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By Kingsley E. Abhulimen

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MODELLINGPERSONNELSAFETYONFLOATINGPRODUCTIONSTORAGEANDOFFLOADING FPSOSYSTEMS

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I. Introduction

Modern day research work on personnel risk analysis focus on safety of complex production systems to determine equipment, instruments and hazards critical to risk and reliability design (Caoeatal (2010), Suardin et.al (2009), Liuetal, 2004, Abhulimen, 2009, Abhulimen and Susu, 2002). Several risk techniques such as fault tree analysis, bow tie, failure mode effect and critical analysis (FMECA), Layers of protection and safety assessment management techniques are available in technical literature (Yang, JB and Singh, M.G (1994), Khan, F.L and Abassi S.A, 1991, Khan, F.L and Abassi S.A, 1998). Nevertheless, none of these methods address prioritizing equipment and process systems critical to optimizing personnel safety (Caoeatal (2010), Suardin et.al (2009), Liuetal, 2004). The personnel safety analysis framework implemented within any risk model are based on the following criteria 1) Selection of a safety strategy on hazard of different component of the system. 2) Appropriating basis for accessing information on redundant systems not critical to the safety of the process or facility. 3) Allotting measures for the correlation of complexity of risk and safety pair of complimentary hazards and reliability systems to prevent loss in containment. 4) Evaluating performance and effectiveness of safety systems. This paper explores the use of pinch technique to achieve effective planning of personnel safety to minimize threat and optimized crises management on an FPSO operated by a Nigerian Deep water oil and gas operator.

Author: e-mail: syntechsysglobal@gmail.com

II. Risk Assessment Method using Weight Index

Abhulimen presented a model for analysing safety of series and parallel risk systems which incorporates the weighted safety factors represented below

For series systems, risk potential is defined

$$Risk\ \ Potential = \frac{\prod_{i=1}^{n} r_i^{\omega_I}}{1-\prod_{i=1}^{n}(1-R_{si})^{\omega_I}} \qquad (1)$$

For Parallel Based Risk Systems

$$Risk\ \ Potential = \frac{\prod_{i=1}^{n} r_i^{\omega_I}}{1-\prod_{i=1}^{n}(1-R_{si})^{\omega_I}} \qquad (2)$$

r_i is the risk variable and R_{si} are the reliability of systems, and ω_I are the associated weights to the risk, where risk is defined by eqn. 3

$$\mathbf{r_i(t) = 1 - e^{-\lambda_\omega t}} \qquad (3)$$

The reliability is obtained by making a subtraction of the risk from 1 to give reliability of of the risk component presented in eqn 4.

$$R_{si} = 1 - r_i(t) \qquad (4)$$

For parallel risk systems we present hazard function as the algebraic sum presented as eqn.5

$$\lambda_{\omega P} = \sum_{i=1}^{N} \omega_i \lambda_i \qquad (5)$$

For series risk systems we present the hazard function as the product sum of hazard rates of the indvdual components:

$$\lambda_{\omega S} = \prod_{I=1}^{N} \lambda^{\omega_i} \qquad (6)$$

The weight index is given by equation 7:

$$\omega_i(t) = (1 - \mathrm{SRF}_i)\left(\frac{t}{\eta_i}\right)^{\beta_i - 1} \qquad (7)$$

SFR_i is a safety factor to different hazard systems, t is the time, η_i is the maximum time for the system to have 66.7% of failure from the weibull classification, β_i and is the hazard shape function.

a) *Safety Targeting by Pinch Technique:* A new technique based on pinch analysis is presented to model management of safety of personnel resources on complex Floating production and process systems. The method is stated below:

1. Assign three event domains in risk analysis in a typical Bowtie:

Event domain 1: Primary hazards system's generating threat streams:

Event Domain 2: Secondary threat streams from the hazard events Domain:

Event Domain 3: Safety controls strategy to contain threats from releasing containments for credible accident scenarios.

2. Define a transshipment model as in a hierarchy. See Figure 1
3. Deploy pinch method to resolve personnel safety without compromising the risk and threat domain matrix
4. The pinch point is located at the point when net risk transfer is zero based on the cascaded design.
5. Figure 1 is a Bow Tie Transshipment model. $\Delta\lambda_n$ is a risk-threat stream and $\lambda_{j+1h} = \lambda_{jh} - \Delta\lambda_h$ is the risk-non threat streams between $h = 1.,2........n$ and added to the risk –non threat stream $\lambda_{j+1c} = \lambda_{jc} + \Delta\lambda_h$ $h = 1.,2........n$ and $c = 1.,2........m$. The safety utilities are used to protect that is: $r_i(t) = 1 - e^{-\lambda_\omega t} = 0$
6. Therefore, threat in step 5 is transfer across boundaries to reduce its risk-threat load such that $\lambda_{j+1h} = \lambda_{jh} - \Delta\lambda_h$, and safety utilities are added as $\omega_{j+1h} = \omega_{jh} + \Delta\omega_h$ and vice-versa as $\omega_{j+1c} = \omega_{jc} - \Delta\omega_c$

Step 1 to Step 6 establishes a transshipment model design to achieve risk reductions in complex production risk process which can be determined in two domains- Level 1 and Level 2 below:

i. *Level 1*

The systems and subsystems in a Bow-Tie are arranged in order of the risk hierarchy with riskier systems located at the top of the transshipment superstructure and less risky systems place at the bottom of the transshipment superstructure and labeled in that order $h = 1.,2........n = r$ representing the risk-threat utilities and $c = r+1, r+2,........m$ representing the risk-non threat streams with the pinch point located r.

ii. *Level 2*

A) The e-Learning tableau tracks plant, process hazard or accident history, risk structure in variables, age, and asset integrity in a defining linear programming tableau.
B) The e-Learning database program receives series of instructions to optimize archiving of hazard data and lessons learnt from previous threat events.
C) The e-Learning model analyzes data output by a key factor K_h within a database e-Learning module using a neural network training program.

b) *Safety Targeting-Pinch Criteria*

Pinch methods assume the following:

1. There are no non threat (safety) utilities/systems above the pinch point
2. There are no net risk at the pinch point, the net risk is zero
3. There are threat (threat) utilities/systems below the pinch point.
4. Transshipment Model of the Bow Tie System

   H- Threat Stream (Riskiest)
   C- Non threat Stream (Safest)
   N –Risk Components- Unprotected 1- Safest System well protected

On a Scale of 10

Hazard		Linguistic Logic	Numerical Constants
$F_{FR}(0)$	-1	Very Low (Negligible)	(VL)
$F_{FR}(1)$	0	Low	(Lo)
$F_{FR}(2)$	1	Reasonably Low	(RLo)
$F_{FR}(3)$	3	Average	(A)
$F_{FR}(4)$	5	Reasonably Frequent	(RF)
$F_{FR}(5)$	7	Highly Frequent	(HF)
$F_{FR}(6)$	9	Too Frequent	(TF)
$F_{FR}(7)$	-11	Worst Case	(WC)

CS is the numerical ranking of severity of failure effects. The linguistic terms are: negligible (N), marginal (Ma), moderate (Mo), critical (Cr) and catastrophic (Ca). The linguistic terms describing consequence can be assigned the following Fuzzy Numeric Constant:

Hazard Class	Linguistic	Numeric	
Zero-Fatality	(Negligible)	F_{CS} (1)	0
Minor	(Marginal)	F_{CS} (2)	0-1
Major	(Moderate)	F_{CS} (3)	2-10
Severe	(Critical)	F_{CS} (4)	11-50
Fatality	(Minor Catastrophic)	F_{CS} (5)	51-100
Disaster	(Catastrophic)	F_{CS} (6)	100+

FCP is the probability consequences with linguistic qualifications as remote to occur, very unlikely (U), unlikely (RU), likely (L), very likely (HL) and definite (D). Have Hazard Class F [1, 2, 3, 4, 5] defined has numerical value assigned as:

Hazard Class	Hazard Rate	Fuzzy Class
Definite to	[>10]/yr	F_{CP} (0)
Very likely	[>1-10] /yr	F_{CP} (1)
Likely	[0.01-1] /yr	F_{CP} (2)
Unlikely	[0.0001-0.01] /yr	F_{CP} (3)
Very unlikely	[0.000001-0.0001] /yr	F_{CP}(4)
Remote	[0.00000001-0.000001] /yr	F_{CP}(5)

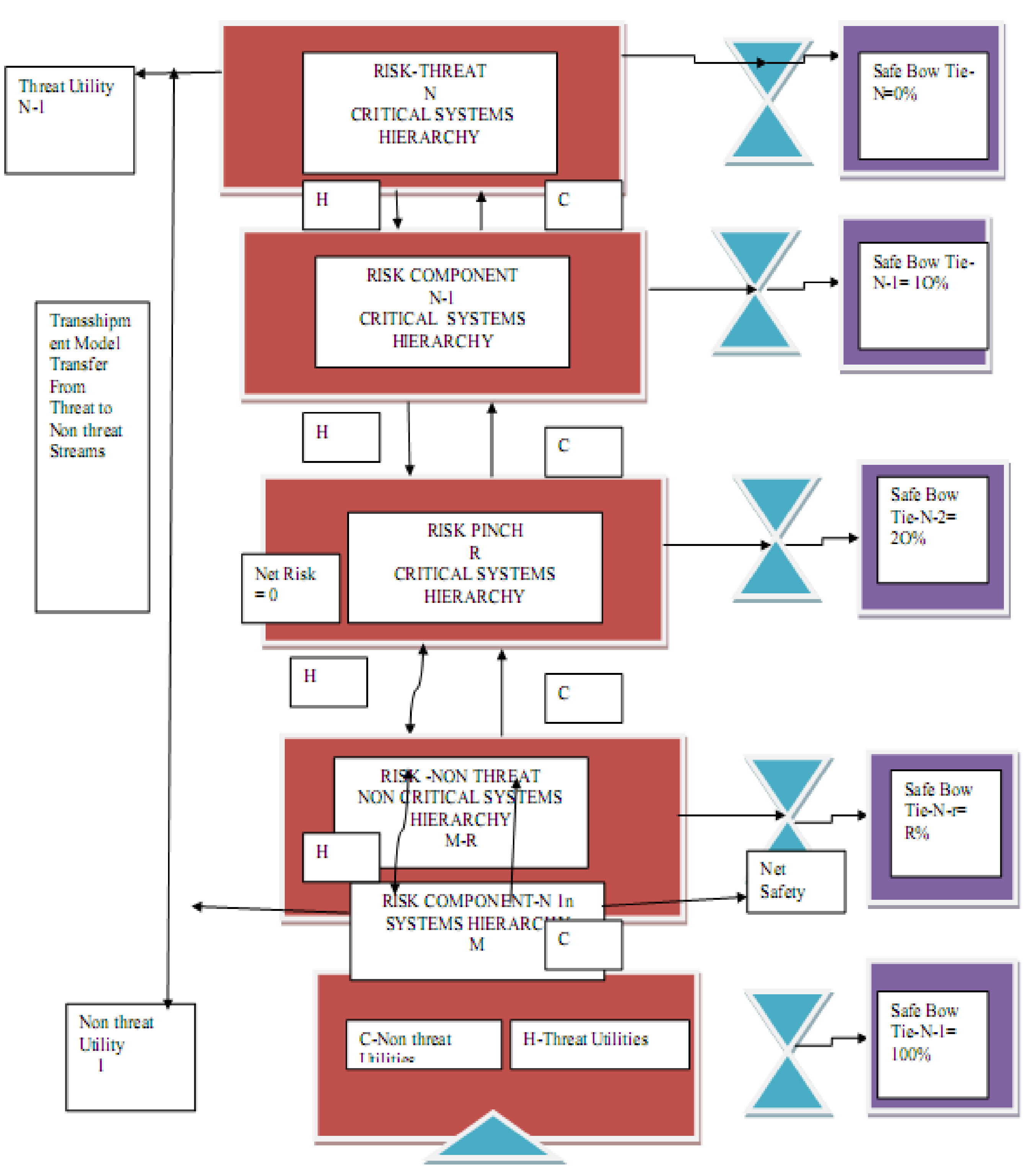


Figure 1: Transshipment Model for Transfer of threats Across Board

III. Application on Bow Tie System for FPSO

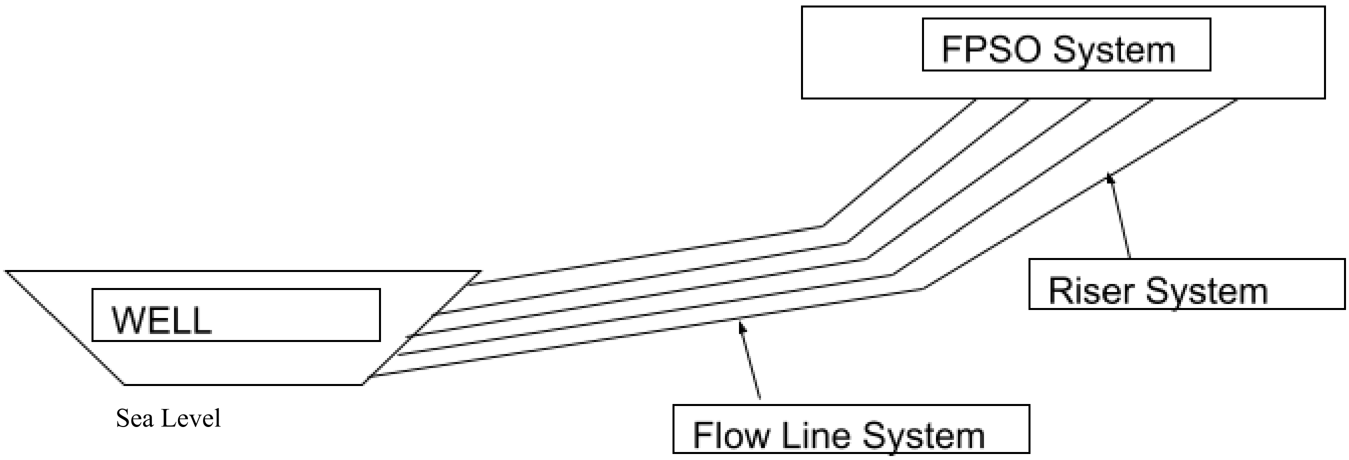


Figure 2: FPSO with riser and Flow lines

The FPSO above is typically a representative model of one currently operated by Multinational Oil Company in the Nigerian Deep Waters. The major hazards are identified in Figure 3.0 of the Bow Tie System constructed for purpose.

Fatalities

Process Worker on FPSO

5.76x 10 -4 fatalities per year.

-Ship crew worker on FPSO

4.19x 10 -4 fatalities per year.

Accommodation Worker on FPSO

3.70 x 10 -4 fatalities per year.

Process worker on platform

(Overnight on FPSO)

458 x 10 -4 fatalities per year.

The major accidents leading to loss in containment falls in two classes: 1) Technical and/or operational failure 2) Human and organizational errors such as Man and machine interface, the availability and effectiveness of operational, procedures which directly affects personnel performance (stress, system understanding, tiredness, etc.). Technical and operational failures are products of designs, age, operations, process and environmental failure factors. Human and Organizational Factors (HOF) is based on general industry practices which have the following elements: People, equipment (e.g. hardware), management systems, culture and environment. Equipment, people and management systems are shown as elements within the framework created by culture and environment. Examples of management systems include procedures, communication, training, management of change, risk assessment. Repair or Safety measures considered for FPSO, off-loading to shuttle tanker, supply and cargo vessels.

IV. Computational Analysis: Pinch to Construct Problem Table

The Problem Table, Grand Risk Composite Curves, Safety Targets and the Transshipment Model. The HAZARD data associated with the FPSO is computed from an Excel Programming provided in Table 1.0

a) Design of the Risk Minimization Problem

The basic principles of the pinch method [6] below represents further illustration and its application to risk minimization and safety targeting.

b) Synthesis, Modelling and Design

The Bow Tie diagram of operating FPSO is shown in Figure 1. A feasible design is to analyze the components separately. Nevertheless, we have only presented analysis for the RENS (Risk Exchanger Network Synthesis) and STNS (Safety target network synthesis) of Bowtie system of an operating FPSO.

For the RENS problem, the following data are required (7)

- ❖ A set of risk-threat streams to be cooled and a set of risk-non threat process streams to be heated.
- ❖ The hazard rates and the risk and safety targets of all process streams
- ❖ The safety weight capacities of each of risk streams versus their hazard rates as they pass through the heat exchange process.
- ❖ The available safety utilities, and index of performance in risk reduction and their costs per unit of heat provided or removed.

For the STNS problem, the following data are required

- ❖ A set of risk process streams generated and a set of risk targets streams
- ❖ The hazard rates and their risk status and risk targets

- The risk critical systems and risk non critical systems.
- Available end pipe treatment facility, their efficiency and cost per unit waste generated.

c) *Analysis of the Problem Table FOR Safety targets Δγmin at 0% to 100%*

The objective of the risk management problem is to minimize threats to personnel by applying a safety targeting technique. A typical Bowtie system contains a hazard stream of several threat levels and safety controls required to contain release to the environment. For our analysis, we have two kinds of stream, the risk threat and risk non threat streams. Therefore, the RENS problem for the bow TIE for risk threat and risk non threat streams. The minimized risk simulated for the personnel on FPSO set safety targets are γT1 (0%).γT2 (10%). γT3 (50%) γT4 (80%).γT5 (90%) from a normal operating targetγ. Change in risk reduction is by altering the operating variables, such that we can achieve 10%, 50%, 80% and 90% risk targets an extended table shown in Table 2, Table 3, and Table 4 can be developed. The target interval is subdivided into sub intervals with a minimum Δ γmin =0.1.

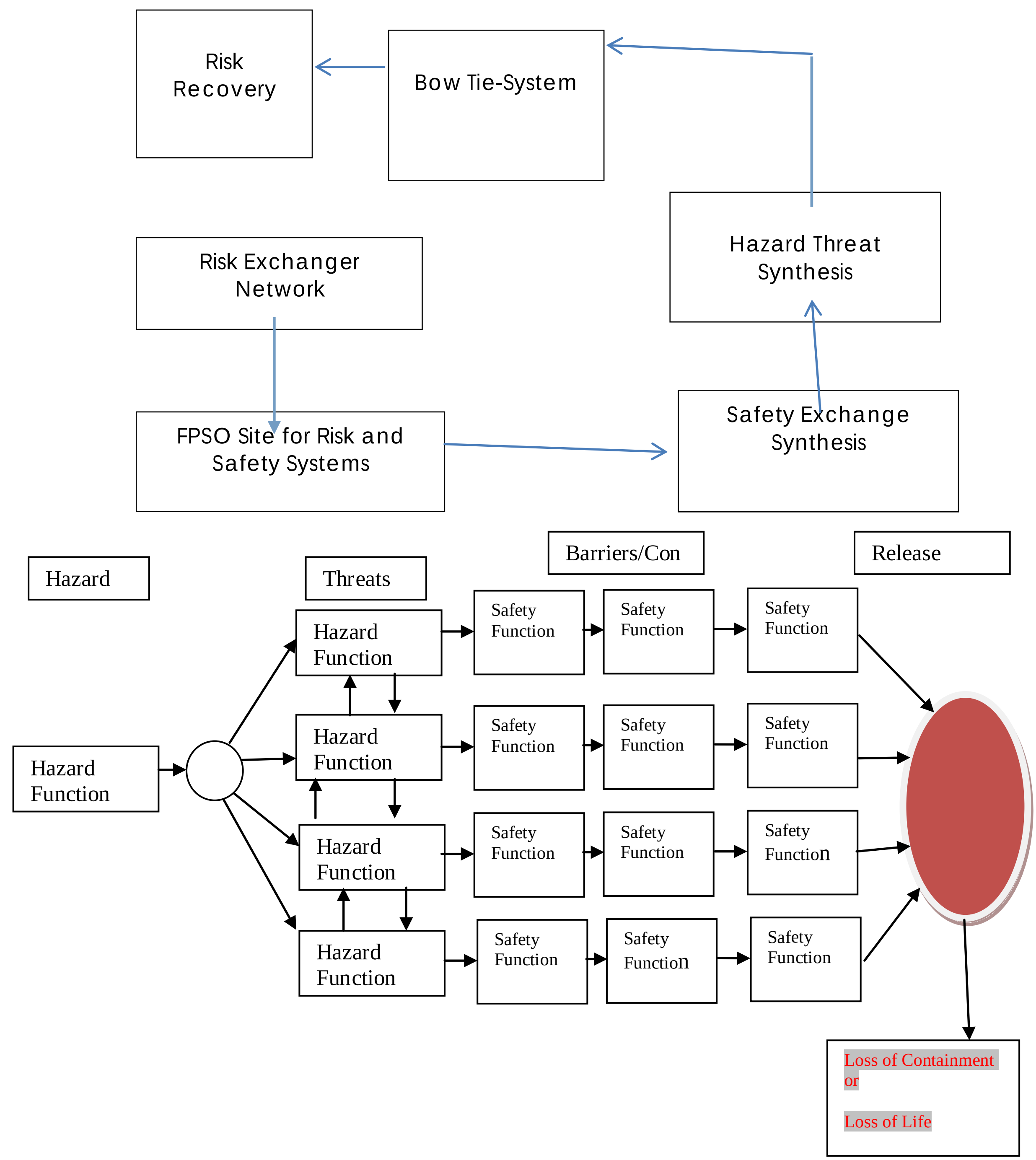


Figure 3: BOW TIE System of an FPSO

d) Hazard/Risk/Safety Targeting/Problem Table

The risk management problem table was derived by setting the non threat streams and the threat streams as follows:

THREAT STREAM

Hazard Class	Hazard Rate	Hazard Class
Definite to	[>10]/yr	FCP (0)
Very likely	[>1-10] /yr	FCP (1)
Likely	[0.01-1] /yr	FCP (2)

NON THREAT STREAMS

Hazard Class	Hazard Rate	Hazard Class
Unlikely	[0.0001-0.01] /yr	FCP(3)
Very unlikely	[0.000001-0.0001]/yr	FCP(4)
Remote	[0.00000001-0.000001] /yr	FCP(5)

The pinch for safety status for process worker on an FPSO in Table 2 to be γT1 (0.553733), γT2 (0.49836), γT3 (0.276867), γT1 (0.110747), and γT2 (0.055373), for 100%, 90%, 50%, 20%, and 10% safety targets respectively. As the safety targets is increased, the pinch point moves through a maximum. Minimum risk reduction stipulates that any streams above the pinch point represent the risk source, while any stream below the pinch represents risk sinks. As the pinch point, moves upward or as more of risk is reduced, the desired risk target objective. This is represented mathematically as Jacobean. As shown below there are four stream and the safety targets weights are:

RH= Risk Threat

RC= Risk Non threat

There are threat risk streams and two non threat risk streams. The hazards on the process worker on the FPSO Platform were considered for threat risk and hazards on the ship crew and accommodation worker is considered non threat streams

Risk-Safety and Hazard Stream Interval Table

The pinch analysis concept maximize the risk reduction between risk threat and risk non threat streams: There are four hazard classifications

$$JP = \left(\frac{\partial r}{\partial S}\frac{\partial S}{\partial h}\right)\langle\rangle\langle R\rangle_{\max imum} \tag{8}$$

The evaluation of available risk status for any interval can be given by the formula

$$R = \left(\frac{(\gamma_{T2}-\gamma_{T1})_{design}}{(\gamma_{T}-\gamma)_{operating}}\right)xR_O \tag{9}$$

$$S = 1 - R \tag{10}$$

Where

$$R\min = 1 - EXP(-\lambda\omega t) \tag{11}$$

Rmin is the minimum risk problem that needs to be targeted in our case, the risk on the process worker, accommodation and crew work. R and S are the design risk, and design safety respectively. Rmin minimum risk status respectively. $(\gamma_{\mathrm{T}} - \gamma)_{\mathrm{w\ operating}}$ and $(\gamma_{\mathrm{T}} - \gamma)_{\mathrm{w\ operating}}$ are the risk and safety interval respectively. The available risk or safety is evaluated as the total risk or safety available within a design interval. Hence, in table 2 for The pinch point for safety status for process worker on an FPSO in Table 2 to be γT1 (0.553733), γT2 (0.49836), γT3 (0.276867), γT1 (0.110747), and γT2 (0.055373), for 10%, 20%, 50%, 80%, 90%.

The Risk Transshipment at any point in Time is given for 100% to 90% safety target interval for a Process Worker on an FPSO

$$R = \left(\frac{0.553733 - 0.49836}{0.49836 - 0.42305019}\right)R_{\min} \tag{12}$$

$$R_{\min} = (1 - EXP(0.01 * 0.55373))T \tag{13}$$

The pinch analysis concept requires maximizing the risk reduction between risk threat and risk non threat streams.

V. Results and Discussions

a) Hazard weight data correlation table

Table 1.0 is a typical safety target table for assessing the complex multifunctional risk systems. The system linguistic class of component uses a weight index to measure multifunctionality and safety systems implemented. The risk index to quantify the levels of threats and the belief index to quantify an expert assignment of the certainty of risk in that systems. These qualifications and quantifications are important to classify the risk.

Table 1.0: Typical Risk and Safety Table

Hazard Class Log in No.	Weight index	Safety Index	Hazard Rate	Risk Index	Risk Target
j1	w_1	s_1	h_1	r_1	ε_1
j2	w_2	s_2	h_2	r_2	ε_2
j3	w_3	s_3	h_3	r_3	ε_3
j4	w_4	s_4	h_4	r_4	ε_4
j5	w_5	s_5	h_5	r_5	ε_5
j6	w_6	s_6	h_6	r_6	ε_6
j7	w_7	s_7	h_7	r_7	ε_7

Table 2.0, Table3.0 and Table 4.0 which are the weight index data for hazard class of type 1, type2 and type 3 respectively has a classification of very likely to occur; for different safety fraction; for different hazard shape constant. We determine that the increase in numerical qualification of safety is significantly related to weight index as measure of such for specific hazard class and hazard shape function.

Table 2.0: Weight Data for Bowtie Hazard Rate for Hazard Class 1

Hazard Class 1	Weights Associated With Each Safety Fraction And Hazard Shape Function Constant											Max Safety
		Safety Index										
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1	0.9
Hazard Shape												
0.1	0.20487	0.1843847	0.163898	0.1434103	0.12229	0.102436	0.0819487	0.061462	0.0409744	0.0204872	0	0.02049
0.2	0.157793	0.1420135	0.126234	0.110455	0.09468	0.078896	0.063117	0.047338	0.0315586	0.0157793	0	0.01578
0.4	0.18720901	0.1684881	0.149767	0.1310463	0.11233	0.093605	0.0748836	0.056163	0.0374418	0.0187209	0	0.01872
0.6	0.296145	0.266531	0.236916	0.207302	0.17769	0.148073	0.118458	0.088844	0.059229	0.029615	0	0.02962
0.8	0.527031	0.474328	0.421624	0.368921	0.31622	0.263515	0.210812	0.158109	0.105406	0.052703	0	0.0527
1	1.00045	0.900405	0.80036	0.700315	0.60027	0.500225	0.40018	0.300135	0.20009	0.100045	0	0.10005
1.2	1.978261	1.780435	1.582609	1.384783	1.18696	0.989131	0.791305	0.593478	0.395652	0.197826	0	0.19783
1.4	4.023522	3.62117	3.218818	2.816466	2.41411	2.011761	1.609409	1.207057	0.804704	0.402352	0	0.40235
1.6	8.353799	7.518419	6.683039	5.847659	5.01228	4.17	3.34152	2.50614	1.67076	0.83538	0	0.83538
1.8	17.6198	15.857823	14.09584	12.333862	10.5719	8.809901	7.0479212	5.285941	3.5239606	1.7619803	0	1.76198
2	37.62817	33.86535	30.10254	26.339719	22.5769	18.8141	15.051268	11.28845	7.525634	3.762817	0	3.76282

Table 3.0: Weight Data Bow Tie Hazard Rate Computation for Hazard Class 2 for different hazard shape index values

Hazard Class 2= Likely to occur	Weight Index associated with each safety index				
0.553484076	Safety index				
Hazard Shape index	Safety index=0	Safety index=0.1	Safety index=0.5	Safety index=0.8	Safety index=0.9
0					
0.1	0.82422	0.741798	0.41211	0.164844	0.082422
0.2	0.50925	0.458325	0.254625	0.10185	0.050925
0.4	0.388808	0.349928	0.194404	0.077762	0.038881
0.6	0.395803	0.356223	0.197902	0.079161	0.03958
0.8	0.4532894	0.4079605	0.226644712	0.090657885	0.045328942
1	0.553733	0.49836	0.276867	0.110747	0.055373
1.2	0.704619	0.634157	0.352309	0.140924	0.070462
1.4	0.922237	0.830013	0.461118	0.184447	0.092224
1.6	1.232212	1.108991	0.616106	0.246442	0.123221
1.8	1.672506	1.505256	0.836253	0.334501	0.167251
2	2.298504	2.068653	1.149252	0.459701	0.22985

Table 4.0: Weight index data for hazard rate simulation for Hazard Class 4

Hazard Class 4= Very Unlikely to Occur	Weight Index Associated with Each Safety Fraction				
5.03E-05	Safety Index				
Hazard Shape Index	Safety index=0	Safety index=0.1	Safety index=0.5	Safety index=0.8	Safety index=0.9
0.1	3.25E-01	2.93E-01	1.63E-01	6.50E-02	3.25E-02
0.2	7.92E-02	7.13E-02	3.96E-02	1.58E-02	7.92E-03
0.4	9.40E-03	8.46E-03	4.70E-03	1.88E-03	9.40E-04
0.6	1.49E-03	1.34E-03	7.44E-04	2.98E-04	1.49E-04
0.8	2.65E-04	2.39E-04	1.33E-04	5.30E-05	2.65E-05
1	5.04E-05	4.53E-05	2.52E-05	1.01E-05	5.04E-06
1.2	9.97E-06	8.97E-06	4.98E-06	1.99E-06	9.97E-07
1.4	2.03E-06	1.83E-06	1.01E-06	4.06E-07	2.03E-07
1.6	4.22E-07	3.79E-07	2.11E-07	8.43E-08	4.22E-08
1.8	8.90E-08	8.01E-08	4.45E-08	1.78E-08	8.90E-09
2	1.90E-08	1.71E-08	9.51E-09	3.80E-09	1.90E-09

b) Analysis of the Problem Table for Safety targets $\Delta\gamma min$ at 0% to 100%

The objective of this study is to minimize the risk to personnel worker on an FPSO platform through a risk targeting technique employing pinch as shown in Table1.

Table 5.0: Typical Data

	Typical Data	FPSO Based Production Facility Case study			
Analysis	Process Worker (PF) on Platform	Process Worker (FP)	Ship Crew Worker (FP)	Accommodation Worker (FP)	
Hazard Class	Very Likely	Likely	Unlikely	Very Unlikely	
Hazard Stream	Risk-Threat	Risk-Threat	Risk-Non threat	Risk-Non threat	
Hazard Class No	J=1	J=2	J=3	J=4	

Table 5.0 is a table of the risk problem, determined as how impact of risk on personnel worker on FPSO can be reduced on minimized. A Bowtie systems contain a hazard stream, which produces several threat streams and safety controls to prevent release on containment. For our analysis, we have two kinds of stream, the risk threat and risk non threat streams. The risk, safety targets, risk targets or risk reduction of a FPSO, ship crew, accommodation worker and process worker on a platform. So, the RENS problem for the bow TIE can be formulated into risk threat and risk non threat. The objective is to minimize the risk on the personnel on FPSO. These can be achieved by setting out safety targets $\gamma T1$ (0%). $\gamma T2$ (10%). $\gamma T3$ (50%) $\gamma T4$ (80%). $\gamma T5$ (90%) from a normal operating targetγ. Assuming also it is possible to change risk reduction by altering the operating variables, such that we can achieve 10%, 50%, 80% and 90% risk targets an extended table shown in Table 2, Table 3, and Table 4 can be developed. The target interval is subdivided into sub intervals with a minimum $\Delta\ \gamma min\ =0.1$. The pinch technique was applied to analyze risk to the personnel on FPSO. The pinch point for safety status for process worker on an FPSO in Table 2 was computed to be $\gamma T1$ (0.553733), $\gamma T2$ (0.49836), $\gamma T3$ (0.276867), $\gamma T1$ (0.110747), and $\gamma T2$ (0.055373), for 100%, 90%, 50%, 20%, and 10% safety targeting respectively. The design targets increases, the pinch point moves through a maximum. Minimum reduction, any streams above the pinch point represents the waste source, while any stream below the pinch represents risk sinks. The pinch point moves upward until desired risk target is achieved. The design that achieve minimize risk from the BOWTIE unit is realized when the Jacobean of the pinch point with respect to operating variable hazard rates favors movement such that maximum risk event occurs.

Table 6.0: Problem Table at 50% risk target

Hazard Classifications (fatalities/yr)	Stream Type	Safety Target 0%	Safety Target 50%	Weight Load Minimum	Safety SHIFTED 0%	Safety SHIFTED 50%	Hazard Rate Minimum	Risk Status	Risk Target 50%	Risk Reduction 50%
Very Likely [>1-10]/yr	Risk-Threat	1.00045	0.500225	0.100045	0.900405	0.40018	1	0.99591323	0.936151201	0.059762028
Likely [0.01-1]/yr	Risk-Threat	0.553733	0.276867	0.055373	0.49836	0.221494	0.01	0.42305019	0.141249497	0.281800692
Unlikely [0.0001-0.01]/yr	Risk-Non threat	0.005004	0.002502	0.0005	0.004504	0.002002	0.0001	0.00503727	1.2635E-05	- 0.005024635
Very Unlikely [0.000001-0.0001]/yr	Risk-Non threat	5.04 E-05	2.52E-05	0.00000504	0.00004536	2.02E-05	0.0000001	5.0499E-05	1.2726E-08	-5.05E-05

Table 7.0 is the risk extended problem table. The table shows the minimum safety target (0%) which can be increase to a safety target of 50%. The hazard rate minimum for the process worker on the platform, process worker on FPSO, ship crew and accommodation is 1, 0.01, 0.001, and 0.0000001 fatalities per year based on the hazard classification very likely, likely, unlikely, very unlikely. This is a reduction in risk target as the safety target is increased from 0% to 50%.

The pinch analysis concept allows us to maximize the risk reduction between risk threat and risk non threat streams: There are four hazard classifications

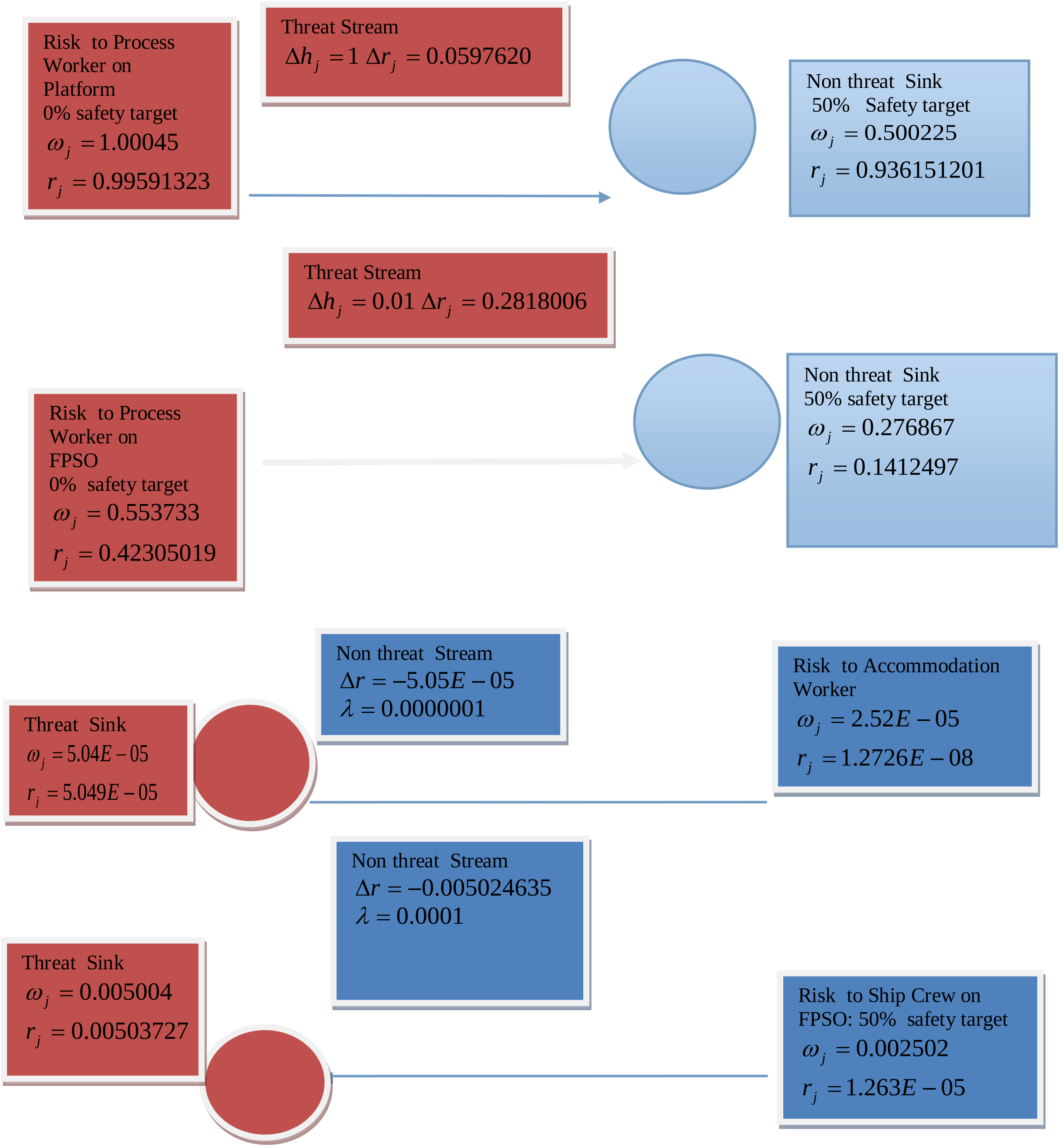


Figure 4: Diagram Design Interval

The risk to the accommodation worker and ship crew are 1.2726E-08 and 1.263E-05 respectively. The level of critical safety systems deployed on these personnel is small and could be referred in our model as non threat sink. The process worker that is exposed to more critical risk is referred as the threat sink on the FPSO and targets is to reduce the threats from 0.996 and 0.4234 by deploying resources allocated to non threats sink (accommodation and ship crew) to the threat sink (process worker) to minimize the risk and threat levels on these personnel.

Table 7.0: Risk-Safety/Hazard Stream–Extended Table

Hazard Classifications (fatalities/yr)	Stream Type	Hazard Rate Minimum	Risk Status	Risk Target 50%	Risk Reduction 50%	Extended Table Problem PINCH DESIGN INTERVAL	Cascade
Very Likely [>1-10]/yr	Risk-Threat J=1	1	0.99591323	0.936151201	0.059762028	0	0.054737393
Likely [0.01-1]/yr	Risk-Threat J=2	0.01	0.42305019	0.141249497	0.281800692	1	0.276776057
Unlikely [0.0001-0.01]/yr	Risk-Non threat J=3	0.0001	0.00503727	1.2635E-05	-0.005024635	(PINCH PT) 2	0
Very Unlikely [0.000001-0.0001]/yr	Risk-Non threat J=4	0.0000 001	5.0499E-05	1.2726E-08	-5.05E-05	3	0.004974135

For the risk target is 50% and 0%, the pinch point is located at interval 2. The risk threat streams are required to cool and the safety sinks is increased, and non threat streams require heat by non critical risk. There is a risk reduction above the pinch and a reversal below the pinch. The pinch is located for the ship crew that is classified as non threat stream.

Table 8.0: Hazard/Risk Reduction Table

Threat To: Risk System	Hazard Classifications (fatalities/yr)	Stream Type	Risk Reduction 100%	Risk Reduction 90%	Risk Reduction 50%	Risk Reduction 20%	Risk Reduction 10%
Process Worker on FPSO	Likely [0.01-1]/yr	Risk-Threat	0.16050302	0.18330776	0.281800692	0.36395731	0.3930541
Ship Crew Worker	Unlikely [0.0001-0.01]/yr	Risk-Non threat	0.00501182	0.00501453	0.005024635	0.00503222	0.0050347
Accomodation Worker	Very Unlikely [0.000001_0.0001]/yr	Risk-Non threat	5.0473E-05	5.0476E-05	5.0486E-05	5.0494E-05	5.05E-05
Process Worker on Platform	Very Likely [>1-10]/yr	Risk-Threat	0	0.00298088	0.059762028	0.32861958	0.5727203

c) Risk Reduction Curve/Risk Status with Safety Targets

The safety composite graphs are shown in Figure 4 and Figure 5. Risk target and risk reduction are below the design risk status for the personnel work showing a reduction in risk as the safety sink increases.

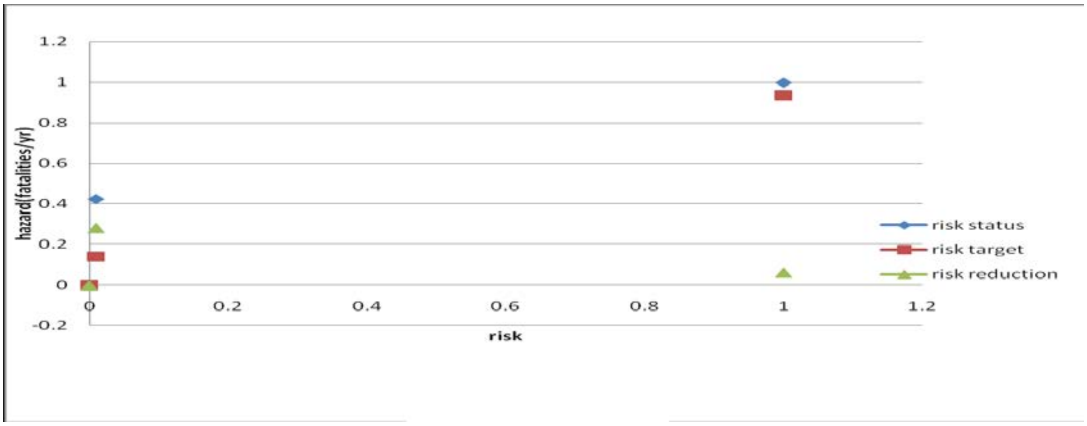


Figure 4: Problem Table on Risk Reduction: Composite Curve

Figure 5.0 show a progressive reduction below the 0% safety classification that is for 10%, 50%, 80%, 90% target, shows a risk target below the design safety for personnel on the platform.

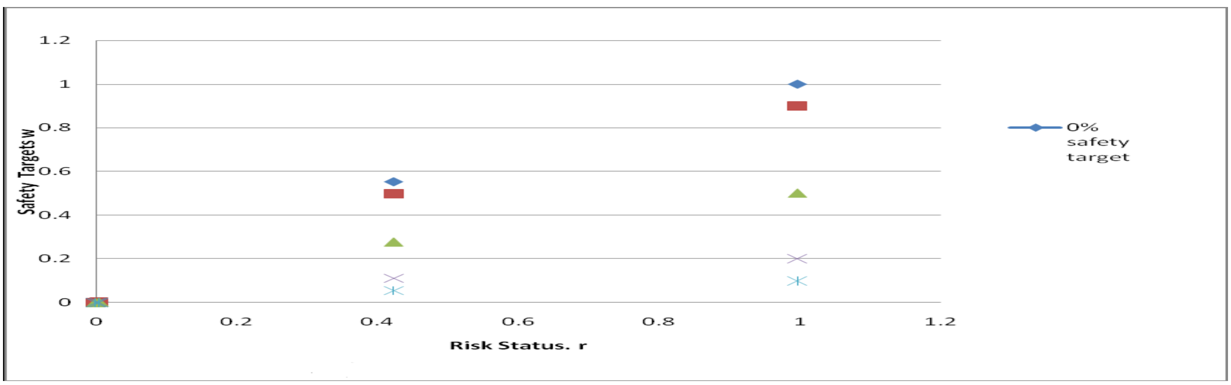


Figure 5: Plot of risk Status with Safety Targets

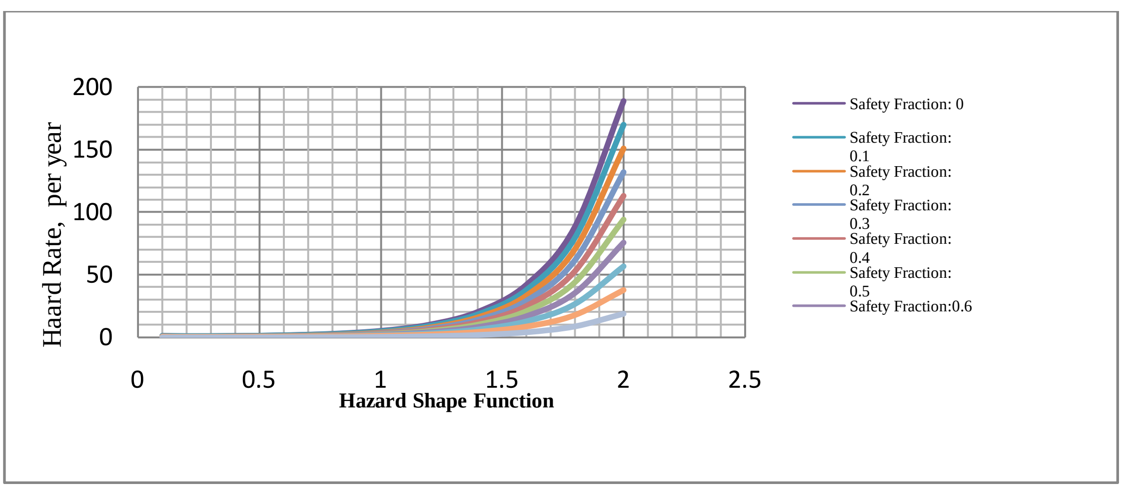


Figure 6: Hazard Rate with Hazard Shape Index for Fuzzy Class 1 for different Level of Safety

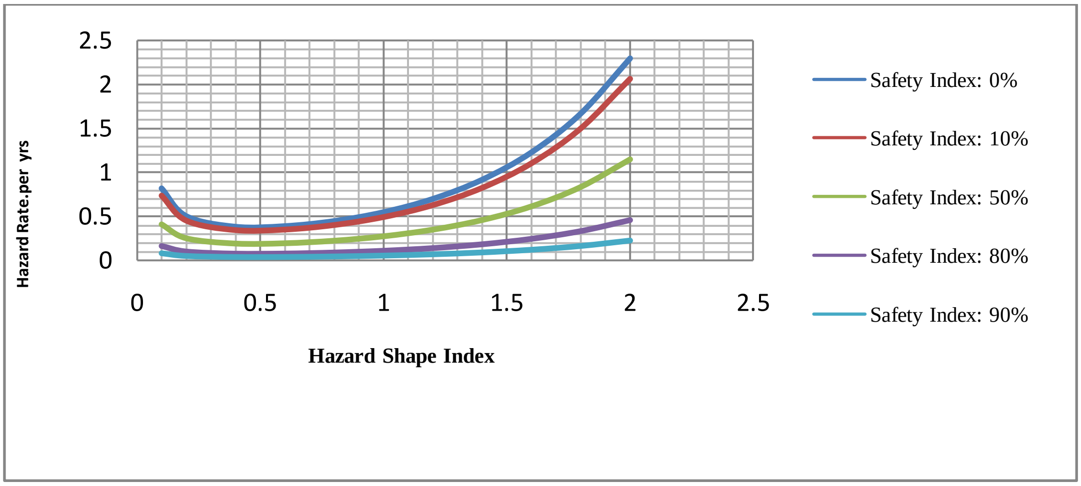
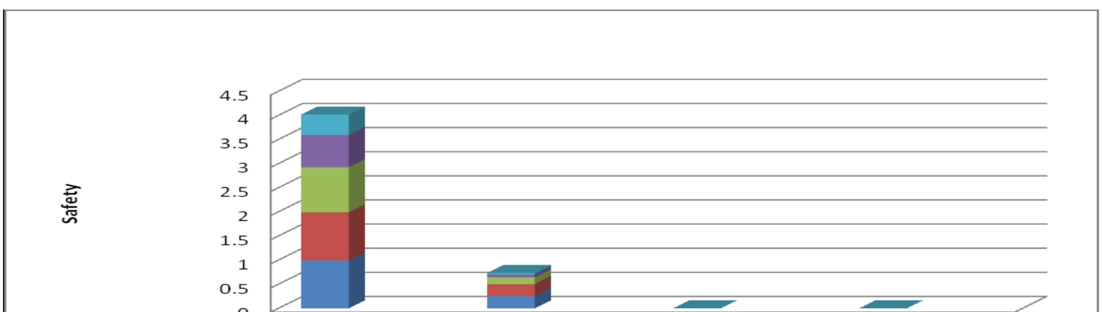


Figure 7: Plot of Hazard Rate with Hazard Shape Index for different Level of Safety for Fuzzy Class 2

Figure 6 shows the simulated hazard rate for hazard class 1, while Figure 7 shows the simulated hazard rate for hazard class 2 for the personnel worker. The hazard class 1 qualification as unlikely to occur appears to reduced as improve safety index are increased from 10% to 90%.

d) The Plots of Hazard Rate for different Hazard Class and Safety Index

Figure 8 and Figure 9 shows that Risk Status/ Risk Reduction Bar Chart. Whereas it is clear from Figure 8 that the safety is highest for the 90% safety and least for the 0% safety. Also the Process worker on platform and FPSO seem to exhibit the greatest Risk Target, while the accommodation and ship crew worker exhibited lesser risk target.



	1	2	3	4	5	6	7	8
90% safety target	0.423193		0.0299961		2.525E-06		2.545E-09	
80% safety target	0.6672936		0.0590929		5.055E-06		5.101E-09	
50% safety target	0.9361512		0.1412495		1.264E-05		1.273E-08	
10% safety target	0.9929324		0.2397424		2.274E-05		2.288E-08	
0% safety target	0.9959132		0.2625472		2.545E-05		2.545E-08	

Figure 8: Bar Chart of Risk Target

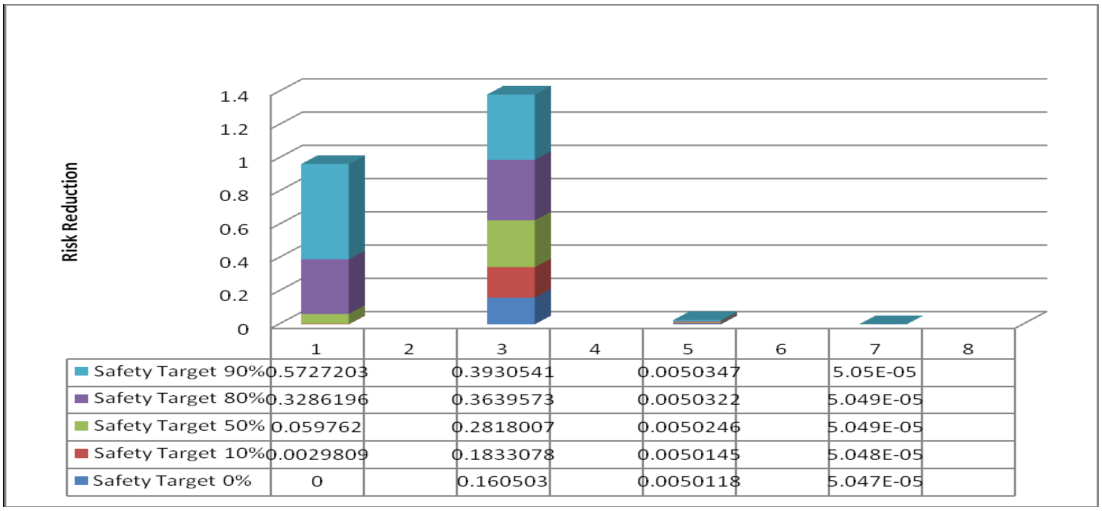


Figure 9: Bar Chart of Risk Reduction

Figure 9 shows that risk reduction bar chart shows that risk reduction for safety index of 0% and highest at the maxum safety index of 90% on process worker on FPSO and Platform are impacted with the most risk threat.

e) Plot of Belief Variable for Hazard class 1 at safety index 0% and safety index 90%

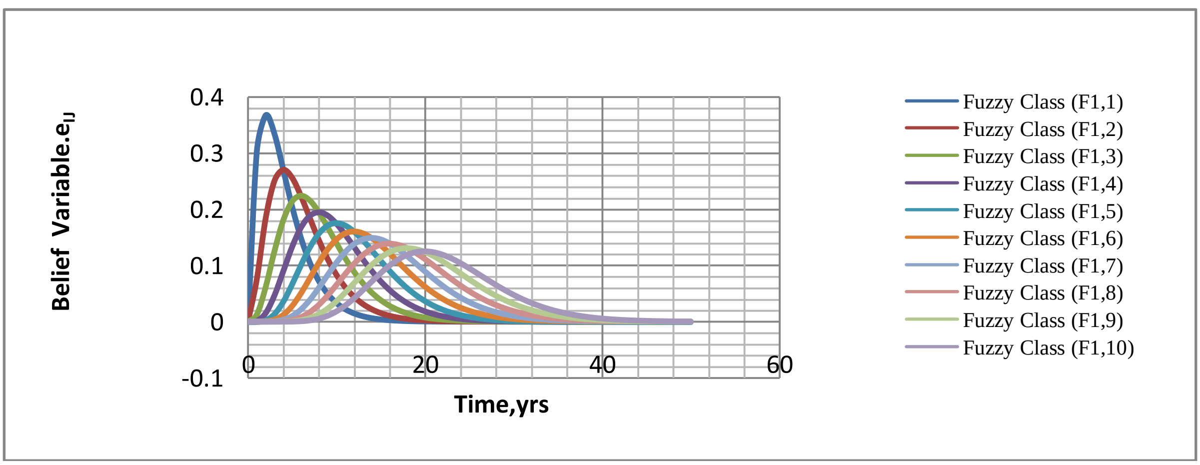


Figure 10: Plot of Belief Variable e_{ij} with Time (yrs) for hazard class 1 for 90% Safety index for different hazard shape =1.0 for no of failures 1-10 constant F1(1,-10)

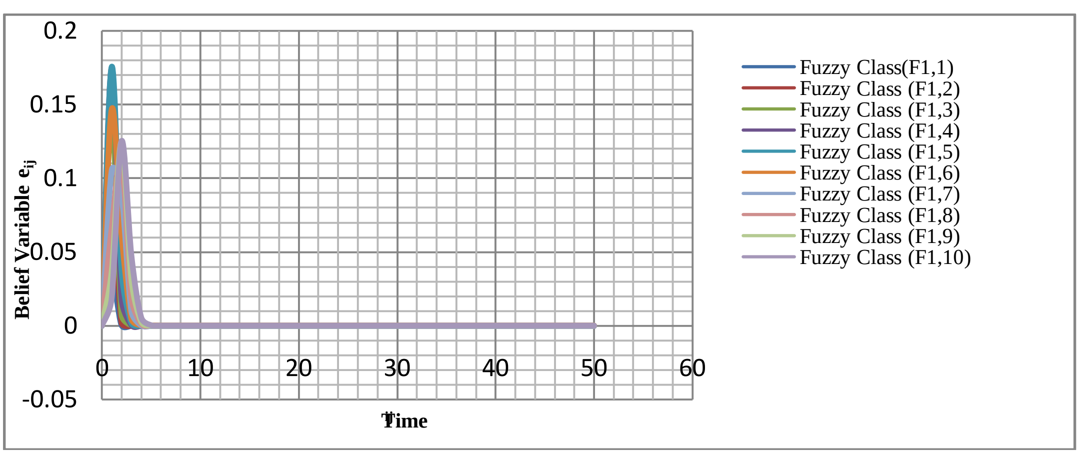


Figure 11: Plot of Belief Variable e_{ij} with Time (yrs) for hazard class 1 for 0% Safety index for hazard shape index =1.0 for no of failures 1 to 10 F1(1,-10)

Figure 10 is a plot of the belief index for hazard class 1 with 90% safety index which has a numerical classification as Very likely [>1-10] /yr assigned a value hazard set value $F_{CP}(1)$ .Figure 11 is the plot of belief variable (confidence level) where the safety index is 0% for a number of failures 1 to 10 for a when hazard shape index=1.0. The belief variable is a measure of the index of certainty that within a particular time, the probability of occurrence is high. The belief variable ε_{ij} represents the uncertainty an expert associates with an input data. For maximum safety index of 90%, the parabolic profile is more evenly spread with time than for the case with safe index of 0%, clearly indicating uncertainty on personnel worker depending on system would fail is higher for a system with lower safety index than a higher safety index.

f) Risk Variable for different Safety Index

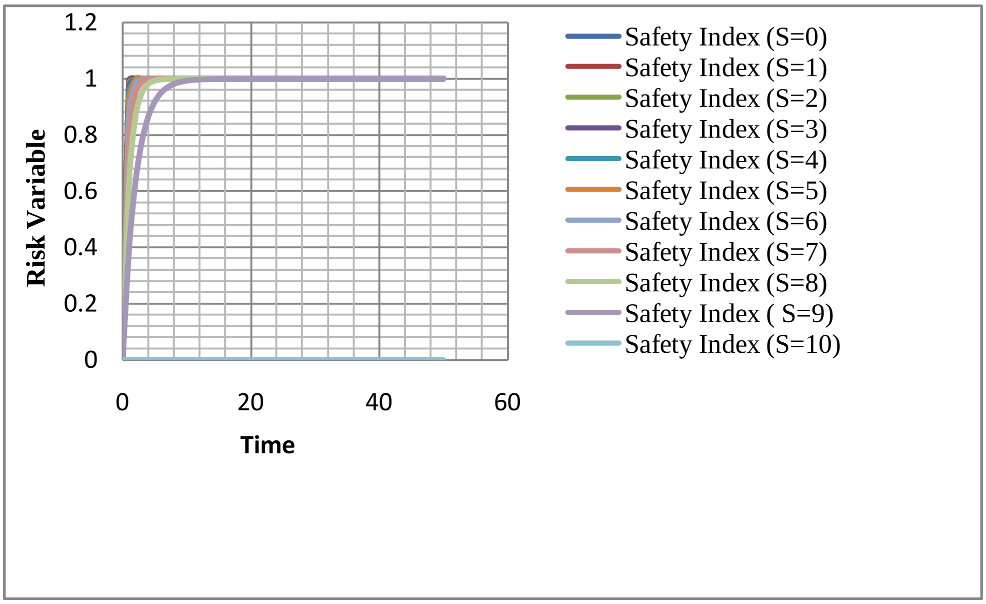


Figure 15: Plot of Risk Variable with Time for Different Safety Index for Fuzzy Class 1 Failures Hazarzd Shape function=1.0

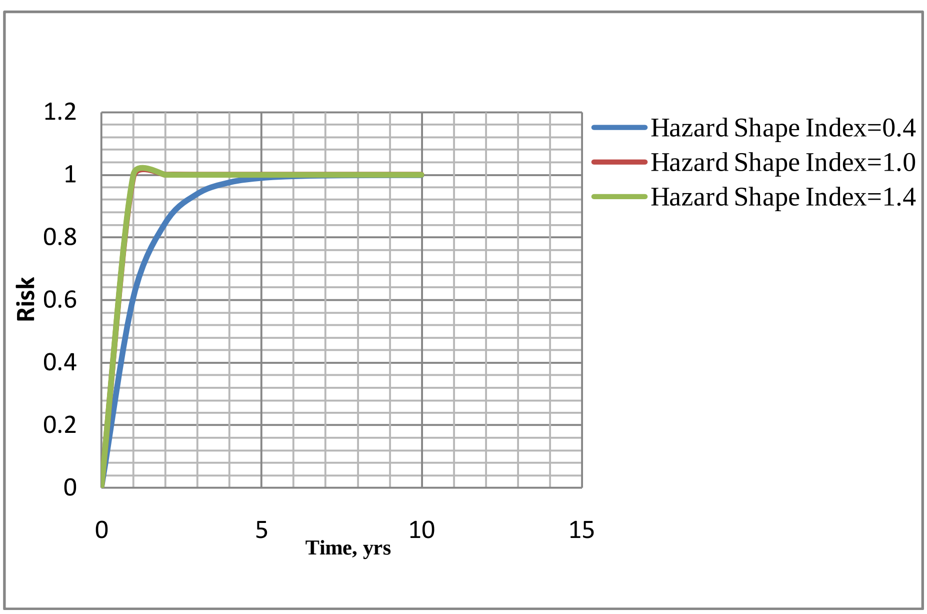


Figure 16: Risk with time for different shape index for 0% safety for fuzzy 1 class hazard

Figure 15 is the plot of the risk in a system with time in relationship to the safety index, for hazards class 1 type. The plot shows that risk of the FPSO's system increases exponentially with time but decreases as the safety index increases. Whereas Figure 16 showed exponentially increase of risk with time for safety that is non-existent 0% for all hazard indexes with the risk taking lesser values for lower hazard shape index.

VI. Conclusion

A model is presented to plan personnel safety on FPSO. Data was obtained from a multinational oil company operating in deepwater. Based on data obtained from a deepwater multinational oil and gas operator in Nigeria, personnel risk reduction on personnel is simulated as safety targets index increases from 0% to 90%. The plots of risk reduction /risk safety composite graph for risk target shows a risk reduction below the design risk status thresholds to plan credible threat reductions on personnel of complex process and production systems.

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VII. Nomenclature

ω_i	Weight index
U_i	Risk or Reliability Factor
r_i	Risk potential
R_{si}	Reliability/Safety
λ_w	Hazard Rate (combined sum)
λ_{ws}	Hazard Rate (Combined Series Sum)
λ_{wp}	Hazard Rate (Combined Parallel Sum)
N	Number of Components
F1	Fuzzy Class (Very Likely)
F2	Fuzzy Class (Likely)
F3	Fuzzy Class (Unlikely)
F4	Fuzzy Class (Very Unlikely)
F5	Fuzzy Class (Remote)
SRfi	Safety Index
β_i	Hazard Shape Index
λ_{ij}	Hazard rate of i-component interacting with j component
λ_{im}	Hazard rate of combined mean
ϖ_{si}	Safety Weight Index
μ_{ij}	Repair rate

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