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System Safety Assessment by Developing Hazard Rate Function Based on 5 years Incidents in an Oil Refinery Using Weibull Analysis and its Estimators

Praveen Patel[*1], Dr. Nagendra Sohani[2]

[*1]PhD. Scholar, Mechanical Engineering Department, Suresh Gyan Vihar Univercity, Jaipur, Rajasthan, India

[2]Associate Professor, Mechanical Engineering Department, Institute of Engineering & Science, DAVV, Indore , Madhya Pradesh., India

ABSTRACT

A comprehensive study on system safety assessment of an Indian Oil Refinery incident for five year was done considering the effect of incidents on refinery infrastructure and human injury/causality. The impact of incidents has been assessed by two parameter first the time between two successive incidents and seconds its consequences. The hazard rate function and cumulative risk function for distinguished category of incident in oil refinery were developed. The study evaluated the status of safety level as well as the scope of improvement for the particular oil refinery safety.

Keywords: Hazard Rate Function, TBO, System Safety Assessment, Safety Analysis.

I. INTRODUCTION

Oil refineries are the major source of world's fuel consumption. The oil refineries are enrich with the hazardous process and operations which includes higher pressure and temperature. The existing system of oil refining and process around the country have been subjected to deterioration due to aging, aggressive environmental factors, inadequate design and improper protect and maintenance. These facility often require extensive maintenance, repair, renewal practices and even replacement of certain components. The integrity of these facility is primary interest of oil refinery based company, governmental agencies, consumers and other stack holder due to potential adverse consequences related to public health, safety and heavy financial liabilities in case of systems failure.

The few large fire and explosion in petroleum and chemical industries which were attracted the attention of world society are as under.

II. METHODS AND MATERIAL

Table 1: List of Major Fire and Explosion accidents in Oil and Gas Industry

Date	Location	Cause	Material	Quantity (tones)	Death (d), injured (i)
7 July 1951	Port Newark, NJ, USA	Fire	Propane (70	2600	14i
1955	Ludwigshafen, FRG	Railroad accident	LPG	*	2i
1955	Cottage Grove, OR, USA	Storage vessel failure	LPG	*	12d, 13i
8 January 1957	Montreal, Canada	Fire	Butane	5100	1d
1958	Michigan, USA	Overfilling	Butane	55	1d
4 January 1966	Feyzin, France	Fire	Propane	1000	18d, 83i
Date	Location	Cause	Material	Quantity (tones)	Death (d), injured (i)

Table 1.1 (Continued)

25 January 1969	Laurel, MS, USA	Fire (derail)	Propane	65	2d, 976i
21 June 1970	Crescent City, IL, USA	Fire (Derail)	Propane (5)	275	66i
30 March 1972	Rio de Janerio, Brazil	Fire	Propane	1000	37d
1972	Rio de Janeiro, Brazil	LPG	Storage spheres (five on site) and cylinders	*	37d, 53i
5 July 1973	Kingman, AZ, USA	Fire	Propane	100	13d, 95i
12 February 1974	Oneonta, NY, USA	Fire (Derail)	Propane (4)	288	25i
30 May 1978	Texas City, TX, USA	Fire	Butanes(6)	1500	7d 10i
19 November 1984	Mexico City, Mexico	Fire	Propane (20)	3000	650d, 6400i
August 1993	Panipat, India	Pressure build-up	Ammonia	*	6d, 25i
7 January 2001	Kanpur, India	Highway accident	LPG	*	12d, 6i
1 July 2001	Jamnagar, India	Damage	LPG	*	12d
19 January 2004	Skikida, Algeria	Explosion	LNG	*	13d, 75i
29 October 2009	Jaipur, India	Fire	Kerosine (SKO) Motor Spirit (MS)	1000	11d, 7i

A. Incident Pattern and Type

There is no general agreement about how accidents and incidents should be defined. In view of this author would like to focus on various types of data which might be included in these two categories and the practical implications. Most commonly used distinction between accidents and incidents is that accidents have a specific outcome while incidents have no outcome such as injuries, damage, fire, leakage etc. in an organization. Accident includes any undesired circumstances which give rise to ill-health, damage to property, plant, products, production loss and increased liabilities. Incident includes all undesired circumstances which could cause accidents; it is preferable to think incidents as part of single, much larger, group of undesired events which leads to accident.

Table 2: The main types of accident and incident data

Quality	Environment	Injuries	Health	Asset damage and other losses
Customer complaints	Spillage	Injuries to employees at work	Sickness absence	Damage to organizations assets
Product non-conformances	Emissions above consent levels	Injuries to others at work	Chronic illness	Damage to other people's assets
Service non-conformances	Discharges above consent levels	Injuries during travel	Sensitization	Interruptions to production
		Injuries arising from unsafe products		Damage arising from unsafe products

B. Collection of Accident and Incident Data

One of the largest Oil Refinery of our country has been consider for this work and author had completed one month vocational training for the collection of accident and incident data for refinery. The major sources of accident and incident data within the oil refinery during vocational training includes Accidents Report, Accident / Incident Record, Accident notification and investigating report. In the oil refinery management system follow the chronology of an accident and the author identified the following states to accomplish the same.

1. The person, who sustains the injury, or someone else, reports that an accident/incident has happened, usually in a online system which is assessable to all EHS professional of refinery.
2. The EHS professional to whom the accident/incident is reported, makes a written record of the salient points, usually in a risk register form.
3. The accident is investigated and, if it is sufficiently serious, is reported to the relevant state authority which is Chief Factory Inspector Labor Department Govt. of M.P.

4. The EHS professional who investigates the accident writes a report on his or her findings, to which are added any suggestions for remedial action.
5. The EHS professional who investigates the accident report back to those involved in the outcome of the investigation and the action to be taken.

The vocational training follows the three major steps in collecting accident and incident data of the oil refinery. First step involve the critical examination of all reported accident and incident available with the EHS department of oil refinery. The second step for checking of non-reporting incident and accident was beginning. Personal interview with people who are likely to have experience or knowledge of the accident or incident were commenced. People are more willing to talk about accident or incident they did not report if they are confident that there will be no adverse consequences as a result of their revelations. The author has carried out an appropriate sample of interviews which make a reasonable accurate assessment of the proportion of accidents or incident which is going unreported. Inspections of locations where incident/ accident took place was done by author during these interviews and one set of incident record is keep ready for cross checking the statement given by individual person. A good data are available from year 2010 to 2015 for analysis of incident/accident within the oil refinery.

Classification of Accident/Incident Data

Incident type has been arranged date wise from last five years in risk register of the concern oil refinery. A short description about the incident/accident was found and based on which the type of incident/accident was categorize. The severity level broadly classified on to different aspect the first in terms of harm to personnel and second in terms of plant damage and loss production. The four major significant scales has been decided the severity level of individual incident which was took place. The detail description on these scales of consequences is given below.

We have set up a scale of harm to personnel as:

Minor - Reportable but non-disabling injuries causing over 3 days absence.

Critical – Disabling injury or severe injury requiring extensive recovery and 1 in 10 chance of fatality.

Severe – Critical injuries and possibly 1 fatality.

Catastrophic – One or more fatalities.

Also when a scale of loss in terms of plant damage and lost production is concern an incident/accident severity described as:

Minor - Short-term loss of production.

Critical - Damage to machines repairable in short time.

Severe - Damage to plant, major repair costs and serious loss of production.

Catastrophic - Substantial damage to plant and potential loss of overall plant.

C. Proposed Safety Assessment using Weibull Analysis

The Weibull Distribution

The weibull distribution is one of the most widely used lifetime distribution in reliability engineering. It is a versatile distribution that can take on the characteristics of other types of distributions, based on the value of the shape parameter and scale parameter. To apply Weibull distribution to the available data from Oil Refinery we have to categories the data in four major category and the estimates of the parameters of the Weibull distribution can be found graphically via probability plotting paper, using least squares (rank regression) analysis

Estimation of the Weibull Parameters

The steps for determining the parameters of the Weibull representing the data, using probability plotting, are First rank the time between occurrence in ascending order as shown in table for All four major category. The method of probability plotting takes of the cdf of the distribution and attempts to linearize it by employing a specially constructed paper. The following sections illustrate the steps in this method using 2 parameter Weibull distribution.

1. Linearize the unreliability function.
2. Construct the probability plotting paper
3. Determine the X and Y positions of the plot points.

Constructing the Paper

The next task is to construct the Weibull probability plotting paper with the appropriate y and x axes. The x-axis transformation is simply logarithmic of time between occurrence (TBO) and y-axis is a bit more

Complex requiring a double log reciprocal transformation as

y= ln (ln (1/1-median rank of y))

x= ln (TBO)

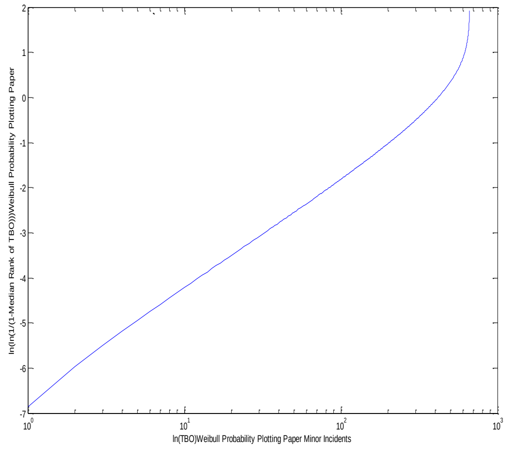

Figure 1: Weibull paper for Minor Incident 2010 to 2015

Least Square Analysis for Minor Incidents & Weibull Estimator

$$\hat{b} = \frac{\sum_{i=1}^{662}(lnti)yi - (\sum_{i=1}^{662} lnti)\ (\sum_{i=1}^{662} yi)/662}{\sum_{i=1}^{662}(lnti)^2 - (\sum_{i=1}^{662} lnti)^2\ /662}$$

$$= \frac{833.598-(227.5682)(-380.8489)/662}{1141.255-(277.5682)^2\ /662}$$

$$= \frac{833.598 + 130.92}{1141.255 - 78.2285} = \frac{703.598}{1063}$$

$$\hat{b} = 0.6618$$

$$\hat{a} = \frac{\sum_{i=1}^{662} y_i}{662} - \hat{b}\ \frac{\sum_{i=1}^{662} lnti}{662}$$

$$= \frac{-380.8489}{662} - \frac{(0.6616x227.5682)}{662}$$

$$= -0.5753 - 0.2274$$

$$= -0.8027$$

$$\widehat{\beta} = \hat{b} = 0.6618$$

$$\hat{\eta} = e^{\widehat{-a}/\hat{b}}$$

$$= e - \left(-\frac{0.8027}{0.6618}\right)$$

$$= e^{1.2130}$$

$$\hat{\eta} = 3.363$$

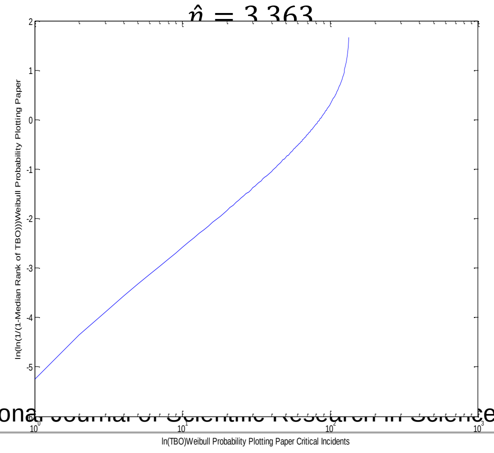

Figure 2: Weibull paper for Critical Incident 2010 to 2015

Least Square Analysis for Critical Incidents & Weibull Estimator

$$\hat{b} = \frac{\sum_{i=1}^{133}(lnti)y_i - (\sum_{i=1}^{133} lnti)\ (\sum_{i=1}^{133} yi)/133}{\sum_{i=1}^{133}(lnti)^2 - (\sum_{i=1}^{133} lnti)^2\ /133}$$

$$= \frac{109.0762 + (217.1707)\frac{(-75.7878)}{133}}{654.5238 - (217.1707)^2/133}$$

$$= \frac{109.0762 + 123.75}{654.5238 - 354.6098}$$

$$\hat{b} = \frac{232.8262}{299.914} = 0.7763$$

$$\hat{a} = \sum_{i=1}^{133} yi - \hat{b} = \frac{\sum_{i=1}^{133} lnti}{133}$$

$$= \frac{-75.7878}{133} - 0.7763\ x\ \frac{217.1707}{133}$$

$$= -0.5698 - 1.2675$$

$$\hat{a} = 1.8337$$

$$\hat{\beta} = \hat{b} = 0.7763$$

$$\hat{\eta} = e^{-\frac{\hat{a}}{\hat{b}}}$$

$$= e^{-}\ (\frac{-1.8337}{0.7763})$$

$$= e^{2.366}$$

$$\hat{\eta} = 10.6638$$

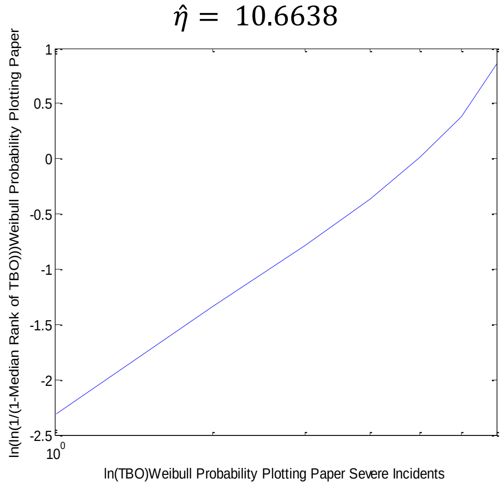

Figure 3 : Weibull paper for Severe Incident 2010 to 2015

Least Square Analysis for Severe Incidents & Weibull Estimator

$$\hat{b} = \frac{\sum_{i=1}^{39}(lnti)y_i - (\sum_{i=1}^{39} lnti)\ (\sum_{i=1}^{39} yi)/39}{\sum_{i=1}^{39}(lnti)^2 - (\sum_{i=1}^{39} lnti)^2\ /39}$$

$$= \frac{1.9959 - (115.2579)\frac{(-21.7429)}{39}}{422.9738 - (115.2579)^2/39}$$

$$= \frac{1.9959 + 64.2574}{422.9738 - 340.6252}$$

$$\hat{b} = \frac{66.2533}{82.3485} = 0.8054$$

$$\hat{a} = \frac{\sum_{i=1}^{39} yi}{39} - \hat{b} = \frac{\sum_{i=1}^{39} lnti}{39}$$

$$= \frac{-21.7429}{39} - \ 0.8045\ X\ (\frac{115.2579}{39})$$

$$= \ -0.5575 - 2.3775$$

$$\hat{a} = 2.9350$$

$$\hat{\beta} = \hat{b} = \ 0.8045$$

$$\hat{\eta} = \ e^{-\frac{\hat{a}}{\hat{b}}}$$

$$= \ e^{-} \ (\frac{-2.9350}{0.8045})$$

$$= e^{3.6482}$$

$$\hat{\eta} = \ 38.4065$$

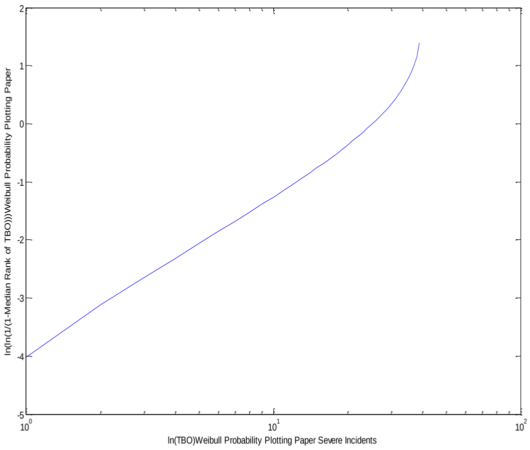

Figure 4: Weibull paper for Catastrophic Incident 2010 to 2015

Least Square Analysis for Catastrophic Incidents & Weibull Estimator

$$\hat{b} = \frac{\sum_{i=1}^{7}(lnti)y_i \ - (\sum_{i=1}^{7} lnti) \ (\sum_{i=1}^{7} yi)/7}{\sum_{i=1}^{7}(lnti)^2 - \ (\sum_{i=1}^{7} lnti)^2 \ /7}$$

$$= \frac{5.6829 - (31.6077)\frac{(-3.5564)}{7}}{166.817 - (31.6077)^2/7}$$

$$= \frac{5.6829 + 16.0585}{166.817 - 142.7209}$$

$$\hat{b} = \frac{10.3756}{24.0961} = 0.4305$$

$$\hat{a} = \frac{\sum_{i=1}^{7} yi}{7} - \hat{b} = \frac{\sum_{i=1}^{7} lnti}{7}$$

$$= \frac{-3.5564}{7} - \ 0.4305\ X\ (\frac{31.6077}{7})$$

$$= \ -0.5080 - 1.9438$$

$$\hat{a} = 2.4518$$

$$\hat{\beta} = \hat{b} = \ 0.4305$$

$$\hat{\eta} = \ e^{-\frac{\hat{a}}{\hat{b}}}$$

$$= \ e^{-} \ (\frac{-2.4518}{0.5080})$$

$$= e^{4.8}$$

$$\hat{\eta} = 124.77$$

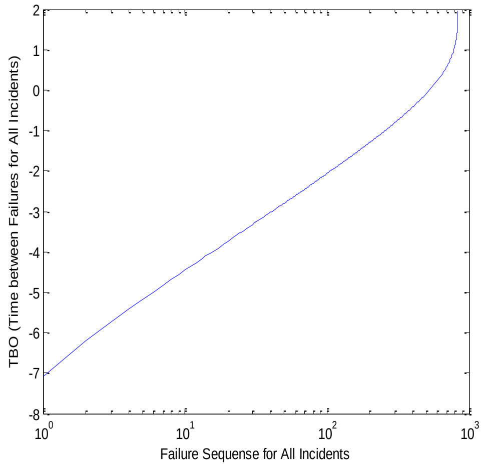

Figure 5: Weibull paper for All Incident 2010 to 2015

Least Square Analysis for All Incidents & Weibull Estimator

$$\hat{b} = \frac{\sum_{i=1}^{839}(lnti)yi - (\sum_{i=1}^{839} lnti) \ (\sum_{i=1}^{839} yi)/839}{\sum_{i=1}^{839}(lnti)^2 - (\sum_{i=1}^{839} lnti)^2 \ /839}$$

$$= \frac{1069.634 - (131.06)(-482.97)/839}{1242.06 - (131.06)^2 \ /839}$$

$$= \frac{1069.63 + 75.44}{1242.06 - 20.47} = \frac{1145.07}{1221.58}$$

$$\hat{b} = 0.937$$

$$\hat{a} = \frac{\sum_{i=1}^{839} y_i}{839} - \hat{b} \ \frac{\sum_{i=1}^{839} lnti}{839}$$

$$= \frac{-482.97}{839} - \frac{(0.937x131.06)}{839}$$

$$= \ -0.575 - 0.1463$$

$$= \ -0.7213$$

$$\hat{\beta} \ = \ \hat{b} = 0.937$$

$$\hat{\eta} = \ e^{\widehat{-a}/\hat{b}}$$

$$= e - \left(-\frac{0.7213}{0.937}\right)$$

$$= e^{0.7699}$$
$$\hat{\eta} = 2.159$$

D. Probability Distribution Function and Hazard Rate Function Development

Weibull Probability Distribution function (PDF) is given by

$$F(x) = \left(\frac{\beta}{\eta}\right)\left(\frac{x}{\eta}\right)^{\beta-1} exp\left(\frac{-x}{\eta}\right)^{\beta}$$

and Hazard function is given by

$$h(x) = \left(\frac{\beta}{\eta}\right)\left(\frac{x}{\eta}\right)^{\beta-1}$$

$$Put\ the\ value\ for\ all\ incidents\ as\ \beta = 0.937, \eta = 2.159, \left(\frac{\beta}{\eta} = 0.433\right), \beta - 1 = -0.063$$

We have

$$f\ (x)_{All\ incident} = 0.45\ x^{-0.063}\ \exp(-0.46\ x)^{0.937}$$
$$h(x)_{All\ incident} = 0.45\ x^{-0.063}$$

$$Put\ the\ value\ for\ Minor\ Incidents\ as\ \beta = 0.6618, \eta = 3.363, \left(\frac{\beta}{\eta} = 0.196\right), \beta - 1 = -0.03382$$

$$f\ (x)_{Minor\ incident} = 0.295\ x^{-0.3382}\ \exp\ (-0.29\ x)^{0.6618}$$
$$h(x)_{Minor\ incident} = 0.29\ x^{-0.3382}$$

$$\text{Put the value for Critical Incidents as } \beta = 0.7763, \eta = 10.66, \left(\frac{\beta}{\eta} = 0.072\right), \beta - 1 = -0.223$$

$$f\ (x)_{Critical\ incident} = 0.00074\ x^{-0.223}\ \exp\ (-0.09\ x)^{0.7763}$$
$$h(x)_{Critical\ incident} = 0.00074\ x^{-0.223}$$

$$\text{Put the value for Severe Incidents as } \beta = 0.8045, \eta = 38.40, \left(\frac{\beta}{\eta} = 0.020\right), \beta - 1 = -0.1955$$

$$f\ (x)_{Severe\ incident} = 0.4\ x^{-0.195}\ \exp\ (-0.26\ x)^{0.8045}$$
$$h(x)_{Severe\ incident} = 0.4\ x^{-0.195}$$

$$\text{Put the value for Catastrophic Incidents as } \beta = 0.4305, \eta = 124.77, (\beta/\eta = 3.4\ x\ 10^{-3}), \beta - 1 = -0.569$$

$$f\ (x)_{Catastrophic\ incident} = 0.053\ x^{-0.569}\ \exp\ (-0.008\ x)^{0.4305}$$
$$h(x)_{Catastrophic\ incident} = 0.053\ x^{-0.569}$$

III. RESULTS AND DISCUSSION

S. No.	Type of Incident	Value of β (shape para meter)	Value of η (scale para meter)	Probability Distribution function f(x)	Hazard Rate Function h(x)
1	All	0.937	2.159	0.45 $x^{-0.063}$ exp $(-0.46\ x)^{0.937}$	0.45 $x^{-0.063}$
2.	Minor	0.6618	3.363	0.295 $x^{-0.3382}$ exp $(-0.29\ x)^{0.6618}$	0.29 $x^{-0.3382}$
3.	Critical	0.7763	10.66	0.00074 $x^{-0.223}$ exp $(-0.09\ x)^{0.7763}$	0.00074 $x^{-0.223}$
4.	Severe	0.8045	38.40	0.4$x^{-0.195}$ exp $(-0.26\ x)^{0.8045}$	0.4$x^{-0.195}$
5.	Catastrophic	0.4305	124.77	0.053x^{-569}exp $(-0.008\ x)^{0.4305}$	0.053 $x^{-0.569}$

IV. CONCLUSION

The hazard function defined as the limit of the failure rate as the interval approaches zero. Thus the hazard function is the instantaneous failure rate of any incident type. The quantity h(x)dx represents the probability that a incident of particular category having time x will be took place within the small interval of time x to x+dx. Hazard function indicates the change in failure rate over the life of a population of point in time.

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