Optimization of Risk and Safety Parameters in Chemical Process Plants

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Abstract: - Chemical Engineering is the mainstay of many industries across the world, India being no exception. The industry and their associated domains are fraught with several risks and attendant safety issues. The most cited lacunae relate to the safety risks and related issues that are attributed to process plants belonging to the petrochemical, cracker, polymer, chemical and pharmaceutical classes. While those on the higher scale have been documented exhaustively, the others in the lower echelons also merit attention. These include retail petrol dispensing units, fuel transfer modules, fire resistant motors and the like. The process industry is replete with several industrial operations involving several streams of Chemical, Electrical and Industrial Engineering. The authors have attempted to delve into the intricacies of associated risks and safety management indices. It is further intended to collate the data in a structured manner and analyse it in a manner compatible for further modelled using suitable heuristics centred on data regression and a suitable correlation coefficient to obtain an arrive at a reasonable course of action. The result is expected to produce a set of metrics related to the optimized choices which home into workable solutions and improve safety parameters that result in safer chemical process plants. These recommendations will be hopefully analysed by the Operations and Management group of the client industry to effect suitable corrective actions.

Key-Words: Safety metrics, Risk, Analytical solutions, Heuristics, Correlation coefficients, Spearman's coefficient

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1. Introduction

Chemical engineering forms the bedrock of numerous industries globally, with India playing a significant role. However, this essential field is inherently linked to a complex web of risks and safety challenges. From large-scale petrochemical complexes to smaller, but equally vital, downstream operations such as retail fuel distribution and vending, the potential for hazardous incidents is ever-present. While major industrial accidents often dominate headlines, a comprehensive approach to safety necessitates addressing risks across all levels of operations. Recognizing the intricate interplay between different branches of engineering, work studies, plant operations in industrial processes, this study delves into the critical aspects of risk assessment and safety management, aiming to provide insights and improve safety indices across the spectrum of chemical engineering applications. Materials and Methods.

2. Outline

The case study spans a concentrated industrial belt in the states of Maharashtra, Gujarat and Andhra Pradesh in that order. These states were selected on the basis of the high incidences of major chemical accidents that occurred between 2019 and 2024. In addition, these are also home to several industries (Chemical and others). They traverse Maharashtra (Dombivli, Roha, Pune, Dhule), Andhra Pradesh (Anakapalli, Visakhapatnam), Gujarat (Ankleshwar, Sachin, Dahej) highlighting the severity of these mishaps.

The geographical spread of these accident sites highlights the concentration of industrial activity within the selected zones. All necessary variables have been gleaned from the statistical data of the mishap sites. These pertain to - Year of inception, Operational period, Work-force, Injury count, Fatality count. The data spread is very meagre, making it difficult to make an accurate correlation between these variables. It is the express intention of the authors to formulate a work-plan for the set of industries under review. The plan intends prepare checkpoints and recommendations for Operations and Management group of the client industry to effect suitable corrective actions and hopefully avoid the recurrence of such accidents. The paucity of base data is sought to be corrected by artifice of employing a set of heuristics. These extend and expand the threadbare data extracted from the sites; the plant details, the year of inception, work-force and finally the casualties related to fatalities and injuries. Additionally, the qualitative tone of some data have been converted to quantitative metrics by introducing appropriate weights. The weights have formed from a logical and natural sequence. These have been presented in the form of weighted measures to arrive at metrics for the different plants under purview. It is to be emphasized that the calculations and resulting conclusions are highly subjective, paving way for future corrections and improvements. The end objective seeks to develop effective safety strategies and mitigate the risks associated with the chemical industry. Muhammad Shah et al. [1] have carried out a comprehensive literature review covering process safety, security, and resilience in the chemical process industry.

3. Mishap Sites

Table-**1** details the spread of the nine mishap sites over a geographical comprising Maharashtra, Gujarat and Andhra Pradesh. These lay emphasis on the locations which were drawn from prominent news reports from several vernacular newspapers. These have been indexed in reverse chronology. These have been analysed by Arun et al.[2]. It analyses Indian chemical accident databases and directly mirrors the data paucity issue highlighted in the paper. Vijay[3] makes a specific analysis of the LG Polymer #7 mishap by employing ETA(Event Tree Analysis) and RCA(Root cause analysis). Table-1 has been trimmed to include the work-force details and is summarized in Table-2.

Table-1 Mishap data locations

#	Year	Plant	Location	Specific Incident	Cause	Fatalities	Injuries
1	2024	Escientia Pharma	Anakapalli, AP	Explosion	Vapour leak-Chemical reactions-Explosion	17	40
2	2024	Amber Chem	Dombivli, Maha.	Explosion	4 boilers exploded-huge fire-quickly spread - nearby factory buildings	9	48
3	2024	Sadhana Nitro	Roha, Maha.	Blast	Welding sparks-Ignition of methanol fumes - Huge explosion-Flames	3	3
4	2024	Detox India	Ankleshwar, Guj.	Tank Explosion	Rupture of steam pressure pipe-Explosion-Massive blast	4	0
5	2023	Aether Ind.	Sachin, Guj.	Electrical Fire	Leakage of flammable chemicals from storage tank-Explosion-Massive fire	7	24
6	2021	SVS Aqua	Pune, Maha.	Fire	Blast in machine-Massive fire	18	0
7	2020	LG Polymers	Visakhapatnam, AP	Gas Leak	Insufficient maintenance - Blast	13	100
8	2020	Yashashvi Rasayan	Dahej, Gujarat	Explosion	Human negligence-Movement of acid to storage tanks-Chemical reaction-Explosions	10	70
9	2019	Rumit Chem	Dhule, Maha.	Fire	Chemical leak-Explosion	13	72

Table-2 Work-force and casualty narration

#	Year	Plant	Yrs. of opn.	Work force	Fatalities	Injuries
1	2024	Escientia Pharma	15	380	17	40

2	2024	Amber Chem	29	50	9	48
3	2024	Sadhana Nitro	51	247	3	3
4	2024	Detox India	14	306	4	0
5	2023	Aether Ind.	10	152	7	24
6	2021	SVS Aqua	3	20	18	0
7	2020	LG Polymers	59	1001	13	100
8	2020	Yashashvi Rasayan	68	501	10	70
9	2019	Rumit Chem	16	100	13	72

4. Analysis

Each of these nine mishap locations are linked to several accident data. Many of these are vastly disparate. Their narratives read as vapour leak, boiler explosion, spread of fire, welding sparks, ingress and ignition of methanol fumes, explosion, flames, rupture of steam pressure pipe, massive blast, storage tank rupture, leakage of flammable chemicals, massive fire, blast in machine, insufficient maintenance, human negligence, acid transport, chemical reaction, chemical leak to cite the major ones. Though these are extensive and elaborate, it makes it difficult to make a detailed threadbare analysis which covers all of these in reasonable detail. Based on this premise, the authors intend to use a heuristic approach. The heuristic selects twelve prominent hazards from the set of these mishaps. Weights are then assigned to these hazards. The selection is not conjecture, but follows a well-thought-out analytical approach. This is best explained by considering a stage-wise sequence of hazards that indicate a natural progression of causes and their resulting effects. For instance, a train of hazards such as sparks may lead to smoke, followed by fire and finally resulting in a possible conflagration.

To elaborate, variable-01 (Poor maintenance-01-PM) is assigned a weight of 01, as contrasted with a variable-02 (Human negligence - 02-HN) with an assigned weight of 02 and yet another assignation of variable-12 (Conflagration-12-CO). The first one has a generic origin, rated as a relatively minor variable. The last one counts as a very severe hazard. Two-letter abbreviations have been employed for the 12 hazards in order to tide over space constraints. The description of the variables and the formulation of the weights are summarized in Table-3.

Table-3 Safety variables and Hazard weights

#	Safety Variable	Abbreviation	Weight
01	Poor maintenance	PM	01
02	Human negligence	HN	02
03	Welding sparks	WS	03
04	Smoke	SM	04
05	Vapour leak	VL	05
06	Gas leak	GL	06
07	Chem. leak	CL	07
08	Chem. reaction	CR	08
09	Boiler explosion	BE	09
10	Explosion	EX	10
11	Fire	FI	11
12	Conflagration	CO	12

The hazard weights have been spelt out in a specific sequence as evinced in the historical narration of the stated hazards.
The transition of the nine sites are narrated in Table-4. Purnendu Mandal et al. [4] have analysed several safety variables in their work which broadly covers the principles and practices of industrial safety management. It integrates theory with real-world applications, including hazard control, safety culture, and regulatory compliance. Sandip Roy et al. [5] have focused on developing risk acceptance criteria tailored to the chemical industry in India. It discusses socio-economic factors, regulatory frameworks, and practical challenges in defining acceptable risk levels. Abbreviations are employed to tide over the space constraints.

Table-4 Hazard transition

Weight	1	2	3	4	5	6	7	8	9	10	11	12
Plant	PM	HN	WS	SM	VL	GL	CL	CR	BE	EX	FI	CO
Escientia					X		X			X		
Amber							X		X			X
Sadhana			X		X					X		X
Detox									X	X	X	
Aether							X			X		X
SVS								X			X	
LG	X									X		
Yashashvi	X	X								X	X	
Rumit							X			X		

The broad picture of the analysis follows the steps
Hazard weights→Hazard transition→Failure and effects (FEA) analysis→Calculation→Correlation check.
The heuristic continues with the assignation of penalties for each of the nine mishap locations. Two penalties have been formulated and invoked for each accident site- Transition penalty(TP) and the Causal penalty (CP). These two penalties are designed to reflect the amounts of transgression incurred by each safety variable for each mishap. A transition penalty involves the transition from one hazard variable to another one, often leaping over many others. The exact placement of these penalties (**marked as X**) are extracted from the word narratives of the nine mishap sites. To be more detailed, these have been extracted from Table-1 (Mishap data)-6th Column (Cause). The transition can range from 01 to 12 with individual idiosyncrasies. A minor contravention will therefore incur a lesser penalty than that for a severe mishap. On the other hand, causal penalties depend on the sum of the absolute individual hazard(s).

To illustrate, the case of the first mishap site (Escientia Pharma) is cited. Reference is made to Table-1(Mishap data locations) #1 listing the Cause (Vapour leak - Chemical reactions - Explosion). Subsequently, Table-3(Safety variables and Hazard weights) is referenced to translate the causes and obtain the corresponding weights (05,08 and 10). The Causal penalty for a specific plant is arrived by summing the associated weights. However, the transition penalty is obtained by using a more detailed approach. This is explained in the following manner. A stage-wise sequence of mishaps indicates a natural progression of causes and their resulting effects. This can be attributed to a train of events such as sparks leading to smoke, followed by fire and finally and possibly resulting in a conflagration. A similar situation finds mention in (3,4,5). On the other hand, to cite the same example, a transition from smoke direct to an explosion indicates lacunae in the eventual mishap. This surmises that necessary safeguards are required in the process. This requires a larger levy of higher penalty by the use of a suitable heuristic.

The Transition penalty(TP) = $\mathbf{5^{(8-5)}} + \mathbf{8^{(10-8)}}$=189. The Causal penalty for a specific plant is arrived by summing the associated weights. In this case, it works out to CP = 05+08+10=23. The specific penalty calculations for all the mishap sites are detailed in Table-5 (Hazard transition and Causal calculation)

Table-5 Hazard Transition and Causal penalty calculation

Plant	TP calculation (Superscript represents to the power of)	CP Calculation
Escientia	$\mathbf{5^{(8-5)}+8^{(10-8)}}$= 189	5+8+10 = 23
Amber	$\mathbf{7^{(9-7)}+9^{(12-9)}}$= 778	7+9+12=28
Sadhana	$\mathbf{3^{(5-3)}+5^{(10-5)}+10^{(12-10)}}$ =3234	3+5+10+12=30
Detox	$\mathbf{9^{(10-9)}+10^{(11-10)}}$= 19	9+10+11=30
Aether	$\mathbf{7^{(10-7)}+10^{(12-10)}}$= 443	7+10+12=29
SVS	$\mathbf{8^{(11-8)}}$= 512	8+11=19
LG	$\mathbf{1^{(10-1)}}$= 1	1+10=11
Yashash vi	$\mathbf{1^{(2-1)}+2^{(10-2)}+10^{(11-10)}}$ = 267	1+2+10+11=24
Rumit	$\mathbf{7^{(10-7)}}$ = 343	7+10=17
	Avg.~ 644	Avg.~ 23

It should be noted that the transition sequence follows a simplified Failure Effects Analysis (FEA). Since all the Causal penalty (CP) values appear to be scaled down, these are scaled up by a factor (Avg. TP/Avg.CP) ~ 23 in order to create a parity between the Transition penalty(TP) and the Causal penalty(CP) two penalties and create the MCP(Modified Causal Penalty). Further, the Net penalty (NP) is created with the relation (Net penalty (NP) = TP + MCP.

$$\boldsymbol{Net\ pen.} = \sum_{k=0}^{n}\binom{n}{0}\boldsymbol{Causal\ pen.} + \boldsymbol{Trans.pen.}$$
(Eqn. 1)

In addition, the Fatality and Injury counts have been normalized to develop a Modified fatality factor(MCF). These are elucidated in Table-6.

Table-6 Net penalty factors and Modified fatality

Safety Variable	Penalty factors				Modified Fatality Statistics			
Plant	TP	CP	MCP	NP=(TP+MCP)	Fatal.	Inj.	Ratio (Inj./Fat.)	Mod. Fatality(MF)
Escientia	189	23	529	718	17	40	2.36	(17+(2.36*40))=112
Amber	778	28	644	1422	9	48	5.34	(09+(5.34*48))=266
Sadhana	3234	30	690	3924	3	3	1.00	(03+(1.00*03))= 6
Detox	19	30	690	709	4	0	0	(04+(0.00*0.00))= 4
Aether	443	29	667	1110	7	24	3.43	(07+(3.43×24))= 89
SVS	512	19	437	949	18	0	0	(18+(0*0))= 18
LG	1	11	253	254	13	100	7.70	(13+(7.70*100))=783
Yashash vi	267	24	552	819	10	70	7.00	(10+(7.00*70))=500
Rumit	343	17	391	734	13	72	5.54	(13+(5.54*72))=412

Two Per capita indices have been introduced - One relating to the Modified fatality factor (PCIF) and - Two relating to the Work-force count (PCIW).

$$\boldsymbol{Per\ capita\ haz.factor\ (PCIF} = \frac{\boldsymbol{Net\ penalty(NP)}}{\boldsymbol{Modif.fatality(MF)}}$$
(Eqn. 2)

$$\textit{Per capita haz.work force } (PCIW) = \frac{\textit{Net penalty}(NP)}{\textit{Work-force}(WF)} \quad (Eqn.\ 3)$$

The PCIF and PCIW variable selections are supported by Ezerins et al.[6] by using risk metrics covering fatalities and injuries. Chitra Rajagopal et al.[7] used pioneering research in applying QRA (Quantitative Risk Assessment) in process plants, outlining methodologies for hazard identification and consequence analysis. They emphasized the importance of systematic risk evaluation in industrial safety. Related research by Naser Badri et al. [8] delved into the role of QRA in siting hazardous installations. They were able to demonstrate decision-making for plant location and risk mitigation. The per-capita index calculations are summarized in Table-7 (Hazard transition).

Table-7 Per-capita indices

Plant	NP	Mod. Fatal.(MF)	PCIF= NP/MF	Work-force(WF)	PCIW= NP/WF
Escientia	718	112	7	380	2
Amber	1422	266	6	50	29
Sadhana	3924	6	654	247	16
Detox	709	4	178	306	3
Aether	1110	89	13	152	8
SVS	949	8	119	20	48
LG	254	783	1	1001	1
Yashashvi	819	500	2	501	2
Rumit	734	412	2	100	8

All the seven factors developed by the heuristic are summarized in Table-8. Tables 1 through 7 have elaborated the narrative data, work-force, casualty narration, hazard weights, hazard transition and hazard analysis in that order. A set of heuristics have been employed to formulate derived parameters such as Modified Causal penalty, Net penalty, Modified fatality, Per capital Index-fatality, Per capital Index-workforce.

The available data is subjective and is dependent on a large number of unrelated variables. It is intended to introduce quantitative assessment of these data by deploying a suitable correlation coefficient to assess the suitability of comparing selected pairs of derived variables. It is to be reiterated that Md. Shah et al.[1] had mirrored the Pearson's correlation approach used in the paper.

Table-8 Hazard heuristic factors

Plant	Plant operat.	Tran. penalty	Mod. Causal penalty	Net penalty	Work force	Per capita Index-Fatal.	Per capita Index-Work force
	PO	TP	MCP	NP	WF	PCIF	PCIW
Escientia	15	189	529	718	380	7	2
Amber	29	778	644	1422	50	6	29
Sadhana	51	3234	690	3924	247	654	16
Detox	14	19	690	709	306	178	3
Aether	10	443	667	1110	152	12	8
SVS	3	512	437	949	20	119	48
LG	59	1	253	254	1001	1	1
Yashashvi	68	267	552	819	501	2	2
Rumit	16	343	391	734	100	2	8

5. Rumination

It is proposed to assess the coefficient correlation for each relevant data pair. The following coefficients under consideration are enumerated in Table-9 (Pair coefficient correlations) for three entities - Pearson, Spearman and Kendall correlations.

Table-9 Pair coefficient correlation

#	Coefficient	Characteristics
1	Pearson's Coefficient	• Linear relationship between two continuous variables assuming both follow a normal distribution • Value ranges from −1 (perfect –ve linear correlation) to +1(perfect +ve linear correlation) • Sensitive to outliers • Pearson's coefficient correlation is defined as r_{xy} $r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}}$ *(Eqn. 4)*
2	Spearman's Rank Correlation	• Measures the degree of association of two variables using ranks • Data need not be normally distributed. Values range from −1 (perfect -ve monotonic relationship) to +1(perfect +ve monotonic relationship). A value of 0 indicates no association between the ranks of the variables • Spearman's ρ responds to monotonic relationships; unlike Pearson's which detects only linear associations • Less affected by outliers $\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}$ *(Eqn. 5)* n = number of paired observations d_i = diff. b/w ranks of each pair
3	Kendall's Tau	Rank-based correlation is robust for small sample Measures the strength and direction of association between two ranked variables More robust than Spearman's for small samples. Range: −1 to +1. $\tau_b = \frac{n_c - n_d}{\sqrt{(n_t-n_1)(n_t-n_2)}}$ *(Eqn. 6)* n_c = number of concordant pairs; n_d = number of discordant pairs n_t = total number of pairs; n_1 and n_2 account for tied ranks in the two variables

This is in part supported by Md. Shah et al.[1] who have assiduously used Correlation analysis linking safety policies to fatality rates. This mirrors the Pearson's correlation approach considered in the paper. Considering their characteristics, all three are impressed upon the Hazard heuristic factors listed in Table-7 (Hazard heuristic factors) (9 x 7 Matrix).

For all the three Pair coefficient correlations, a correlation greater
than 0.50 is deemed worthy of further analysis.
To begin, the derived heuristic variables of Table-8 (Hazard heuristic factors) are depicted as a check-list. Variable-pairs found fit for further investigation are selected. This exercise is reflected in Table-9.
Of the 7x7=49 entries, the ones marked X are

prohibited/redundant. This leaves the available pair suitability to be only 19 marked ✓ as listed in Table-10 (Selected variable pairs). Thus, the three pair coefficient correlations – Pearson, Spearman, Kendall are calculated for all 19 pairs. These are listed in Table-11.

Table-9 Preliminary variable pairs

	PO	TP	MCP	NP	WF	PCIF	PCIW
PO	X	✓	✓	✓	X	✓	✓
TP	X	X	✓	✓	✓	✓	✓
MCP	X	X	X	✓	✓	✓	✓
NP	X	X	X	X	✓	✓	✓
WF	X	X	X	X	X	✓	X
PCHF	X	X	X	X	X	X	✓
PCWF	X	X	X	X	X	X	X

Table-10 Selected variable pairs

#	Relational variables
01	Plant Operation Vs. Transition penalty
02	Plant Operation Vs. Modified Causal penalty
03	Plant Operation Vs. Net penalty
04	Plant Operation Vs. Per capita Index-Fatal.
05	Plant Operation Vs. Per capita Index-Work force
06	Transition penalty Vs. Modified Causal penalty
07	Transition penalty Vs. Net penalty
08	Transition penalty Vs. Work force
09	Transition penalty Vs. Per capita Index-Fatal
10	Transition penalty Vs. Per capita Index-Work force
11	Modified Causal penalty Vs. Net penalty
12	Modified Causal penalty Vs. Work force
13	Modified Causal penalty Vs. Per capita Index-Fatal
14	Modified Causal penalty Vs. Per capita Index-Work force
15	Net penalty Vs. Work force
16	Net penalty Vs. Per capita Index-Fatal
17	Net penalty Vs. Per capita Index-Work force
18	Work force Vs. Per capita Index-Fatal
19	Per capita Index-Fatal Vs. Per capita Index-Work force

.

Table 11: Calculation of Coefficients

#	Relational Variables	Pearson	Spearman	Kendall
01	Plant Operation vs Transition penalty	0.262	- 0.133	- 0.056
02	Plant Operation vs Modified Causal penalty	- 0.162	- 0.134	- 0.085
03	Plant Operation vs Net penalty	0.220	- 0.050	0.056
04	Plant Operation vs Per capita Index-Fatal	0.194	- 0.536	- 0.423
05	Plant Operation vs Per capita Index-Work force	- 0.386	- 0.471	- 0.343
06	Transition penalty vs Modified Causal penalty	0.429	0.377	0.310
07	Transition penalty vs Net penalty	0.992	0.967	0.889
08	Transition penalty vs Work force	- 0.250	- 0.733	- 0.500
09	Transition penalty vs Per capita Index-Fatal	0.910	0.460	0.366
10	Transition penalty vs Per capita Index-Work force	0.242	0.874	0.686
11	Modified Causal penalty vs Net penalty	0.542	0.494	0.423
12	Modified Causal penalty vs Work force	- 0.517	- 0.092	- 0.028
13	Modified Causal penalty vs Per capita Index-Fatal	0.439	0.756	0.629

14	Modified Causal penalty vs Per capita Index-Work force	0.028	0.278	0.203
15	Net penalty vs Work force	- 0.306	- 0.600	- 0.389
16	Net penalty vs Per capita Index-Fatal	0.909	0.444	0.310
17	Net penalty vs Per capita Index-Work force	0.230	0.765	0.572
18	Work force vs Per capita Index-Fatal	- 0.144	- 0.360	- 0.310
19	Per capita Index-Fatal vs Per capita Index-Work force	0.156	0.532	0.435
	No. of qualifying entries	5	8	5

Coefficient values of 0.50 or higher (+ve or –ve) qualify the variable pairs as worthy of further analysis. These have been marked as shaded cells. Hence, relational variable pairs (# 04, 07, 08, 10, 13, 15 and 19) have been selected and listed in Table-12. Spearman's Rank Correlation with 08 qualifying entries are superior to Pearson's coefficient and Kendalll's Tau correlations.

Table 12: Enumeration of selected variable pairs

	#	Relational Variables	y-axis	x-axis	Spearman
1	04	Per capita Index Fatal vs. Plant Operation	PCIF	PO	- 0.536
2	07	Net penalty vs. Transition penalty	NP	TP	0.967
3	08	Transition penalty vs. Work force	TP	WF	- 0.733
4	10	Per capita Index -Work force vs. Transition penalty	PCIW	TP	0.874
5	13	Per capita Index-Fatal vs. Modified Causal penalty	PCIF	MCP	0.756
6	15	Net penalty vs. Work force	NP	WF	- 0.600
7	17	Per capita Index-Work force vs. Net penalty	PCIW	NP	0.765
8	19	Per capita Index-Fatal vs. Per capita Index-Work force	PCIF	PCI W	0.532

Thus, eight plots have been constructed as in Table-13.

Table-13: Correlation Coefficient Plo**ts**

Table-13.1

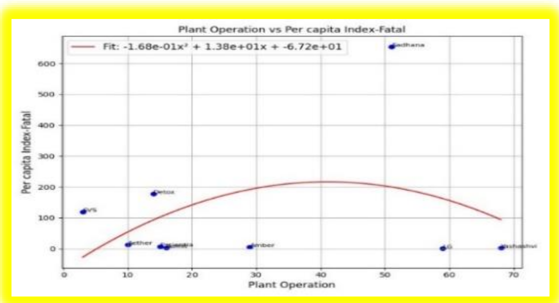


Table-13.2

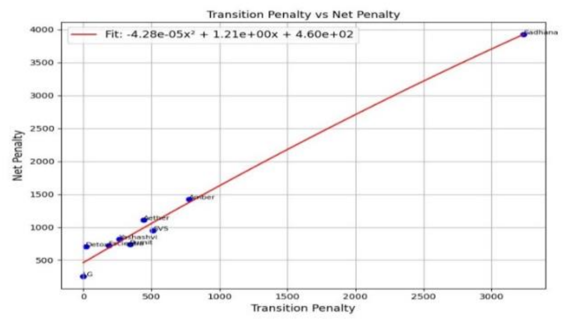


Table-13.3

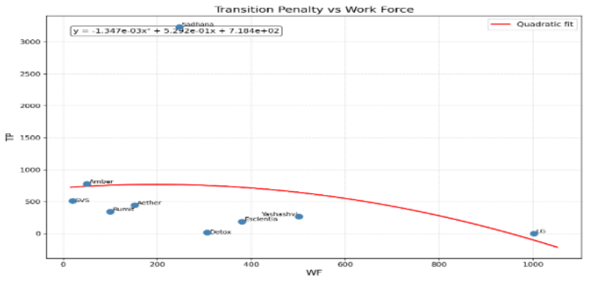


Table-13.4

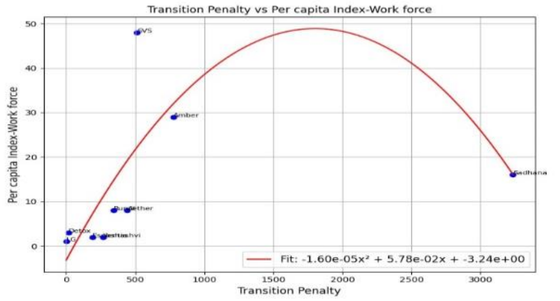


Table-13.5

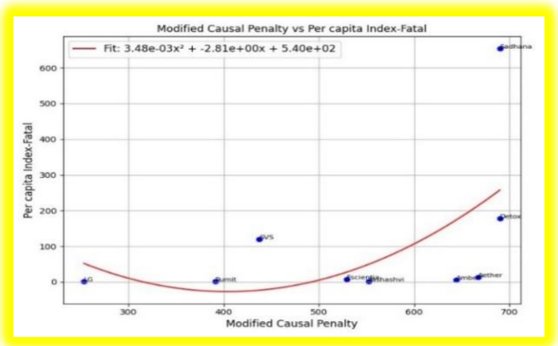


Table-13.6

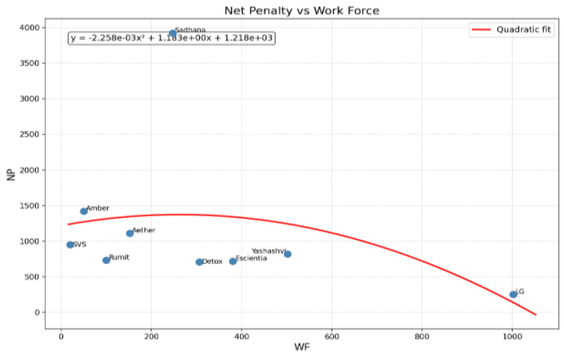


Table-13.7

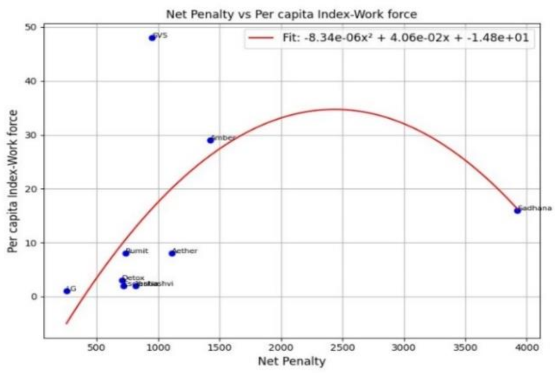
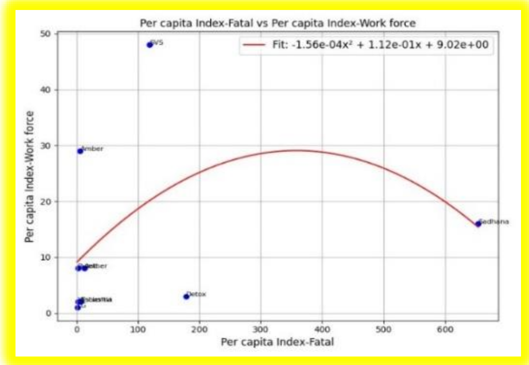


Table-13.8



PCIF has been selected as the prime factor in deciding the efficiency of the variable. It is found that a higher PCIF relates to a lower value of NP (Net penalty). Table-13 has three associated plots related to PCIF, namely 13.1,13.5 and 13.8

6. Heuristic

The foundational concepts on hazard progression, accident causation, and safety engineering principles underpin the heuristic model. PCIF has been selected as the prime factor in deciding the efficiency of the variable. It is found that a higher PCIF relates to a lower value of NP (Net penalty). Table-13 has three associated plots related to PCIF, namely 13.1,13.5 and 13.8 (Marked with a yellow tinge).

These are used to determine an averaged predictive equation.

Individual Regression Equations

1. Plot.13.1: PCIF VS. PO $PCIF = -0.168 \cdot PO^2 + 13.8 \cdot PO - 67.2$
2. Plot.13.5: PCIF VS. MCP $PCIF = 0.00348 \cdot MCP^2 - 2.81 \cdot MCP + 540$
3. **3.** Plot.3.8: PCIF VS. PCIW $PCIF = -0.000156 \cdot PCIW^2 + 0.112 \cdot PCIW + 9.$

Adding LHS and RHS terms of all three equations:

$$3 \cdot PCIF = (-0.168 \cdot PO^2 + 13.8 \cdot PO - 67.2) + (0.00348 \cdot MCP^2 - 2.81 \cdot MCP + 540) + (-0.000156 \cdot PCIW^2 + 0.112 \cdot PCIW + 9.02)$$

Final Averaged equation (Divided by 3)

$$PCIF = -0.056 \cdot PO^2 + 4.6 \cdot PO + 0.00116 \cdot MCP^2 - 0.937 \cdot MCP - 0.000052 \cdot PCIW^2 + 0.0373 \cdot PCIW + 160.61 \text{ (Eqn.6)}$$

Thus PCIF = fn.(PO, MCP, PCIW). It is to remembered that MCP= fn.(CP,TP) and PCIW=fn.(WF,NP)

PO and WF are independent variables, whereas CP,TP,MCP,PCIF and PCIW are derived variables.

Eqn. 6 can be considered to be a working premise on which to act on decisions concerning newer projects.

Thus PCIF can be forecast given that the independent variables (PO, WF) are known forehand. The forecast of derived variables

require approximation. CP, TP employing Tables-3 and an expanded Table-4. The MCP can be calculated with a fair amount of accuracy by using an expanded Table-3 and incorporating the statistic of the new facility into Table-4 and expanding it.

The procedure for analysing the PCIF factor new installations is listed in Table-14(Future hazard planning).

Table-14 (Future methodology and hazard planning)

#	Procedure	Detailing
1	Select new installation	Determine infrastructure details
2	Fix independent variables	PO and WF
3	Assess derived variable	CP from historic data and trial runs
4	Assess derived variables after 5 years of production	TP,MCP,PCIW
5	Assess PCIF after 5 years of prodn.	Examine TP in detail.
6	Scrutinize Table-3 (Safety variables and Hazard weights) and Table-4 (Hazard transition) in detail	Take Engg. wing into confidence and make suitable process chain modifications
7	Review the corrective plans after 3 months of prodn.	Newer derived variables may be called for.
8	Change in independent variables	Is expected owing to the dynamic nature of the plants. Hence, close linkage with O&M is recommended.
9	Model validation	Can only be pursued after future industrial validation
10	The proposed regression model is derived by averaging three separate quadratic regressions.	Statistical model validation (e.g., R^2 values, residual analysis, overfitting checks, significance testing) are to be employed in future works.

7. Conclusion

The history of the mishap sites over a specified geographic zone have been enumerated. The casualties covering the fatalities and the injuries have been detailed for each plant. The operational periods and the work force data forming independent variables have been set forth. Hazard weights have been newly incorporated to add emphasis to the quantitative aspect of the analysis. Hazard transitions and FEA analysis have been used in tandem to generate three sets of correlation coefficients (Pearson, Spearman and Kendall). Causal penalties, Transition penalties and Per capita hazards have been generated to add depth to the analysis. Of these, those cases with correlations greater than 0.5 have been analysed in detail.

The use of the above-mentioned statistic techniques have been strengthened with several sets of heuristics to reduce the fatality count in older installations by deploying Safety variables, Hazard weights and Hazard transition chains. When these are adequately deployed with improved safety mechanisms and enhanced adequate equipment and personnel, it serves to reduce the injury and fatality count in chemical installations. It is certain that the strengthening of O&M measures will ease the problem. It should be brought out very forcefully that the mere use of trend-lines or regression techniques should not be used as cardinal solutions. Rather, the heuristics will form a base-line to implement hazard minimization measures.

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