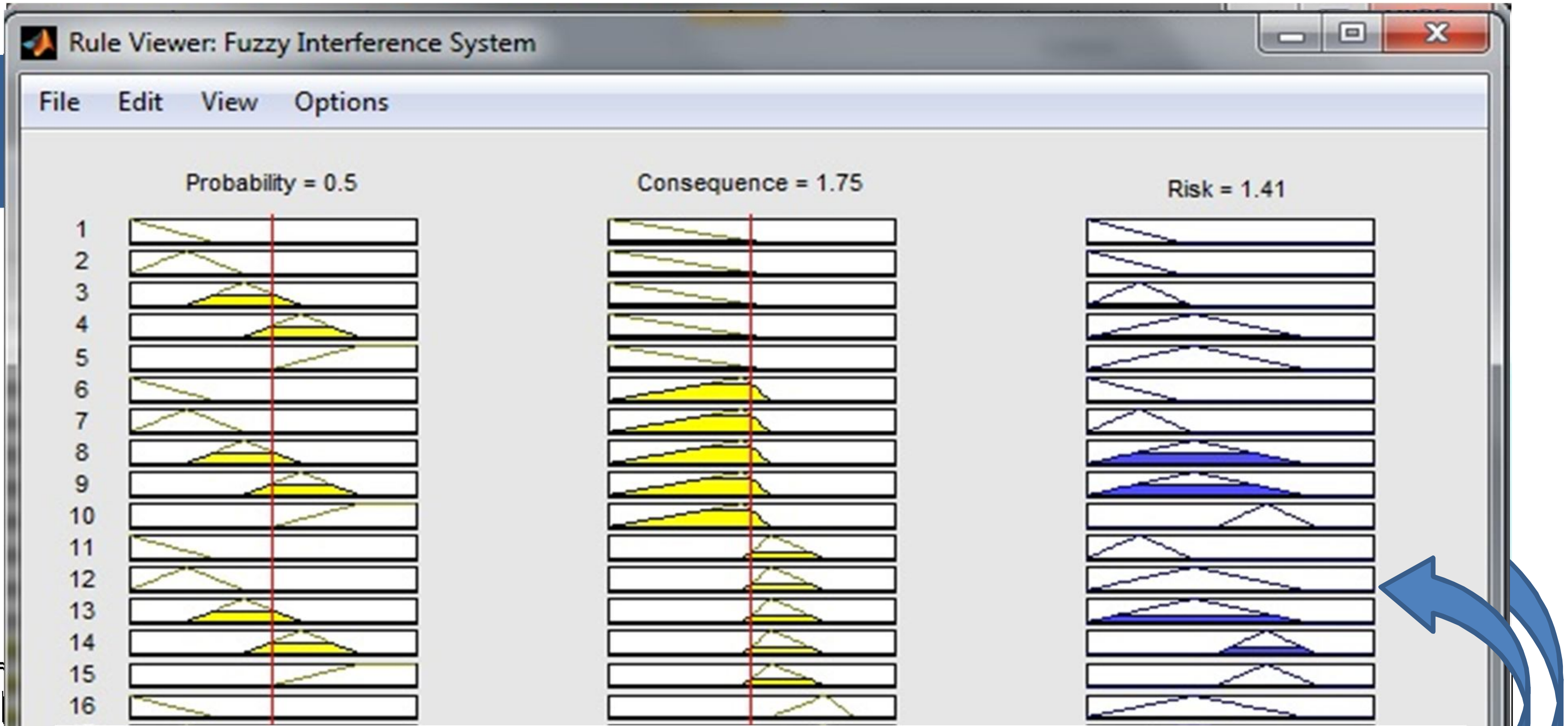

Consequence	Very High	Medium	Medium	High	Very High	Very High
	High	Medium	Medium	High	High	Very High
	Medium	Low	Medium	Medium	High	High
	Low	Very Low	Low	Medium	Medium	High
	Very Low	Very Low	Very Low	Low	Medium	Medium
		Very Low	Low	Medium	High	Very High
		Probability				

Opened system Fuzzy Interference System, 25 rules

Help Close

*Source: Risk Matrix for natural gas release (Shahriar et al., 2011)

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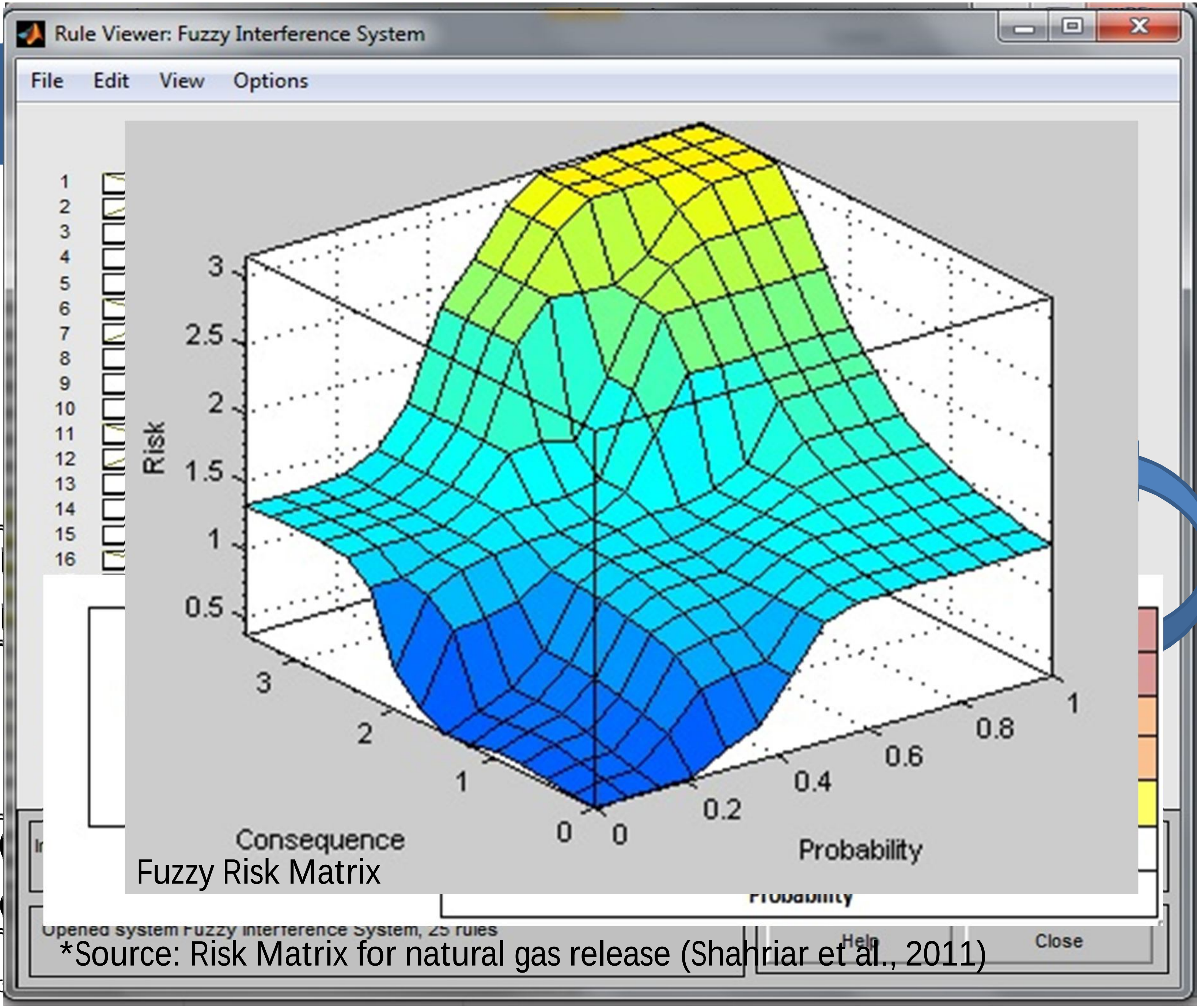
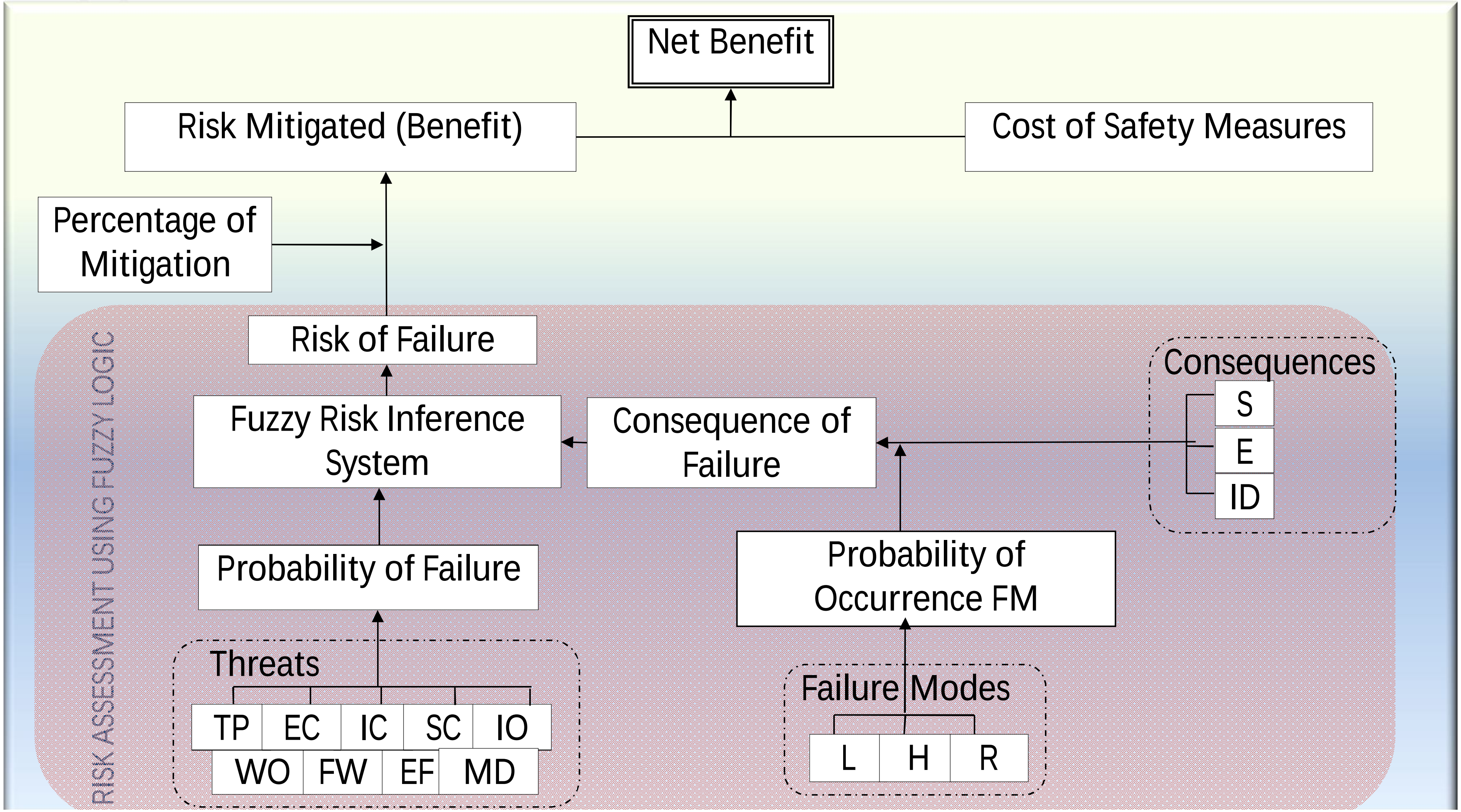


*Source: Risk Matrix for natural gas release (Shahriar et al., 2011)

Figure c

3. Results

3.2 Benefit Measurement Framework



3. Results

3.2 Benefit Measurement Framework (Cont.)

Net Benefit

Mathematically the benefit model is expressed as:

$$B_m = \sum_{i=1}^{M}\sum_{j=1}^{N}\sum_{k=1}^{Q} P(\theta_i \parallel failure) \cdot L_{jk} \cdot P(\beta_k \parallel \theta_i) \cdot \Delta R_{ijk} - C_i$$

Where:

$B_m = Net\ Benefit\ of\ the\ safety\ measure,$

$M = Threats,\ N = Consequences,\ Q = Failure\ Modes$

$\theta_i = Threat\ of\ failure,\ \beta_k = Mode\ of\ failure,$

$P(\theta_i \parallel failure) = Relative\ Probability\ of\ Failure\ for\ the\ Threat\ i,$

$L_{jk} = Consequence\ of\ failure\ j\ given\ the\ failure\ mode\ k,$

$P(\beta_k \parallel \theta_i) = Probability\ of\ the\ ocurrence\ of\ the\ failure\ mode\ k\ for\ the\ Threat\ i,$

$\Delta R_{ijk} = Perecentaje\ of\ Risk\ Reduction\ for\ a\ given\ measure\ ,$

$C_i = Cost\ of\ the\ given\ measure\ for\ the\ threat\ i$

4. Case Study

- Selection criteria: Availability of information and the openness for new technological development.
- Properties of the Pipeline selected: Length of 471 Kilometres and diameters of 18, 20 and 24 inches along the way.
- The pipeline is virtually divided into 165 segments along its way.

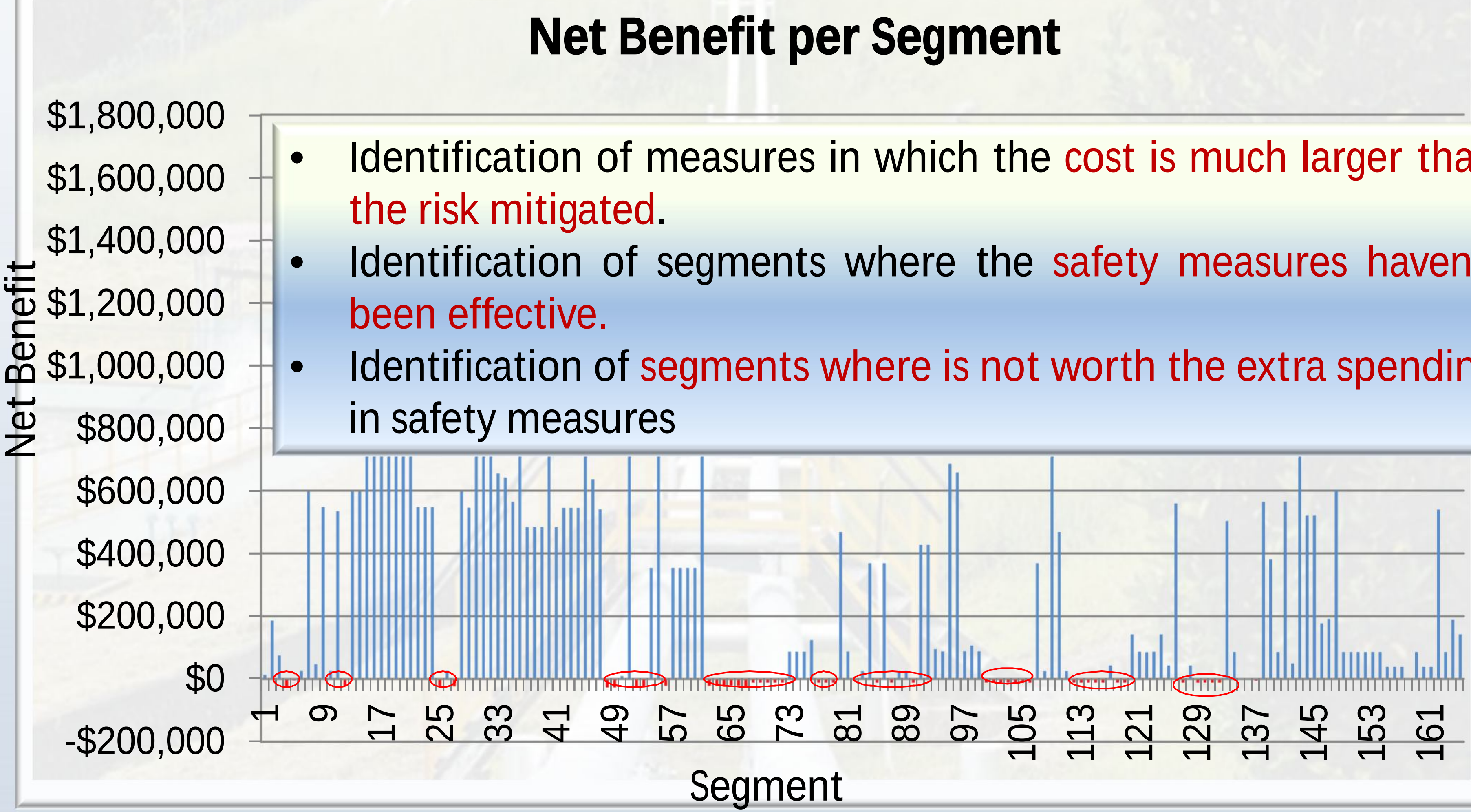
Table of data for the Segment # 1

Threat	Probability	Total Consequence [USD]	Fuzzy Risk Value [USD]	Percentage of mitigation	Cost of the Measure [USD]	Net Benefit [USD]
TP	0.00	$23,238,258	$457	0.30	$2,349	-$2,212
EC	0.50	$647,736	$181,970	0.20	$21,368	$15,026
IC	0.20	$647,736	$912	0.40	$420	-$55
					Total	**$12,760**

Photo Source: http://www.ecopetrol.com.co/especiales/carta_petrolera125/ingles6.htm

4. Case Study

Analysis of the Results



- Identification of measures in which the cost is much larger than the risk mitigated.
- Identification of segments where the safety measures haven't been effective.
- Identification of segments where is not worth the extra spending in safety measures

5. Conclusions & Further Research

- The application of the benefit model aims to demonstrate intangible returns of the investment in safety activities specifically in areas where the risk of failure of the pipeline is high from a social, environmental or economical perspective.

- Although the selection of the risk assessment approach depends on factors related with the environment and the quality of the information available, the most efficient and accurate assessment could be achieved by a combination of qualitative and quantitative methods.

- The quantification of the benefit should be evaluated with an accurate estimation of failure consequences. However, to estimate these consequences, the models usually requires a huge amount of data that generally is not available. Then the most suitable methodology is prioritizing where the largest consequences are expected.

Further Research:

- Application of time value of money
- Detailed estimation of risk mitigation
- Detailed estimation of consequences

6. References

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THANK YOU!

Image source: http://www.ecopetrol.com.co/especiales/Informe_Gestion_Empresarial_y_Finanzas_2009/finan-expansion.htm