# Design of Occupational Health and Safety Management Systems for Viscose Staple Fiber Division, Grasim Industries Limited

**THESIS**

Submitted in partial fulfillment
of the requirements for the degree of

**DOCTOR OF PHILOSOPHY**

by

**Samir Ramdas Kale**

Under the supervision of

**Prof. (Dr.) Arun Maity**

**BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE**
**PILANI – 333 031 (RAJASTHAN) INDIA**

2015

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BITS Pilani
Pilani | Dubai | Goa | Hyderabad

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2015

**BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE**
**PILANI – 333 031 (RAJASTHAN) INDIA**

# CERTIFICATE

This is to certify that the thesis entitled **"Design of Occupational Health and Safety Management Systems for Viscose Staple Fiber Division, Grasim Industries Limited"** and submitted by **Samir Ramdas Kale**, ID.No. **2002PHXF026P** for the award of Ph.D Degree of the Institute embodies the original work done by him under my supervision.

Signature: ________________

**Prof. (Dr.) Arun Maity**

Associate Professor,

BITS-Pilani, Off Campus Center, Kolkota

Date: ______________

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# Abstract

As majority of the process industries nowadays operates at relatively higher operating conditions of process variables (such as temperature, pressure, use of hazardous chemicals, etc.) there is an increased risk of accidents or occupational exposure to hazardous chemicals in process plants.

With this emphasis and understanding that the number of accidents is reoccurring in the process industries, it can be inferred that there are loopholes in the implementation of the OHSMS program and further research is required in this domain.

Comprehensive design of OHSMS through a stepwise methodology is carried out in this study. The method used for the design is gap analysis, empirical investigation of pillars, reliability and validity criteria, structural model and the statistical validity of the structural model.

For carrying out these investigations statistical software such as SPSS was used and from Exploratory factor analysis (EFA) and Confirmatory factor analysis (CFA) it was confirmed that there are six pillars which are critical for the success of OHSMS. The pillars identified are TMC (Top management commitment), STD (Safety training and development), Workplace environment and health monitoring systems, HIRA (Hazard identification and risk assessment), OHSIM (Occupational health and safety management systems) and AUR (Audit and review).It was confirmed from CFA model fit results that there is an underlying structure among the six pillars. To determine the path for implementation of OHSMS framework, ISM methodology was used, this methodology predicts the path for the pillars to develop OHSMS. It was found that these pillars have high degree of correlation with OHSMS and was confirmed by the hypothesis testing. To test whether this structural model is statistical significant the model fit parameters were calculated and the values were found to be within the norm. Therefore, the model can be used to develop the framework for OHSMS in the process industries. The two most important pillars of STD (bottom of the structure) and HIRA (top of the structure) were further analyzed for the specific case study of Grasim Industries Limited (GIL).

While analyzing STD and its relation to accidents (measure of OHSMS effectiveness), the accident data and the corresponding training data for 7 years was collected (2004-2011) for various departments of GIL. It was found that spinning and after-treatment was the most vulnerable department with respect to accidents. The training function was determined for the various modes of training provided, the findings were that by increasing only the training hours the accidents won't be reduced, therefore it was appropriate to design a priority based training program which is suggested in the present study. The other pillar which was found to be significant for GIL was HIRA, therefore first the critical equipment was identified and then the HIRA tools were applied to them. These tools will help to avert major disasters and mishaps. Further, the consequence analysis of the critical equipment handling the hazardous solvent was carried out using the Pasquill-Gifford model and the release distance of various maximum credible scenarios was done.

The major contributions of the thesis were the development of the structural model and applying it to a real life case study. Therefore, the thesis addressed a very important ongoing problem to reduce accidents and improve the overall OHSMS process.

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# Abbrevations and nomenclature

## Abbreviations

| | |
|---|---|
| AMOS | Analysis of moment structures |
| ANSI | American national standards institute |
| asir | Asset integrity and reliability |
| AUR | Audit and review |
| BHS | British health safety |
| BIS | Bureau of Indian standards |
| BLEVE | Boiling liquid expanding vapor explosion |
| CCPS-AiChE | Center of chemical process safety-Americal institute of chemical engineers |
| CFA | Confirmatory factor analysis |
| CIMAH | Control of industrial major accident hazards legislation |
| conm | Contractor management |
| cosc | Compliance with standards |
| CSA | Canadian standards association |
| CSF | Critical success factors |
| DSM | Dutch state mines |
| EFA | Exploratory factor analysis |
| emm | Emergency management |
| EST | Electrical safety training |
| ET | Emergency training |
| FAT | First aid training |
| FMEA | Failure mode and effect analysis |
| FRM | Final reachability matrix |
| FRP | Fiber reinforced plastic |

| | |
|---|---|
| GIL | Grasim industries limited |
| HAZOP | Hazard and operability procedure |
| HIRA | Hazard identification and risk assessment |
| HOD | Head of department |
| HSE | Health safety and environment |
| ICMR | Indian council of medical research |
| ILDH | Immediately dangerous to life or health |
| ILO | International labor organization |
| incii | Incident investigation |
| IRM | Initial reachability matrix |
| ISM | Interpretative structural matrix |
| ISO | International organization for standardization |
| KMO | Kaiser-Meyer-Olkin |
| $LC_{50}$ | Lethal concentration  (animal lethal concentration) |
| MAH | Major accident hazard |
| MC | Management commitment |
| MCA | Maximum credible scenario |
| MIC | Methyl iso cynate |
| mmh | Measurement and metrics of health |
| moc | Management of change |
| MP | Madhya Pradesh |
| MSDS | Material safety data sheet |
| MT | Metric ton |
| MW | Mega watt |
| OHS | Occupational health and safety |
| OHSIM | Occupational health and safety information system |
| OHSMS | Occupational health and safety management system |

| | |
|---|---|
| OJT | On the job training |
| PCA | Principal component analysis |
| pkm | Process knowledge management |
| PPE | Personal protective equipment |
| psc | Process safety competency |
| RM | Reachability matrix |
| SEM | Structural equation modeling |
| SFD | Staple fiber division |
| SME | Smal and medium enterprise |
| SPSS | Statistical package for the social sciences |
| SSIM | Structural self-interaction matrix |
| STD | Safety training and development |
| swp | Safe work practices |
| TCDD | Tetrachlorodibenzo-p-dioxin |
| TMC | Top management commitment |
| TPD | Tonnes per day |
| TS | Trainers skill |
| VBT | Video based training |
| VCE | Vapor cloud explosion |
| VSF | Viscose Staple Fiber |
| W | Workers attitude |
| WDP | Workmen development training |
| WEHMS | Workplace environment and health monitoring systems |

## Nomenclature

| | |
|---|---|
| AGFI | Adjusted goodness of fit index |
| CFI | Comparative fit index |
| CMIN | The minimum discrepancy |
| CMIN/DF | Likelihood ratio test statistics (Chi square) |
| DF | Degrees of freedom |
| Fmin | Minimum discrepancy function |
| FO | Population discrepancy |
| GFI | Goodness of fit index |
| HI90 | Upper limits at 90% confidence interval |
| IFI | Incremental fit index |
| LO90 | Lower limits at 90% confidence interval |
| MI | Modification indices |
| NFI | Normed fit index |
| NPAR | Number of parameters |
| P | probability |
| PCFI | Parsimony goodness of fit index |
| PNFI | Parsimony normed fit index |
| PRATIO | Initial parsimony ratio |
| RFI | Relative fit index |
| RMR | Root mean square residual |
| RMSEA | Root mean square error of approximation |
| TLI | Tucker-Lewis index |

# Chapter - 1

# Thesis overview

The field of occupational health and safety management system (OHSMS) has gained significance over the last three decades due to its potential for reducing work related injuries and illnesses, also it increases productivity by reducing direct and indirect costs associated with the accidents as evident by International Labor Organization guidelines (ILO) (2001). The understanding of OHSMS concept and its applicability has to be studied for carrying out research in this domain.

## 1.1 Introduction to OHSMS

According to Gallagher (2000), OHSMS is defined as "A combination of planning and review, the management organizational arrangement, the consultative arrangement, and specific program elements that work together in an integrated way to improve health and safety at work." According to ILO (2001), OHSMS is a ''A set of interrelated or interacting elements to establish OHS policy and objectives, and to achieve those objectives, the elements should be assembled together." Nevertheless, another researcher Nielsen (2000) argued that the management systems should not only include the management components but technical components as well. According to Nielsen, "OHSM systems are not, of course, a well-defined set of management systems. Indeed, there are no clear boundaries between OHS activities, OHS management, and OHSM systems." It is therefore presumed from the above definition that there are divergent views on OHSMS.Therefore, it can also be hypotized that OHSMS in general, depends on the characteristic of an individual organization, and one cannot justify single definition of OHSMS for the entire domain of industries. The elements of OHSMS are characterized by the nature of the organization.

OHSMS can be adopted by organizations either voluntary or mandatory. Robson et al. (2007) results show that after the intervention of OHSMS, there was a decrease in injury rates, which was 18% (10 yrs post-intervention vs. 4 yrs pre-intervention) for mandatory OHSMS organizations and 24 to 34% for voluntary OHSMS (18 month intervention for 15 manufacturing organizations). This suggests the commitment of the organization is important to produce positive results, whether it is mandatory or voluntary. Koh (1995) expressed that better OHSMS reduces the health cost and due to fewer accidents it increases the productivity.

Cox and Vassie (1998), also argue that OHSMS may improve the safety standards of operations, enhancing communication, morale and productivity, thus helping companies in meeting legal responsibilities in managing safety. As industrial accidents generate financial losses due to the disruptions in industrial processes.It is necessitated to see how OHSMS has changed over the past many years. It has been found that there is a continuous increase in thrust for improvement in quality and product throughput which has made present day industries to undergo a major transformation in operations in the recent past. As the majority of the these industries now operates at relatively higher operating conditions of process variables (such as temperature, pressure, use of hazardous chemicals, etc.) there is an increased risk of accidents or occupational exposure in these industries. However, OHSMS application for the entire gamut of industries is beyond the scope of the study. One procedure is to compare the key loss statistics indices across all sectors and then study the particular sector (group of industry). Accordingly, Crowl and Louvar (Crowl and Louvar, 2002) who compared the loss statistics of all industries (chemical process industries, motor vehicles, steel, paper, coal mining, food, construction, meat product, trucking and all manufacturing) found that the incidence rate (index to calculate the number of lost days due to accidents) for chemical industries is 0.35 and fatality accident rate (no of fatalities/no of workdays*20000) is 1.6 (year 1998 as the base) which is found to be lowest among all as compared to general view that these industries are the most hazardous and risky.

Then the question arises as to why there is such a hue and cry about the chemical process industries being the most risky organizations. This view can be substantiated because though the index shows lower numbers it doesn’t account for the fatalities and accidents due to the disasters so in a sense the number can be misleading to show that chemical process industries are the safest Vivid reminders of few disastrous events related to chemical process industries are Union Carbide, Bhopal, India; Icmesa Chemical Company, Seveso, Italy; Three-Mile Island Nuclear Station, Piper Alpha, USA (Knegtering, 2002; Willey, et al., 2006; BHS, 1976; Hopkins, 2001) prove the point that these group of industries are vulnerable to major disasters.. Even after these disasters and subsequent timely updated legislations in safety management changes thereof, there are reports of continuous accidents and incidents reoccurring in the chemical process industries as evident from Table 1.1.Such incidents reiterate the concern of safety for process workers (technical employee, management employee and workmen).

**Table 1.1: Incidents and consequences of reported industrial accidents**

| **Reported incidents** | **Observed consequences** | **Month, year and place** | **Reference** |
|---|---|---|---|
| Gasoline pipeline from the refinery ruptured | 3 killed and \$3.05 million fined | June, 1999 Washington, USA | CNN, 1999a |
| Explosion in an oil storage tank during repair work | 2 killed and one seriously injured | June, 1999 Tennessee, USA | CNN, 1999b |
| Leak of liquefied petroleum gas from ahmadi refinery | 4 killed and 49 Injured | June, 2000 Ahmadi, Kuwait | CNN, 2000b |
| Explosion at the AZF fertilizer factory due to vapor cloud explosion | 29 killed and 500 injured | September, 2001 Toulouse, France | Barthelemy et al., 2001 |
| Vasudev chemicals | Four employees were killed | June, 2004 Vadodara, India | Business line, 2004a |
| Fire at Indian oil depot | Economic loss | June, 2004 Rajbandh, India | Business line, 2004b |
| Fire at Gulf oil R&D center | Economic loss | August,2004 Hyderabad, India | Business line, 2004c |
| Fire at reliance industries limited, IPCL, Nagothane complex | Three employees killed | June, 2008 Nagothane, India | Business line, 2008 |
| Acid leak at Shasun chemicals | Production halt for many days | March, 2011 Vadodara, India | Business line, 2011a |
| Fire at Vizag HPCL refinery unit | Economic loss | April,2011 Vizag, India | Business line, 2011b |
| Fire at Chevron BP refinery unit | 15000 people were given first aid and major economic loss | August, 2012 Texas, USA | CSB, 2012 |
| Fire at Vizag HPCL refinery unit | Economic loss and fourteen employees killed | May, 2013 Vizag, India | Indian express, 2013 |
| Fire accident at chemical factory | Economic loss | May, 2014 Dhar, India | IBN, 2014 |

From the reports of the accidents, it can be deduced that the chemical disasters are repeating itself, even in the presence of a formal OHSMS which undermines the role of its implementation and design. Therefore, OHSMS framework and design is aimed for chemical process industries to avert these repetitive incidents. The research need for such a framework with extensive interrelation of factors governing OHSMS effectiveness is needed for chemical process industries. The research emphasis is for an improved design of OHSMS in chemical process industries.

## 1.2 Research need

The interrelation of factors governing OHSMS effectiveness has been developed and implemented by many major organizations, studies on their implementation and effect have rarely been carried out.

There is a close interrelationship between OHSMS and accidents. Basically accidents constitute a behavioral problem signifying disintegration in the equilibrium of the individual in relation to the work situation. The cause of nearly all accidents may be classified into unsafe conditions and unsafe acts. While unsafe acts of the people are harder to control and less immediate in effect. Even though in the short run, more certain and quicker results can be obtained by rectifying unsafe conditions, in the long run, the only way to make workplace accident free is to teach people to work safely and to see that they practice it. Many of the industrially developed countries of the world have seen injury and illness rates decline drastically over the last 50 years. However, these rates have generally reached a plateau over the last decade. Many novel approaches have been tried to further improve performance using behavior-based-safety techniques, improved health and safety auditing concepts, and management systems schemes. There is no doubt that many other approaches will also be tried in the future. Nevertheless, as mentioned, one of the newer techniques is the use of a management-systems approach. This is possible if the management systems address OHS indicating the positive and negative factors affecting them. Occupation and health are a two-way relation between health and work and therefore it combines to form Occupational health i.e. health problems related to workplace. With the goal of reducing occupational injury, illness, fatalities and their associated costs, strategies for augmenting traditional command-and-control regulatory and management approaches are to be explored. One such approach is the application of OHSMS. The current attention being given to OHSMS stems from the developments in the International Organization for Standardization (ISO), nation-states, professional societies, industry bodies; and, health, safety and environmental consultancies.

Thus, basically it can be observed that the implementation of the OHSMS depends on the intervention. Research should be aimed at how this intervention affects the target population.The best way is to incorporate theoretical constructs into the intervention itself and the kind of measurement tools that should be developed to assess the change in the constructs. This type of work will find out whether the change desired by the intervening variable is achieved or not. The implementation can address such questions such as (i) What are the components of the intervention and how can they be provided? (ii) What is the quality of intervention? (iii) Are there any objections from the workers and why? (iv) How the intervention deviate from the expected?

Although there are formal and documented OHSMS in many organizations, they fail in the intended objectives and therefore it can be presumed that there is problem in implementation and this can be achieved by identifying the factors that have a positive effect on the intervening variable which will bring a positive change. With this background, the research objectives of the thesis have been summarized in the next subsection 1.3.

## 1.3 Objectives of the research

a. OHSMS gaps from standard requirements (ILO) available from the literature and industry practices
b. Identify critical pillars of OHSMS for chemical process industries
c. Developing a structural model by articulating significant pillars for better implementation of OHSMS and Empirical validation of proposed structural model through structural equation model (SEM) and hypothesis testing of pillars with OHSMS
d. An indepth study of two critical pillars of OHSMS with Grasim Industries Limited (GIL) as the base case study

## 1.4 Organization of the thesis

In order to achieve the desired objectives the thesis has been organized as follows.

Chapter 1 presents the overview of the thesis and outlines the objectives of the research.

Chapter 2 is the study of an exhaustive literature survey carried on the evolution of OHSMS, disasters in the process industries to understand the loopholes in OHSMS, perceptions of various authors and researchers for OHSMS. Study the various Occupational accident models and then the study is being undertaken by comparing OHSMS standards adopted in various industries such as metallurgy, fertilizer and chlor-alkali units. This will help in identifying the gaps of existing research and provide the scope of research.

Chapter 3 discusses the methodology for the research by studying the gaps between the standard requirements of OHSMS and the OHSMS followed in a particular process industry. Stepwise research using exploratory factor analysis (EFA), confirmatory factor analysis (CFA), interpretative structural matrix (ISM) methodology and structural equation modeling (SEM) approach is adopted for OHSMS framework. The approach used is the survey experiment.

Chapter 4 relates to the discussion of the results of factor analysis and model specification. Results of interitem internal consistency, construct validity and discriminant validity which are the part of the CFA has been discussed . Further, this chapter includes ISM dependence diagram to identify the path of the OHSMS structure and lastly SEM is used to test whether the structure is statistical fit or not.This model can be applied to GIL, which is taken as a base case study for OHSMS implementation.

Chapter 5 is about the implementation approach for the model of OHSMS at GIL which follows the derived model, which predicts the various levels in implementing an OHSMS. The bottom pillar in this structure is safety training and development, and at the top of the hierarchy is hazard identification and risk assessment, other pillars such as an OHSMS information system, health monitoring system and OHSMS audit are only reviewed for their existing loopholes for further research and scope. Suggestions with respect to these pillars have also been covered in this chapter appendix. Elaborate analysis of safety training and development pillar is discussed. Accident data of 7 years have been collected to study the impact of unsafe act and lack of training resulting in accidents. On-going safety training modules are developed for GIL and redesigned by carrying a survey among the shop floor workers, management and supervisors. These modules are analyzed for the specific item wise design modification.

This chapter also details the hazard identification and risk assessment pillar.Since GIL process is an integrated process. It involves various unit operations and occupational jobs that pose hazards. Categorizing every operation in the process is very vast and therefore, a structured approach of identifying the critical equipment was adopted. The hazard identification tools are then applied to this critical equipment. The tools adopted are checklist approach, hazard identification and operability studies (HAZOP), failure mode effect analysis (FMEA) and DOW Index. Although all these tools have some limitations either qualitative or quantitative, but they are widely used across all the process industries as they prove to be beneficial in the decision making process. Consequence analysis modeling is also being carried out for the critical equipment. The suggestions and recommendations to eliminate or mitigate the hazards of all critical equipment are included in the sheets described in this chapter and the accompanying **Appendix-G**.

Finally, Chapter 6 discusses the concluding remarks about the design and development work done and explores the benefits of such a design. Future work for further research is also suggested.

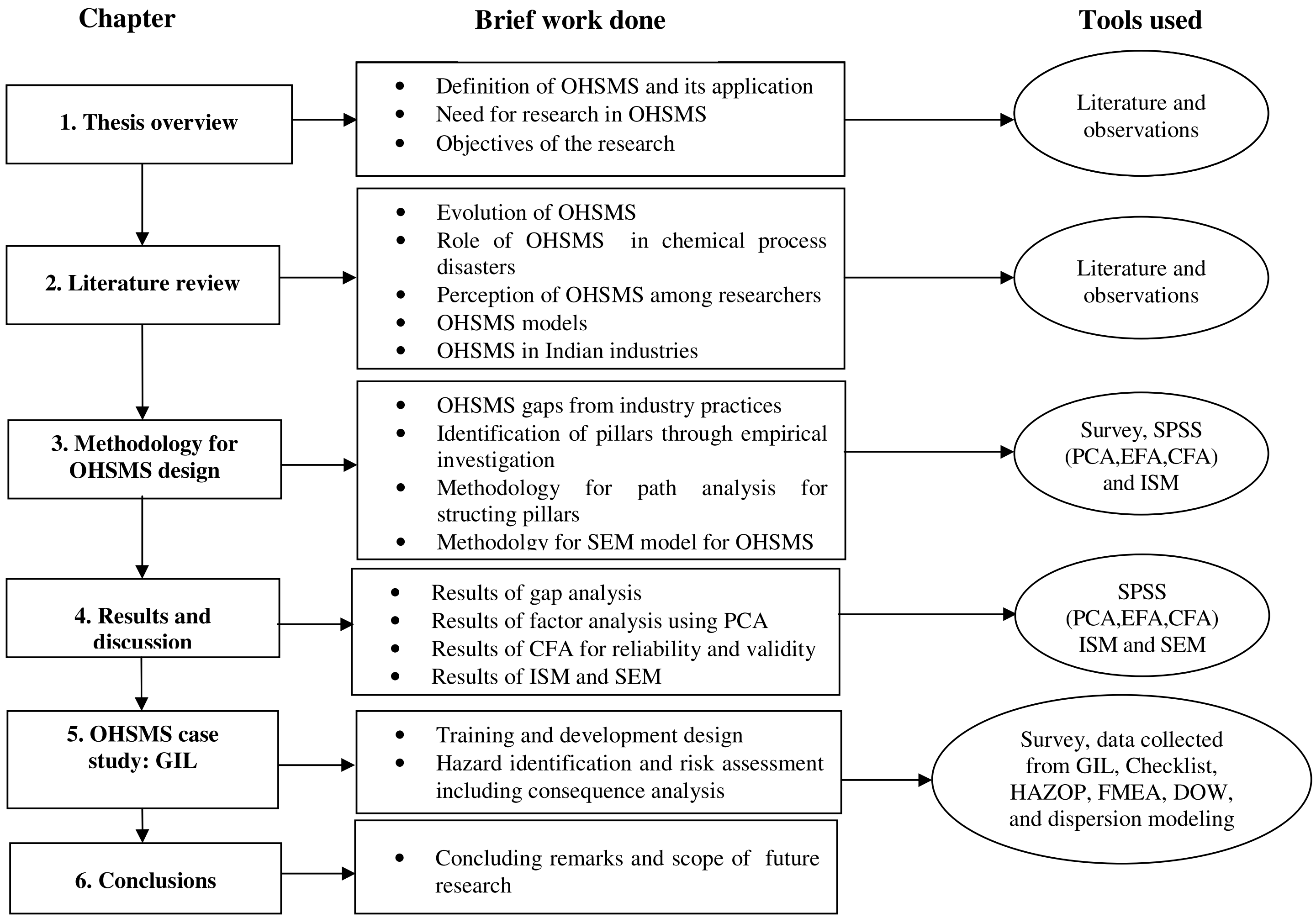



**Fig 1.1: Organization of the thesis**

# Chapter - 2

# Literature review

The objective of the research outlined in the chapter 1 is to find out the gaps in the literature and industry practices relevant to the OHSMS field in chemical process industries. This can be done by carrying out an indepth literature review which is discussed in this chapter. First, it discusses the evolution of OHSMS, OHSMS learnings from previous process plant disasters, the perception of OHSMS among various researchers, the significance of various models to OHSMS and current OHSMS practices in Indian process industries.

## 2.1 Evolution of OHSMS

After the Bhopal disaster in 1984 and Piper Alpha disaster in 1987, Lord Cullen identified the requirement for systematic safety management (Cullen,1990) and also started working on the goal-setting approach first laid out in the report of Robbens committee that resulted in the UK Health and Safety Work Act, 1974 (Robbens,1972). The International Organization for Standardization (ISO) considered developing an international management standard for OHS similar to those already established for quality (ISO 9001) and the environment (ISO 14001). Support for this development among member organizations was insufficient. However, the project was disbanded in 2001 (Bennett, 2002).Companies have, nevertheless sought certification to an ISO-compatible OHS standard. Indeed, the British Standards Institute developed Occupational health and safety assessment series (OHSAS) 18001 in response to this demand (Abad et al., 2002). This standard was internationally recognized and then adopted by various industries as a proxy for an ISO standard. In some industries, more management pressure was observed from trading partners to adopt OHSAS 18001 standards, as there have been previously for ISO 9001 and ISO 14001. In addition, some companies also see potential efficiencies by adopting an OHSMS that can be integrated with their existing ISO-based management systems for quality and environment (Winder, 1997; Wright, 2000).

The international OHS standard project was referred by ISO to the ILO, which was thought to be a more appropriate forum for it. Following this referral, ILO developed guidelines on OHSMS in 2001 (ILO, 2001) through a consensus process that included equal representation from government, labors and employers. The ILO guidelines were envisioned as models for national standards.

Dalrymple et al. (1998) found that national voluntary standards for OHSMS in the draft or final form existed in Australia, New Zealand, Ireland, Jamaica, Netherlands, Norway, Spain, and the United Kingdom. The forerunner of the British Standards Institute's OHSMSs (BS 8800, OHSAS 18001) was developed by the public sector health and safety executive (HSG65, HSE 1997). The American National Standards Association (ANSI) and the Canadian Standards Association (CSA) both adopted the process of developing a national standard. The Canadian organization had also included the ILO Guidelines, OHSAS 18001, and the draft ANSI standard as reference documents. As a result of this growing acceptance of standards by other countries, Indian organizations too started attaching the same importance to achieve high OHS performance as they do to other key aspects of their business activities (BIS, 2001).

Therefore, Bureau of Indian Standards (BIS) decided to formulate an Indian standard on OHS management systems considering its benefits and a great demand from the industry for a comprehensive framework of OHS. Many organizations have reported improvements in workplace health and safety, along with significant savings from the implementation of OHSMSs (Redinger and Dalrymple, 1999), but there was a need felt to test the effectiveness of all the standards with respect to different elements.

Further, Dabanbneh (2007) suggested that OHSMS would be effective only by integration of the certain elements of each standard (OHSAS 18001, ILO-OSH 2001 and OR-OSHA) as each one has some merits and demerits The requirement for organizations to develop safety management systems (SMS) grew out in the aftermath of a number of disasters, predominantly in Europe. The Flixborough accident in 1974, at the Nypro Ltd caprolactum production facility, led to the first requirement for the petrochemical companies to present a safety case. The control of industrial major accident hazards (CIMAH) legislation was restricted to UK onshore facilities. The Seveso incident in 1976 resulted in the European directive 82/501/EEC, known as the Seveso directive, which has been brought up to date with the Seveso II guidelines as required by the

Council Directive 96/82/EC (BHS, 1976). Kletz's review of 20 major industrial accidents (Kletz, 2001), including Bhopal, India, Flixborough, UK and Seveso, Italy identified poor safety management practices at the root of all these incidents. In order to understand the series of events that triggered these disasters, it is necessary to study these events and learn lessons from them to avoid such incidents for posterity. Various studies on major process plant disasters and their impact on the development of SMS for industrial cases are discussed below in section 2.2. Such incidences emphasize the role of safety management to prevent these catastrophic events.

## 2.2 OHSMS learning's from process plant disasters

In order to understand the loopholes in SMS it is necessary to study what went wrong operationally, organizationally and technically in the process. With this elementary view it is necessary to discuss these disasters in detail. The detailed discussion is followed in the subsections below.

### 2.2.1 Union carbide disaster

Union Carbide had a plant manufacturing carbaryl at Bhopal. The capital city of Madhya Pradesh located in Central India. (Kharbanda and Stallworthy, 1988). The description of the process, the sequence of events, the damage and the lessons learnt has been discussed as follows.

Carbaryl was manufactured by taking the methyl iso cynate (MIC) route, which is itself made by reacting monomethyl-amine with phosgene, and reacting it with alpha-naphthol.

In order to understand the sequence of events on 2-3 December 1984, one has to understand what had actually happened between the two (B and C) shifts. Union Carbide had three shifts (A shift: 7:00 a.m. to 3:00 p.m.; B shift: 3:00 p.m. to 11:00 p.m.; C shift: 11:00 p.m. to 7.00 a.m.). It was around 10.15 p.m. just before the end of the B shift, supervisor asked an operator to wash the piping around one of the MIC tanks. Since the valves on the tank were known to be leaking at times, a slip blind had to be inserted near the valve to seal off the tank so as to prevent the ingress of water. Water in the tank would initiate a polymerization reaction that is considered to be highly exothermic. Water actually entered the tank via nitrogen pressure line. Around 11:00 p.m. the new shift operator noticed that there is a pressure rise in the same tank, but assumes that the last shift operator increased the pressure of nitrogen in order to transfer its contents to the pesticide unit. Half an hour later at 11.30 p.m. the operators sense a little irritation to their eyes because of a small MIC leak. That wasn't an unusual phenomenon, so it was again ignored (without knowing the root cause of eye irritation). At 12.00 midnight, temperature and pressure continue to build up in the tank and the water sprayed over the tank proved ineffective. Pressure built up was several times the permissible limit. It bursted the rupture disc, blew the safety valve, and MIC rushed straight through the 33 m high atmospheric vent line out into the Bhopal air (Kharbanda and Stallworthy, 1988).

Once MIC escaped in the atmosphere it had catastrophic effects. MIC, being heavier than air settled to the low lying ground area. People started inhaling the gas, which lead to immediate death. Many people died in their sleep, while others suffered secondary infections and permanent disabilities. No exact figures are available, but according to survey carried out by Indian Council of Medical Research (ICMR), more than 20,000 people died with over 1, 00, 000 with permanent disabilities or some kind of side effects. After-effect of the damage was deleterious with infant mortalities, lung disinfections, disabilities, etc. Even, today according to the analysis of ICMR, the soil is contaminated with toxic substances. This catastrophic incident changed the image of process industry forever, and therefore, safety became the primary concern for process industries.

#### *2.2.1.1 Learnings*

Management decisions had disabled many control measures, which would have prevented or reduced the consequences of this incident. Mitigation controls were also ineffective, for example water sprays only reached a height of 15 m, yet the MIC was released at 33 m (Chouhan 2005, Marshall 1987 and Wells 1997). MIC was an intermediate product in the production of carbaryl and the storage of such large quantities was unnecessary. The most important lesson from Bhopal being '*What you don't have, can't leak*' (Kletz 2001), which is now a key concept in inherent safety.

### 2.2.2 Flixoborough disaster

Nypro, in 1964 took the charge of the company owned by Dutch State Mines (DSM) and Fisons (MoL, 2001). The major product manufactured was caprolactum, a basic raw material for Nylon 6. The process route used was to produce cyclohexanone by the oxidation of cyclohexane (air injection in the presence of catalyst) instead of hydrogenation of phenol, which was originally designed). The new process was more economical and hazard prone, but still was adopted in the company's expansion phase. The chemical reactions for the production of cyclohexanone by the oxidation of cyclohexane are as follows

$$\underset{(\text{Cyclohexane})}{C_6H_{12}} \xrightarrow{O_2 \text{ in presence of catalyst}} \underset{(\text{Cyclohexanone})}{C_6H_{10}O} \tag{2.1}$$

$$\underset{(\text{Cyclohexanone})}{C_6H_{10}O} \xrightarrow{\text{NH}_2\text{OH}} \underset{(\text{Cyclohexanoxime})}{C_6H_{10} = NOH} \tag{2.2}$$

$$\underset{(\text{Cyclohexanoxime})}{C_6H_{10} = NOH} \xrightarrow{\text{H}_2\,\text{SO}_4} \underset{(Caprolactum)}{C_5H_{10}N = O} \tag{2.3}$$

At 4.53 p.m. on Saturday, 1st June 1974 the caprolactum plant was virtually demolished as a consequence of a huge explosion. This explosion was the result of BLEVE (Boiling liquid expanding vapor explosion) due to cyclohexane. The complete reaction scheme is shown through Eqs. 2.1-2.3. The plant incorporated six reactors where cyclohexanone was formed by the oxidation of cyclohexane. Two months back, reactor No 5 was found to be leaking due to a 2 inch crack in the shell. In view of this serious damage, it was decided to take reactor No 5 out of service. This meant it has to be bypassed. The relevant openings on these reactors were 71 cm diameter, so it was decided to construct a bypass between reactor No 4 and reactor No 6 using a 50 cm diameter pipe**,** since this was the largest size pipe immediately available on the site. The two reactor flanges were at different levels, so the bypass took the form of 'dog-leg'. The 50 cm diameter pipe was thought to be adequate in size for the volumes that would be flowing from reactor to reactor, and wall thickness could bear high pressures. The 'dog-leg' stress calculation was ignored and even the detailed drawings were missing. The complete large amounts of nitrogen were being consumed for purging.

On 29th May, an isolating valve was found to be leaking, so the plant was shut down once again, the leak repaired, and the plant started up once again on 1$^{st}$ June. On startup, it was noticed that when the temperature in reactor No 1 was about 110°C the pressure rose suddenly to 8.5 kgf/cm$^2$, and that when the normal operating temperature of 155°C, the pressure was 9.1-9.2 kgf/cm$^2$. The pressure was normally controlled by venting the off-gas, but this required a considerable quantity of nitrogen. At this point of time, nitrogen was in short supply, and a further delivery was not expected until after midnight, some ten hours later, so there was a need to limit the usage of nitrogen. Thus, there was reluctance on the part of operators for venting gas. During afternoon time the 50 cm diameter pipe ruptured, and the resulting vapor cloud ignited by an unknown source. It revealed that the assembly was not pressure tested.

The cyclohexane plant was completely destroyed, together with the neighboring plants and the tank farm went on fire. The strong blast shattered the control room windows and its roof collapsed. All 18 people in the control room died. The main office block was also demolished but since it was the weekend, there was no one there. In all 28 people died and explosion were felt miles away. This is the worst chemical incident with reference to property damage, but unlike Bhopal the casualties were far less as the plant was located on the outskirts and also the town was sparsely populated so information dissipation was proper. As a result of these, people ran on the opposite direction of wind which saved many lives.

#### *2.2.2.1 Learnings*

Some hard lessons were learnt from this event, which led to a major legislation change in UK with respect to hazardous installation (Kletz, 1998). Very large quantities of hazardous material (cyclohexane) were stored on-site without a license and without the knowledge of authorities. This was significant finding, although the licensing provides a false sense of security, and many accidents may well be the result of such an assumption.

The accident disclosed the need for local planning authorities to be notified of the fact that the plant could present a major hazard. Lastly, it was the management aspects. The event reveals the discrepancies of SMS at Flixborough works. There were insufficient complement of appropriately skilled and qualified personnel and some people were seriously overworked and therefore, much more liable to make errors of judgement. The most significant point on management is that no provision of covering of the duties of key personnel was observed when they were on leave. Furthermore, in order to produce more, safety was overlooked that lead to the disaster. If the initial observation of more nitrogen usage could have been pondered the accident would have been prevented in this case. No guiding, anchoring and support for the bellows, connecting reactor No.4 and reactor No- 6 was done, which is key part of designing any process equipment.

### 2.2.3 Seveso disaster

The Seveso disaster was an industrial accident that occurred around 12:37 p.m., July 10, 1976, in a small chemical manufacturing plant approximately 15 km (9.3 mile) north of Milan in the Lombardy region in Italy (BHS, 1976) . It resulted in the highest known exposure of 2, 3, 7, 8-tetrachlorodibenzo-p-dioxin (TCDD) in residential populations, which gave rise to numerous scientific studies and standardized industrial safety regulations. These regulations were later adopted in Europe and are known as the Seveso II Directives.

The accident occurred in building B. The chemical 2,4,5-trichlorophenol (was being produced there from 1,2,4,5-tetrachlorobenzene (De marchi et al., 2012) by the nucleophilic aromatic substitution reaction with sodium hydroxide. The 2,4,5-trichlorophenol was intended as an intermediate for hexachlorophene, although it can also be used as an intermediate for the herbicide (2,4,5-trichlorophenoxyacetic acid) - see reaction 2.4.

This reaction must be carried at a temperature above that of the normal process utilities that were available, so it was decided to utilize the exhaust steam from the electricity turbine on site, and pass that around an external heating coil on the reactor. This exhaust steam was at 12 bar and 190°C, resulting in a reaction mixture at 158 °C (with a boiling point of 160°C). Safety testing showed an onset of an exothermic side reaction at 230 °C. On this occasion, the batch process was interrupted prior to finishing the final step of removal of ethylene glycol by distillation, due to an Italian law requiring shutdown of plant operations over the weekend. Other parts of the site started to close down as batches finished, and no more were started. This caused the load on the turbine to fall dramatically, resulting in the exhaust steam temperature rising to around 300 °C, heating the reactor wall above the level of the liquid to the same temperature. (No steam temperature reading was available to the plant operators.) This batch was then stopped by isolating the steam, and turning off the stirrer. The residual heat in the jacket then heated the upper layer of the mixture next to the wall to the critical temperature (which was actually only 180°C, 50°C lower than believed), starting a slow runaway decomposition, and after seven hours a rapid runaway reaction ensued when the temperature reached 230 °C (Kletz, 2001 and Kletz, 1998).

The relief valve eventually opened and 6 ton of material were distributed over an 18 $km^2$ including 1kg of 2, 3, 7, 8-tetrachlorodibenzodioxin (TCDD) which is obtained by removal of 2 molecules of HCl from 2,4,5 trichlorophenol as shown in reactions through Eqs. 2.4-2.5, which is normally seen only in trace amounts of less than 1 ppm. However, in the higher-temperature conditions associated with the runaway reaction TCDD production apparently reached 100 ppm or more.

The initial damage was sensed when all the vegetation was found to be contaminated, and animals began to die. An area of about 5 kms was suspected to be contaminated and the public was warned against the use of anything grown in this area. However, the area was not completely isolated and closed off. 250 people were evacuated of the contaminated site. These people showed signs of disability in their later years. Although the visible casualties were not very numerous, it is said that even after an expenditure of US $200 million the site is still not clear of contamination.

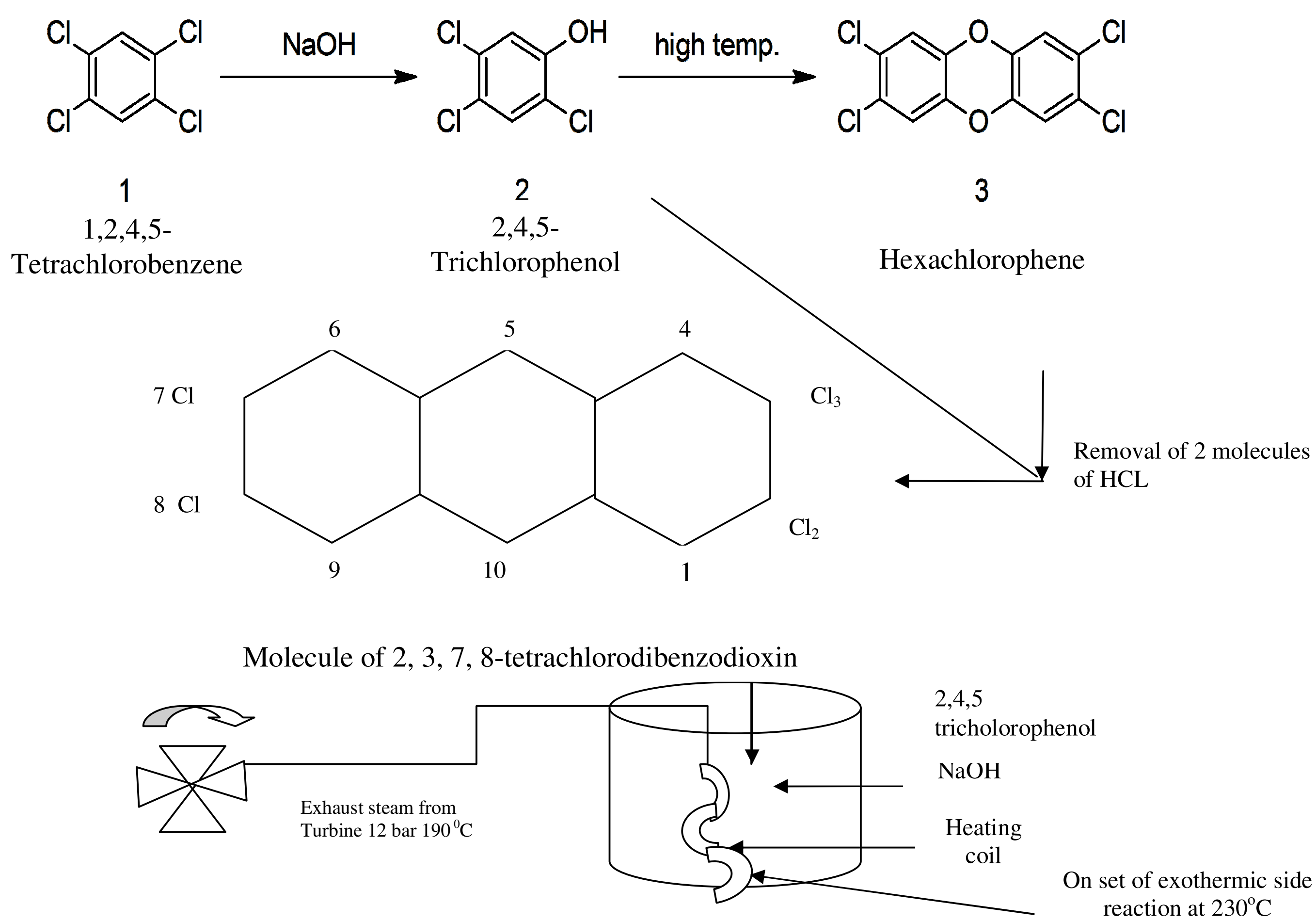
#### *2.2.3.1 Learnings*

This incident again reveals the shortcomings on the part of management.

a. Before these disasters, there were examples of TCDD leaks, but the management didn't bother to collect the information on how did they tackle the leak? For Example in BASF, Germany it was attempted to decontaminate using detergents, burning off the surfaces and removing all insulated material. Eventually they destroyed the whole building to get rid of this chemical.

b. Lack of full-scale investigation and report.

c. Toxicity studies were not conducted. The dioxin produces long-term effects and has deleterious effects on nature and human being; as a result Dow Chemical stopped its manufacturing in 1983.




(2.4)

(2.5)

**Fig. 2.1: Chemical reaction and reactor setup at Seveso, Italy**

Although, only three major disasters are discussed here, there are number of such process plant disasters (for example Basel-1986, Antwerp-1987, Pasadena-1989, Panipat-1993, Mumbai-1995, and Vishakhapatnam-1997) in which the death toll would have been as high as in Bhopal if the areas where the accidents took place were not less densely populated as highlighted by Lees and Marshall (Less, 1996, Marshall, 1987). It was also observed by the researchers that the underlying prominent root cause of all these disasters was ineffective SMS.

Thus, major reforms in SMS were the urgent need of the process industries. Later on SMS also covered occupational health issues which resulted in OHSMS field as discussed before. Few organizations adopted voluntary OHSMS whereas some of them adopted due to mandatory regulations. However, this realizations and perceptions of organization's adopting OHSMS had varied differences within the research community which is discussed in section 2.3.

## 2.3 Perceptions about OHSMS and its effectiveness

Review and guidance from diverse studies related to OHSMS available from literature is warranted to understand the doubts and views of various researchers. According to Lynda et al. (2007) and her research team there is no systematic literature review on the topic of OHSMS, except some narrative reviews exist (Frick et al., 2000, Gallagher et al., 2003, Saksvik and Quinlan, 2003, Walters, 2002). They also concluded that these narrative views are biased in nature and therefore there should be high quality studies in OHSMS to identify, appraise and synthesize the results in OHSMS field.

Another researcher Patrick Hudson (2001) of center for safety research also had the view that systematic basis of OHSMS was not covered by organizations and had many gaps in their coverage.. He therefore doubted the effectiveness of OHSMS.

To study the effectiveness of OHSMS Gardner (2000) related it to Quality Management System (QMS). According to him the failure rate of QMS has been documented as ranging from 67% to 93.And therefore there is reason to expect that the failure rate of OHSMS would be at least as high as QMS. His premise was that typically, the level of management commitment to high product or service quality is higher than to employee health and safety. Further, Quinlan and Mayhew (2000) also doubted effectiveness of mandatory OHSMS strategies as they observed that the current trends of the globalization of business has led to the casualization of the labour force and declining unionization.

Contrast to the observations by the above researchers there is also a body of research in organizations (e.g., Cohen, 1977, Habeck et al., 1998, LaMontagne et al., 1996, Reilly et al., 1995, Shannon et al., 1996) which emphasize that there is a correlation of low injury rates and OHSMS. However, these studies were not able to suggest which potential elements of OHSMS are correlated with these low injury rates. Therefore, some researchers (Mearns et al., 2003, Simard and Marchand, 1994) developed their researcher-defined measures of OHSMS and concluded that a more developed OHSMS is correlated with a lower injury rate. While these studies are a valuable contribution to the literature, they cannot tell what is the likely effect of a particular type of OHSMS intervention in a particular type of workplace. They are limited by their cross-sectional design and the lack of an OHSMS intervention variable A separate stream of research and practice related to SMS in high hazard and high reliability operations, such as in the nuclear, chemical process, airline, rail and marine transportation industries, has also been developed (e.g., Figuera and Lo´pez, 2003, Hale, 2003, IAEA, 2005, SAMRAIL Consortium, 2004).

However, the concept of a SMS overlaps with that of an OHSMS, but is generally distinct. For instance, the scope of concern for a SMS, unlike that of an OHSMS, extends beyond workers to include the physical work environment and the surrounding community. Furthermore, the scope of an OHSMS covers a broad range of workers health concerns, in contrast to that of a SMS which focuses on preventing traumatic injuries related to the loss of control of processes. Many OHS practitioners presume that OHSMS interventions will be effective in lowering injury and illness. After all, OHSMS standards and guidelines synthesize expert knowledge, much of which is consistent with the research cited in the first paragraph of this section. Some criticisms of OHSMS have also emerged in more academic circles.

Suggested deleterious effects of OHSMS in general or of particular types of OHSMS have included: the weakening of external regulatory approaches (Bennett, 2002); a false sense of security derived from the presence of a formal OHSMS (Gallagher et al., 2003); the development of blame-the-worker attitudes (Nichols and Tucker, 2000; Wokutch and VanSandt, 2000); and a shift in the power balance away from workers towards management (Lund, 2004; Nichols and Tucker) which hampers the success of OHSMS which primararily is likely to be dependent on the nature of the intervention, characteristics of the workplace and characteristics of the external environment. Effectiveness depends on wide range of OHSMS interventions under a wide range of conditions. In order to focus on such interventions various occupational accident models have been developed by researchers and are briefly discussed below in section 2.4.

## 2.4 Occupational accident models

Occupational accidents are major contributor to individual risk; however their analysis is not rigorous as in case of major accidents (Attwood et al., 2006). Therefore, it is necessary to focus on tools and techniques which could predict the occupational accident frequency. Model development is one such popular technique that can be applied to occupational accident issue. The effectiveness of such models is well documented in the literature (Kjellen and Sklett, 1995; Tomas et al., 1999; Thompson et al., 1994; Brown et al., 2000; Lees, 1996). Therefore, only the key features of each of the models are given below in Table 2.1.

**Table 2.1: Features of occupational accident models**

| Model | Key feature | Reference |
|---|---|---|
| Gordon’s Model | There is a parallel between the accident process and the popular theory of how a disease overwhelmed a susceptible patient.The ‘‘agent’’ in the accident analogy was considered to be some form of damage-inflicting energy. | Gordon, 1949 |
| Houston Model | The driving forces were considered in place of elements used in Gordon’s model. Both probabilistic and deterministic parameters were considered. Various actions were proposed to reduce the accident likelihood, including the removal of input factors and probability of simultaneous presence of all such factors. | Houston, 1971 |
| Haddon Model | Further contributed to Houston model by limiting the various driving forces effectiveness. | Haddon, 1973 |
| Embrey’s machine Model | Embrey proposed a model of accident causation using hierarchical influential network. It considers accident causation to be a three level process as below: human errors, hardware failures and external events. | Embrey, 1992 |

| Model | Key feature | Reference |
|---|---|---|
| Fault Tree Model | Accidents are initiated by an event having the potential of escalating into a more serious situation, but by doing so only if a series of enabling events occurs or a series of preventive actions fails to occur. For example operator protection, equipment protection, operator recovery and mitigative measures. | Wells et al., 1992 |
| Thompson's confirmatory Model | The model analyzed the relationship of safety climate, management support for safety and perceived safety conditions at a US aviation logistics center. The model was based on organization politics, goal congruence, supervisor fairness and management support. | Thompson et al., 1994 |
| Kjellen's comparison analysis Model | Kjellen and Sklett concluded that there were no combinations of types of accident criteria and risk analysis methods that covered the full range of occupational accidents. | Kjellen and Sklett, 1995 |
| Pate-Cornell and Murphy's SAM approach model | Pate-Cornell and Murphy (1996) applied their ''System-Action-Management (SAM)'' approach to the accident of the Piper Alpha disaster. The authors proposed that the fraction of accidents involving some human and/or corporate responsibility ranges from 50% to 90%. Accordingly, the objective of the SAM approach was to facilitate the inclusion of corporate and human factors (HF's) in a probabilistic risk analysis, thereby improving it as a tool for managing and reducing risks. SAM offered a link between management approaches, the decisions and actions they affect, and system failures. The approach used was conditional probability theory. | Pate-Cornell and Murphy, 1996 |
| Hurst's risk assessment model | Hurst concluded that accidents result from breakdowns in a three-way (hardware-people-corporate) infrastructure. People failures formed a level of Hurst's model, and were subdivided into the nature of the failure, for example slips and lapses, and the underlying causes, which were considered to fall into one of three categories (skill, rule, or knowledge). | Hurst, 1998 |
| Tomas' structural equation Model | The model has used suitability of structural equation modeling to describe occupational accidents. | Tomas et al., 1999 |

| Model | Key feature | Reference |
|---|---|---|
| Brown's socio-technical Model | Studied accident process from three perspectives. Person as cause, system as cause and system-person sequence as a cause. Tested the validity of the three views via a survey conducted in the steel industry. | Brown et al., 2000 |
| Event tree Model | Markov chain analysis is used to determine probability of transitions in time between respective states. It comprises of real life simulator for plant. The model has the following advantages.<br>a. effectively manage uncertainties in the monitored system states and inputs.<br>b. rank the likelihood of system faults<br>c. production of fewer branches, thereby reducing problem size | Munteanu and Aldemir, 2003 |
| Le Bot Model | Made attempt to integrate human reliability data in accident models and retrospectively analyzed the Three mile island nuclear disaster. Le Bot concluded that following are the points responsible for system breakdown.<br>a. insufficient operator training<br>b. incomplete or incorrect procedures<br>c. ineffective system and human interfaces<br>d. organization inefficiencies | Le Bot, 2004 |
| Wilpert Model | Wilpert (2009) presents a comprehensive discussion of the impact of globalization on human work. He describes the impact of new information technologies, changing work structures in industrialized countries and changing industrial relations systems | Wilpert, 2009 |
| MIMOSA Model | In one direction it represents the acquired level of guarantee of worker's health and safety, by the other direction,it is useful to all other companies that want to improve their compliance with law requirements. | Ada Saracino et al., 2012 |

Various models as given in Table 2.1 includes both qualitative and quantitative. However, the review suggests that the human error and HF's are the most dominant contributing factors in causing accidents. The importance of including HFs in the accident process has been recognized and reinforced by the UK HSE in their document ''Good practice and pitfalls in risk assessment'' (UK HSE, 2003b). It is reported therein that 80% of accidents may be attributed, at least in part, to the actions or omissions of people Some psychological aspects of risk perception also exist in which people are generally too frightened of strange situations and too casual about familiar ones, and tend to underestimate the risks they choose to take and overestimate the risk associated with mandated activities. Because there was evidence of higher than average accident rates in groups that underestimate risks, the importance of ensuring that the workforce assesses risk as accurately as possible was stressed by the various authors who contributed to the development of the above models.

Workers seem to be aware of the relatively higher risk associated with occupational accidents and were generally positive about their ability to avoid them. All of these models are representation of safety management practices by industries in USA and European countries which are developed countries. However, the Indian scenario is different due to its diverse geographical nature, cultural gaps, and varying regulations in different states which necessitates a review of OHSMS study in Indian industries and is therefore discussed in section 2.5.

## 2.5 OHSMS in Indian industries

Every Indian organization is supposed to frame the safety rules and prepare a safety manual based on The Factories Act, 1948 and state Factory Rules to take care of the health and safety of its employees, covering the various manufacturing activities employed in the company. To what extent these are practiced in reality depends on the commitment of the top management of the organization. Committed managements subsequently adopt various safety management practices to safe guard their employees from work related hazards whereas others try to manage safety of employees by encouraging them to work safely. To study the Indian scenario with respect to OHSMS, a study funded by the ILO office was carried out by Gupta (1990), the study identified major accident hazard installations in India , which revealed a total of 586 major accident hazard (MAH) units and 75 hazardous chemicals. The distribution of MAH unit and hazardous chemicals across various states of India was presented by Raghavan and Swaninathan (1996). It is seen that the states of Gujarat and Maharashtra have the largest number of MAH units and also handle the largest number of hazardous chemicals. No wonder, then, that the maximum number of accidents in the past occurred in these two regions.

This puts forward the immense potential of OHSMS study in MAH units. Three well known MAH process industries in central India have been studied through field survey and available literature.

These industries are the largest private are as follows. The largest private fertilizer company (Company F), largest private zinc producer company (Company Z) and the largest private caustic manufacturing company (Company C) .All these companies are located in western belt of India. It was observed that one of them gives priority to production; one of them neglect OHSMS in order to achieve higher production at times while one of them keep a balance between production and safety.(Note: Name is not disclosed for it is the observation of the researcher) Only a scientific investigation into this only can reveal what is happening inside the organization so that improvement methods can be suggested.

Though, there are third party audits in the organizations often they can't comprehend the process dynamics which cause the incidents/disasters. Safety audit is widely accepted as a method of safety management measurement in industries (Kennedy and Kirwan, 1998). However, safety audits have inherent measurement biases at various levels, as it examines what is documented, but fails to reveal what truly exists in practice (Mearns et al., 2003; Kennedey et al., 1998).

Survey among the workforce using valid and reliable self-reporting questionnaire is reported to be the most effective method for measuring the level of safety management practices (Flin et al., 2000; Mearns et al., 2003). For a successful organization, these measurements need to have positive relationships with safety outcomes such as accident rate or injury rate. The above three Indian organizations from different sectors have been reviewed for studying OHSMS intervention variables and its effectiveness.

a. Fertilizer Industry [Company F]
b. Metallurgical Industry [Company Z]
c. Chlor-Alkali Plant [Company C]

These studies are done only for the academic purpose to observe how OHSMS varies in different sectors; therefore the propriety rights have not been violated. All the three organizations have received various safety awards for their achievements in safety, and have a well documented Occupational health and safety (OHS) policy. The observations are based on the researchers field trips to the organizations, however the evidence are not substantiated by any form of data which can be studied by further research into the organization. The interpretation of OHSMS intervention has been done from their safety manuals and process manuals which are readily available.

**Table 2.2: OHSMS comparisons of various Indian process industries**

| **Title** | **Company F (Environment and safety manual, Company F(2005) )** | **Company Z (Fire and safety manual, Company Z (2008))** | **Company C (OHSAS manual, Company C (2006))** |
|---|---|---|---|
| Production | Largest private manufacturer of urea, ammonia in india<br>capacity : 3400 MT Ammonia<br>6100 MT urea | Largest zinc producer in india<br>capacity : 70000 MT | Largest caustic soda manufacturer in india<br>capacity: 258000 M.T |
| Inception | 1999 | 1966 | 1970 |
| Safety policy | Provides highest priority and is prepared according to ILO guidelines (**Appendix A.1**) | Has policy integrated with Environment and health and refers to HSE policy. (**Appendix A.2**) | Provides highest priority and is prepared according to ILO guidelines (**Appendix A.3**) |
| Awards and accoloades | British safety council, Five star rating, OHSAS 18001 certification from DNV | Golden Peacock, OHSAS 18001 certification from DNV | Golden Peacock, OHSAS 18001 certification from DNV |
| Intervention and rules | Follows the 14 elements of process safety management. Compliance along-with accountability and resource allocation forms a strong basis for OHSMS, therefore only a little intervention such as monitoring is required to keep the OHSMS up-to-date. | Rules and regulations are in place, however, due to inherent hazards in the process and lack of participation from all levels of management the interventions of OHSMS are not effective. | Rules and regulations are strictly adhered to. However, some OHSMS elements such as communication of hazards, health monitoring are not effective, which need interventions and management support. |
| Training and development | External faculties from various consultancies/universities are | Training needs are mostly met with the internal faculty. As the plant is | Training needs are mostly met by the internal faculty. However, the |

| Title | Company F (Environment and safety manual, Company F(2005) ) | Company Z (Fire and safety manual, Company Z (2008)) | Company C (OHSAS manual, Company C (2006)) |
|---|---|---|---|
| | often called to update the employees regarding safety tools and techniques that can be applied in the plant. The training and development at Company F focuses on emergency planning, management of change, near-miss reporting, first aid and behavioral aspects. | vast and therefore to cater to the needs of the plant, a exhaustive tie-up with various safety agencies to handle safety training program should be done. The present safety training methods are found to be inadequate | internal faculty focuses on the traditional tools and techniques which don't cover the OHSMS in process/technology changes which can be rectified through train the trainer's plan. |
| Hazard identification and Risk assessment | Traditional tools like checklists, HAZOP while risk assessment is done using matrix tool. | Traditional tools like checklists, HAZOP while risk assessment is based on audit | Uses checklists, HAZOP for hazard identification while FMEA for risk assessment. |
| Management of change | Any changes in the process are done through the license provider i.e. Kellogg, Snamprogetti which does the detail engineering and provide the SOP (Standard operating Procedure) which is communicated to the process HOD and engineers | Mostly the process changes are done with view of saving and better return on investment at unit level, therefore some lapses may occur in the Management of change process. | Process change decision is taken at unit level with much deliberations and consultations from top management is sought. It is also communicated at the department level |
| Audit review | Audit review changes are subjected to licensor agreement | Audit review are considered on the basis of priority and economic feasibility | Audit review changes are done as per the decision of a safety sub-committee. |

## 2.6 Gaps in the existing OHSMS practices and research

Considering the OHSMS review as given through section 2.1 to 2.3 and the relevant description, following are the OHSMS practices and research gaps that need to be addressed. The objectives of the present study will be formulated considering the below mentioned gaps.

a. The three disasters revealed significant gaps in SMS till 1984 as discussed in section 2.1. Subsequent legislation changes and awareness of the process industry resulted in reduction of human casualty. But, it has been observed that many such mishaps are occurring and have occurred post 1984 as discussed in this previous chapter and section 2.2 which substantiates that there are gaps in the implementation of SMS in many organizations.
b. The OHSMS research and review suggests that the OHSMS intervention variables are useful in lowering injury rate depend on the sector/industry dynamics. Study of the concerned organization will only reveal the dominant OHSMS intervention variables affecting the injury rate.
c. There is not enough collaboration of safety researchers and industries in India to make OHSMS more effective.
d. Survey of Indian industries should be done meticulously by the audit committee to provide them the rating based on sound quantitative analysis

### 2.6.1 Scope of the work

The above gaps in literature and OHSMS require a need to carry the study of OHSMS in a critical way which is beneficial to the organization and to the mankind. Therefore, with this intention, OHSMS design study work has been undertaken. The design is taken with a view to aim towards the ideal zero accident policy which every company aspires to be.
The next chapter therefore will outline the methodology for OHSMS design wherein the research steps for the thesis have been outlined.

Chapter - 3

# Methodology for OHSMS design

The literature review focussed on the various occupational accident models adopted by the OHSMS researchers and the current practices prevalent in the Indian industries. Therefore, the focus of this chapter is to present the stepwise methodology for OHSMS design by reviewing the previous methods for OHSMS design and investigation. This methodology is used to develop a structural model of OHSMS framework for a process industries in the Indian context.

## 3.1 OHSMS methodology review

A wide range of methods was applied to research on OHSMS. It is clear that quantitative research design was a preference among OHS studies, with survey as the most popular data collection method, followed by the use of government and other secondary data sets. Although Baril Gingras et al., (2006) claim the potential contribution of qualitative methods to OHS studies appeared to be an underutilized choice, with only 14.4% articles included qualitative techniques (e.g. interviews and archive data) when collecting data. The various types of methodologies used in OHSMS field can be categorized as follows.

a. Effectiveness of OHSMS interventions: Evaluation of the effectiveness of safety programs, regulations and other interventions
b. Contextual OHSMS analysis: Analysis of legislation and programs, OHS in a particular industry, hazardous occupations and their characteristics, and national level of occupational accidents
c. Methodological topics in OHSMS: Measurement development and methodological issues in OHSMS
d. Practices related to OHSMS: Human resource management (HRM) and Industrial relations (IR) related practices (e.g. outsourcing OHS and management audit), training, safety analysis and other particular practices
e. Antecedents & workplace factors influencing OHSMS and safety performance: Contextual and occupational factors, organizational factors, government

interventions, individual factors, stakeholder psychological states towards OHS leadership (e.g., safety training, risk management and use of work teams and just-in-time production)

f. OHSMS methods and models relevant to OHSMS: Proposition of approach/method promoting OHS, proposition of model evaluating OHSMS interventions, model development and testing of specific model implementation
g. Outcomes of OHSMS: The influence of OHS status and performance on individual wages/performance and organizational cost/performance
h. OHSMS in small enterprises: Factors influencing OHS in small and medium enterprises (SMEs), an approach to OHS management, accident characteristics and OHS practices

All these approaches have their own pro’s and con’s. Some practices and program methods are common to a particular set of organizations, whereas for other organizations a different approach is required. There is no consensus on a universal approach due to the technicalities and culture involved across all sections of industries.

Therefore, more systematic assessments regarding production processes and management activities should be taken into account when evaluating the implementation and effectiveness of a regulation in the future studies. Managerial interventions are the workplace level initiatives such as OHSMS programs and activities (e.g., safety training), safety investigations and management systems. As aforementioned, OHS research on emerging/developing economies, organizations lags the theoretical and empirical developments of research with respect to the developed country organizations. For instance, Zhu et al., (2006) suggest that the study of OHS in China is at an early stage that focuses solely on the technical aspects of engineering systems and processes, in contrast with the greater emphasis on the impact of the attitudinal, organizational, cultural, and social dimensions of OHS in research carried out in developed countries and across diverse industries. More research should be done regarding safety management in emerging economies.

As indicated before, lack of theory building has blocked the development of the field and relevant OHS management research. LaPorte (2011), argues for the need for further deep contextual studies of a qualitative nature that embrace 'embedded observed', where researchers conduct longitudinal fieldwork to observing an organization in order to disclose how things happen in practice and how employees are situated within their culture.

A case study method was selected as the research design for this study, which is designated as a bounded system. Case study method focuses on what Burns (2000) contended is a bounded system, which is an entity in itself and allows examination in depth. He further claimed that the researcher can probe deeply, undertaking intensive analysis of the subject of the case study to be examined. Study of a particular case might reveal insights, which Burns has found, may relate to the typical class of events from which the case has been drawn. According to Punch (1998), case study method allows for a variety of research questions and purposes which allows the researcher to develop a full understanding of that case as possible. Burns contended that there may be a concern that case studies provide very little evidence for scientific generalization, however, he also argued that this view is valid only where there is an assumption that producing generalisable theory is the only worthwhile goal of the investigation. Further, Punch pointed out that with the case study method, understanding the case may be the major focus as it is not the intention of such a study to generalize, but rather to understand this case in its complexity and entirety. The present study undertaken focused on OHS workplace practice and the way the practice is perceived by the people involved in the implementation of OHS policy with the process industries. It was considered to be important to investigate the research questions in the workplace setting. In the absence of studies concerning workplace practice in OHS (La Montagne, 2003), the study was considered to be exploratory in nature. The setting for the investigation, that is, the study of Grasim Industries Limited (designated as Company V earlier and will be referred as GIL further) was identified as a bounded system and a case study method was deemed to be found appropriate.

Therefore, a stepwise methodology has been devised for the current research problem and is summarized as follows. The workplan is based on the steps discussed below as shown in Fig 3.1.

## 3.2 Research Steps

The research steps have been outlined by way of a flow chart shown below.

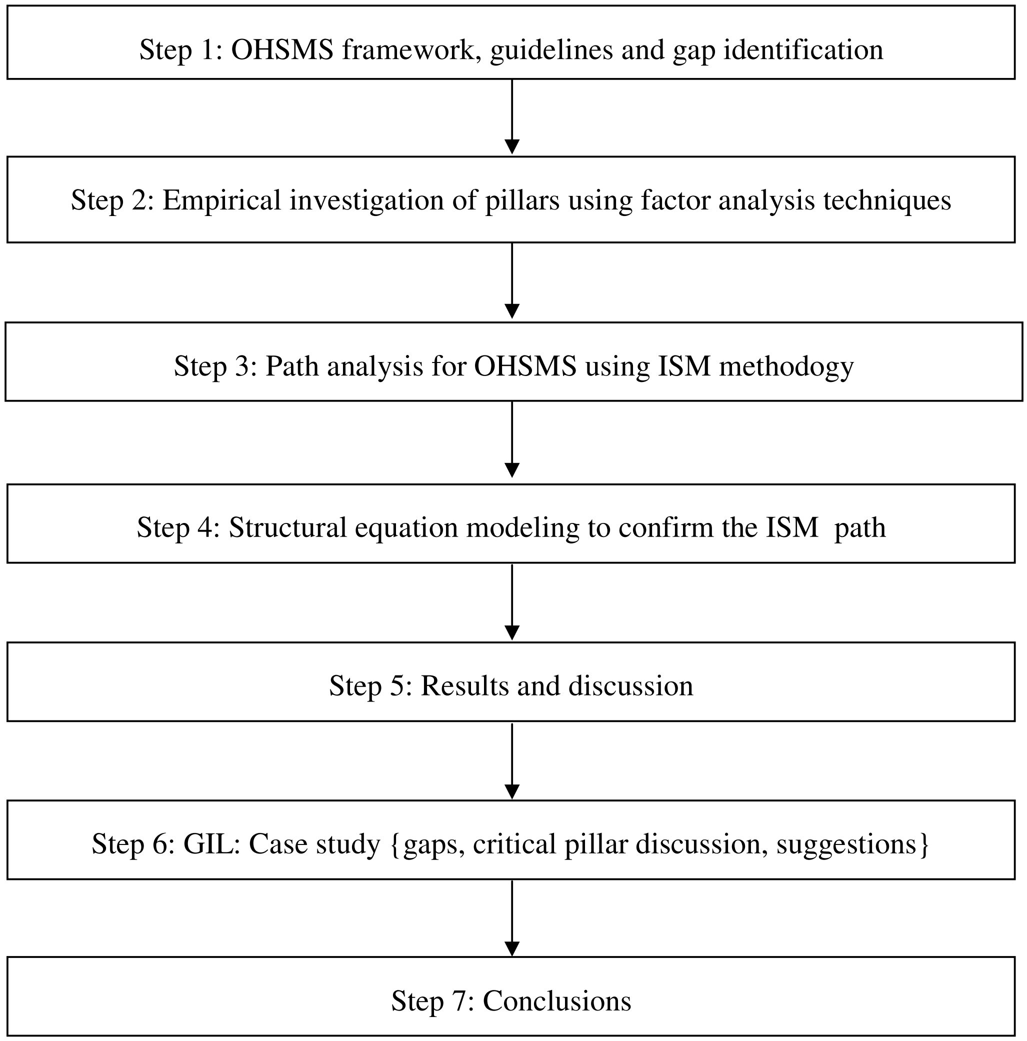



**Fig 3.1: Research steps for OHSMS design**

The research steps from step 1 to step 6 have been described from section 3.3 to 3.6 elaborately as below.

## 3.3 OHSMS framework, guidelines and gap identification

Basically, general system theory and fundamental properties of the OHSMS clearly suggests that the general characteristics of OHSMS include OHSMS objective, OHSMS specification, the relationship of the OHSMS to other systems and the OHSMS maintenance. Although OHS features as stated above are highly recommended, its realization results are a considerably diverse (John and Anthony, 2001). To build generalization Robson et al., (2005) presented the basic conceptual framework underlying the review of OHSMS as shown in Fig 3.2

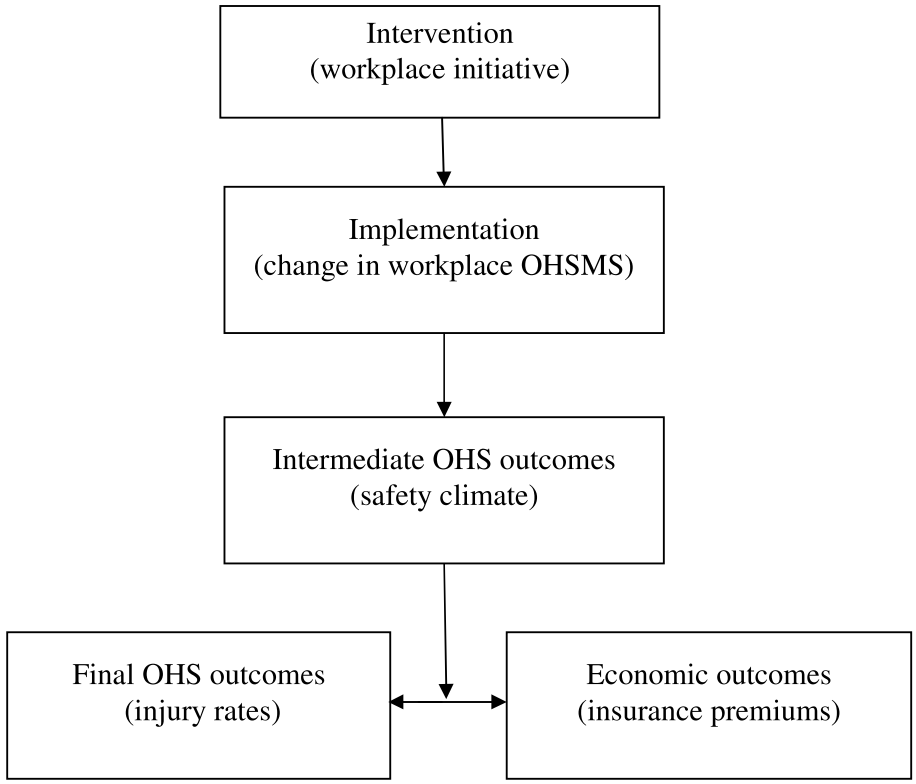



**Fig 3.2: A conceptual framework for the review of OHSMS (Robson et al., 2005)**

### 3.3.1 OHSMS guidelines

Based on OHSAS 18001:1999 (1999), its specification gives an OHSMS to enable the organization to manage their risks and improve their performance. There are five key elements of OHSAS 18001 which are used as OHSMS implementation tools. These core elements are shown in Fig 3.3. To have a better understanding all elements will be discussed below.

**(a) Policy**

The OHS policy is the basis for developing, implementing and improving an organization's OHSMS. A documented policy statement that gives an overall sense of direction and sets the principles of action for an organization to be produced and authorized by the organization's top management (ICMR Bulletin, 2003).

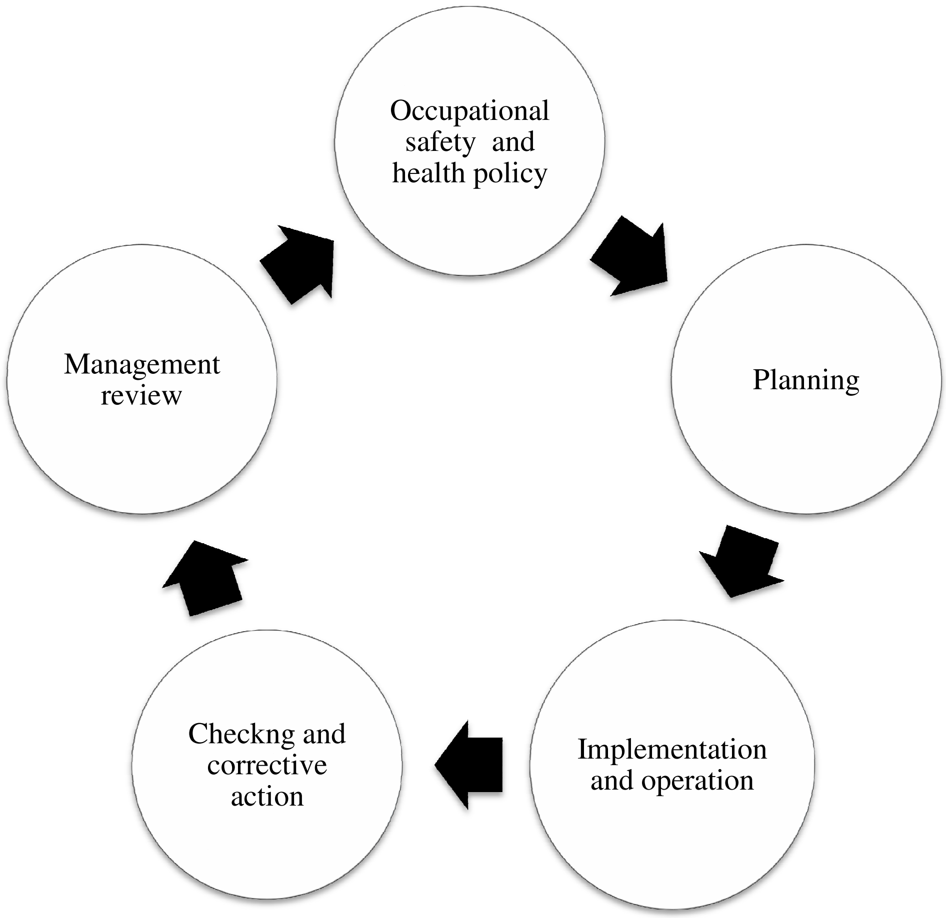



**Fig. 3.3: Five key elements of OHSAS 18001 (ICMR, 2003)**

**(b) Planning**

In the planning stage, the system must be integrated with the hazard prevention, meet statutory, regulatory and policy requirements, develop OHS goals and objectives, and to establish OHS management program (ICMR Bulletin, 2003). Therefore, the sub elements covered under the planning process are as below:- Hazard identification, risk assessment and risk control – According to Dababneh (2001), planning necessitates to document in detail listing all work hazards, risk assessment of each hazard, and the required measures for controlling the risk of each hazard. The particulars of the planning process are discussed below.

***(i) Legal and other requirements***

Information on legal and other requirements to its employees and other relevant parties' should be up-to-date due to accessing information and identifying the current legal requirement based on the latest data. OHSAS objectives – According to Yunus (2006), part of OHS objective is the reduction of risk level, the introduction of additional features into the OHS management system, the steps taken to improve existing features, or the consistency of their application and the elimination or reduction in frequency for the particular undesired incidents.

***(ii) Occupational safety and health management program***

This needs to meet the objectives, designated activities, products, services or operating conditions of the organization through the review by a regular authority for the achievement of OHSAS 18001.

**(c) Implementation and operation**

ICMR Bulletin (2003) states that the implementation of OHSAS/OHSMS, prioritizing the use OHS resources, defines the structure and responsibility of personnel, establishes documentation of the core system elements and its interaction. The sub elements are covered below.

***(i) Structure and responsibilities***

It indicates the structure and responsibilities of the personnel, who manage, perform and support activities to explain clearly, document and communicate in order to facilitate OHS management. As a result the responsibilities of all employees and other relevant parties are easier to detect for any problems in a work task (ICMR Bulletin, 2003).

***(ii) Training, awareness and competence***

Based on OHSAS 18002 (2000), training procedures must consider through the different levels of responsibility, ability, literacy and risk assessment for ensuring the competence of the personnel to carry out their designated functions effectively.

***(iii) Consultation and communication***

In the workplace communication takes place between managers, supervisors, employees, internal/external experts, sales representatives, designers, manufacturers, suppliers, engineers, principal contractors, other contractors, government officers and consultants. It is essential to ensure that all messages are clear and agreed by others (OHS consultation, 2002).

***(iv) Documentation***

The documentation is to ensure that all information needed by all parties is available to refer and easier to maintain the up-to-date and relevant requirement. Therefore, the organization is suggested to keep all information in paper or electronic form to prevent problems or as a referee in the future (Dababneh, 2001, overview of OHSAS 18001, 2011).

***(v) Document and data control***

All documents and data critical to the operation of the OHSMS and the performance of the organizations OHS activities should be identified and controlled. Thus, the organization should encourage establishing and maintaining documented procedures for controlling all safety documents and data to ensure it can support OHSMS and its activities (OHSAS 18002, 2000). The organization needs to determine the operations and activities which are associated with the hazards. It is imperative to control and manage the operational risks as well as in order to eliminate or reduce OHS risks at their source (Dababneh, 2001)

***(vi) Emergency preparedness and response***

The assessing for the potential accident need to develop plans in detailed procedures to cope, to test and to seek and improve the effectiveness of its responses. The review of emergency preparedness and response plans for the occurrence of incidents or emergency situations (Dababneh, 2001) needs continual action to ensure safety in line for the current cases.

**(d) Checking and corrective action**

It is imperative to evaluate, monitor and control OHS hazards through established procedures based on the sub elements like

***(i) Performance measurement and monitoring***

Procedures to monitor and measure OHS performance to establish, implement and maintain on a regular basis providing the proactive measures for the OHS program controls and the operational criteria (BS OHSAS 18001, 2007).

***(ii) Accidents, incidents, non-conformances, corrective and preventive action***

Any changes in the documented procedures resulting from corrective and preventive action need to record (Dababneh, 2001) for reporting and evaluating accidents, incidents and non-conformances. According to BS-OHSAS 18001 (2007), the corrective action and preventive action for new or changed controls the procedure that must be required for the proposed actions to be taken through a risk assessment technique prior to implementation.

***(iii)Records and records management***

The records should include the list such as training records, OHS inspection reports, OHSMS audit reports, consultation reports, accident and incident reports, OHS meeting minutes, medical test reports, health surveillance reports, personal protective equipment (PPE) issues and PPE maintenance records, emergency response and drills reports, management reviews, hazard identification, risk assessment and risk control records (OHSAS 18002, 2000).

***(iv) Audit***

The periodic OHSMS audits to be carried out in order to determine whether or not the OHSMS conforms to the planned arrangements for OHS management.

After the study of standard guidelines, there is a need to devise a methodology that would identify the gaps and plan to plug it through implementation for the real life cases which is discussed in subsection 3.3.2

### 3.3.2 Gap identification

As stated in the literature review chapter, there are gaps in the implementation of OHSMS guidelines by various organizations. As far as the present study is concerned, it is important to identify these gaps. Survey was the most appropriate tool to find out the deviations from the standard requirements of OHSMS.

The study conducted by Redinger and Levine (1998) found that there are 13 different OHSMS and environment management systems (EMS) in an organization and in an attempt to define these OHSMS universe he presented a general OHSMS model containing 27 elements. Out of 27 only 16 primary elements were valid for their model.

The elements are as follows: management commitment and resources, employee participation, OHS policy, goals and objectives, performance measures, system planning and development, OHSMS manual and procedures, institutional effects on OHSMS system, hazard control system, preventive and corrective action system, procurement and contracting, communication system, evaluation system, continual improvement, integration, and management review. OHSMS outlines broad work environment objectives for companies and require them to perform certain functions and employ specialized individuals. Organizations need to comply with the minimum requirements of the standards and those imposed by national legislations, beyond the fact that they need to establish performance targets for themselves, as well as deciding what means they intend to employ to meet these targets. The process of how organizations can improve their standards is to some extent open and undefined. This can be done by the observation and interviewing method. The gaps can be identified and then discuss the interrelationship of these elements to improve the OHSMS program. The steps followed for the research is as follows:

a. Review accident inquiries from one process industry

b. Input from subject matter experts from 3 process industries

c. 28 in-depth interviews with workers and their supervisors

d. 15-day field observation

The interview and the snapshot are discussed in results and discussion chapter since it's the outcome and would be better represented in the results. Initial literature review, gap analysis and discussion with safety experts led us to concentrate on the following critical elements obtained by the survey technique which will be termed as pillars hereafter.

#### *3.3.2.1 Top management commitment (TMC)*

According to Deming (1986), top management is responsible for most of the safety problems because they control the assignment of resources, establish and implement the methods of work, develop the policies, and so forth. For these reasons, each management should be the lone sponsor of their own particular results (Sznaider, 1998). In a review of earlier research, Cohen (1977) reveals that management commitment to safety was a consistent factor in successful safety programs, although other factors were also found. In one of the first investigations of safety climate, Zohar (1980) found that management's commitment to safety is a major factor affecting the success of safety programs in the industry and this parameter is capable of discriminating between high and low accident rate organizations. Management commitment remains a key component of contemporary safety climate research (e.g., Flin et al., 1996, Marsh et al., 1998, Cox and Cheyne, 2000). This can manifest itself through management participation in safety committees, consideration of safety in job design, review of the pace of work, accident and near-miss incident investigation and follow-up actions, priority, assigned for safety, occupational health programs, etc. Investment by the company in these areas fosters perceptions of company's commitment and builds worker loyalty in areas such as safety behaviour (Mearns et al., 2003). Employees' perceptions will reflect how employees believe that safety is valued in the organization (Neal et.al, 2000). In high risk environments like chemical industries, management commitment has been repeatedly highlighted. In five plants recognized by the National Safety Council for `no lost working days', all of the plants required advance approval by safety personnel for any changes in the design of the work facilities. In four of the plants, the plant safety director had direct contact with the plant manager on a daily basis (Cohen and Cleveland, 1983). The motivation to perform a job in a safe manner is a function of both the individual's own concern for safety as well as management's expressed concern for safety. The safety commitment of the management must result in an observable activity on the part of the management and must be demonstrated in their behaviour as well as their words (Hofmann et al., 1995).

#### *3.3.2.2 Safety training and development (STD)*

Safety training enables the workers to recognize health and safety hazards present in the workplace and prevent them from injuries and accidents. As a result, training increases productivity and worker morale. Training also keeps workers abreast of the safety techniques and also makes them aware of the process and equipment changes. It also updates the older and more experienced workers. According to Cohen and Jensen (1984) "a well-designed and administered training program, emphasizing safe work practices and derived from a true assessment of need can be effective in improving on-the job behavior. Even better performance can be achieved by following training with a program based on goal setting and performance feedback supplemented with informal peer group modeling". Further, Cohen and Jensen emphasize the need to redefine the peer modeling behavior and a behavior sampling procedure specifying performance based criteria.

Individuals after performing a given task number of times, develop an automatic “procedure” for its accomplishment. However, the problem faced by the operators is making mistakes in not adhering to the written procedures. Both Kletz (1985) and Reason (1990) conclude that slips will occur, but suggest that these slips can be minimized through better training, instructions and procedures (Hoffmann et al., 1995). Safety training provides the means for identifying actions leading to accidents. The basic difference between safe employees and those who gets frequently hurt is the recognition of hazard and hazardous situation in the workplace system. Further, the studies of Lee (1998), Ostrom et al., (1993), Tinmannsvik (2003), Cohen et al., (1975), Smith et al., (1975) and Zohar, (1980) have found that those companies with lower accident rate were characterized by good safety training to employees.

#### *3.3.2.3 Hazard identification and risk assessment (HIRA)*

The identification of areas of vulnerability and specific hazards is of fundamental importance for OHSMS of an organization to be successful. Once these have been identified, the battle is more than half won. However, such identification is not a simple matter. In many ways it has become more difficult as the depth of technology has increased. There is no single ideal system of hazard identification procedures. The most appropriate system varies to some extent with the type of industry and process. Thus, for example, a firm involved in the batch manufacture of a large number of organic chemicals is likely to be much more interested in techniques of screening and testing chemicals and reactions than one operating ethylene plants. The choice of hazard identification technique also depends on the purpose for which the study is done. For the identification of hazards and operating problems on a plant, a hazard and operability study (HAZOP) is suitable, while for the identification of sources of release one has to consider hazard assessment to carry out a specific review of such sources. It is only sensible in hazard identification to make use of past experience. The use of standards and codes, of course, helps to avoid hazards of which people may not even be aware. As far as hazard identification is concerned, however, the principal means of transmitting this experience in readily usable form is the checklist. (Lees, 1996)

#### *3.3.2.4 Workplace environment and health monitoring systems (WEHMS)*

Evaluation of workplace environment is an essential part of OHSMS. In order to carry out effective workplace environment analysis, monitoring of different parameters should be carried out. These parameters include noise levels, lighting, ventilation, personal protective equipment (PPE), toxicant, spillage, and housekeeping. If these are above permissible limits can lead to reduced work performance, psychological and physiological effects (ICMA, 2003).Thus, workplace environment impacts the occupational health of the workers. In order to verify the interaction between these two variables, there is to need to know the current status of the health of the worker with respect to workplace parameters. Suitable health monitoring systems should be developed under occupational health specialists. Based on their recommendations a SOP (standard operating procedure) should be developed to reduce the workplace environment interacting variables in the particular department.

#### *3.3.2.5 Occupational health and safety information system (OHSIM)*

OHSIM is a fundamental element in the process of creating knowledge, developing skills, and performing safety related activities and tasks in accordance with planned occupational health and safety objectives. For the process industries, compiled and up-to-date safety information is a necessary resource for a variety of users, including site supervisors and operators who handle daily operations; the team that performs the process hazards analysis; those developing the training programs and the operating procedures; contractors whose employees will be working with the process; those conducting the pre-start up reviews; local emergency preparedness planners; insurance and enforcement officials. From the process operation, legislative compliance and business competition viewpoints, every process plant is required to maintain an integrated system that optimizes the collection, transfer and presentation of safety and health information, in accordance with defined procedures, whether automated or manual. An OHSIM system should be treated as the essential framework for supporting safety management practices. Fig 3.4 illustrates the role of an OHSIM system in providing a safety management framework. The need of current, accessible, accurate and secure OHSMS information is driven both by safety management and business requirement. Examples abound of missed or ignored warning signals of failure to handle safety information in ways that could have prevented catastrophic outcomes (Tzu et al., 2004), The process industries need an integrated approach to evaluate the performance measurement (an early proactive measurement) can be expected to be more effective in preventing accidents than safety audit as shown in Fig 3.5.

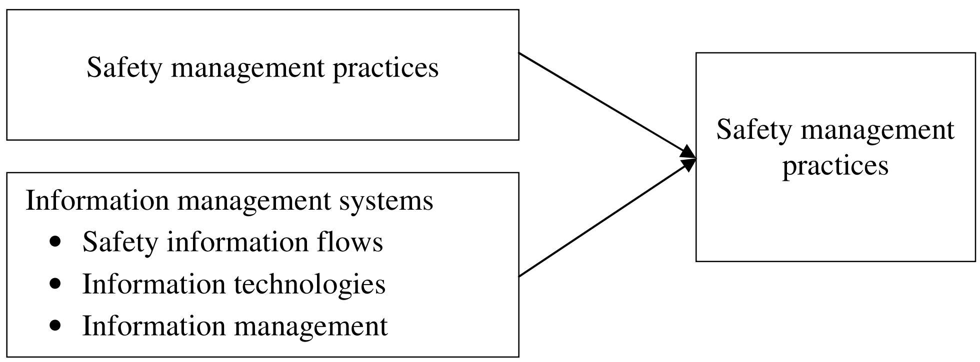



**Fig 3.4: Role of OHSIM system in providing safety management framework**

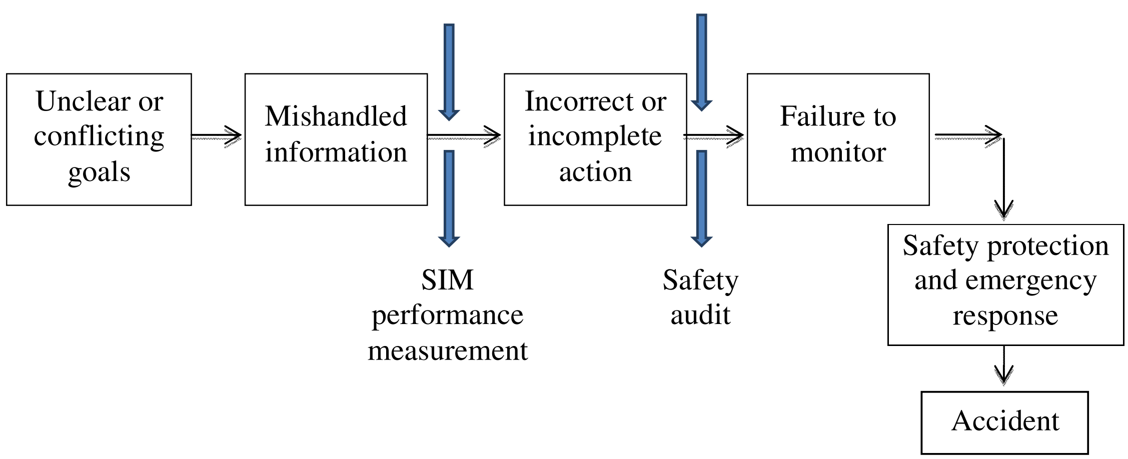



**Fig 3.5: SIM performance measurement: proactive measurement to prevent accidents**

### *3.3.2.6 Audit and review (AUR)*

OHSMS audit is defined as the structured process of collecting independent information on the efficiency, effectiveness and reliability of the safety management system and drawing up plans for corrective action (ILO, 2001).OHSMS audit comprises of pre-audit, on field observations and post-audit activities. The pre-audit comprises of planning of schedule visit, selection of suitable audit team and collecting background information related to the organization (process, raw materials, products, byproducts, hazardous chemicals, accident records and major accidents in the previous ten years etc.). After these activities the audit team prepares for checking on-field observations and monitor the deviations from the statutory guidelines by conducting interviews, reviewing the records and field observations. Here, the team gives marks/points to rate each department. The finding and marks are given to the top management of the organization. Based on the audit findings, top management plans for corrective action and follow up operationally. The follow up involves an oral or a written inquiry based on the review done by internal or external auditors.

Further, to investigate whether this pillars positively influences the overall OHSMS it needs to be addressed carefully and systematically. The hypothesis that can be designed for the current research is as follows:

**Hypothesis $H_1$**: TMC positively affects OHSMS

**Hypothesis $H_2$**: STD positively affects OHSMS

**Hypothesis $H_3$**: HIRA positively affects OHSMS

**Hypothesis $H_4$:** WEHMS positively affects OHSMS

**Hypothesis $H_5$**: OHSIM positively affects OHSMS

**Hypothesis $H_6$**: AUR positively affects OHSMS

The answers can only be revealed by using a survey instrument and tools to validate it. Therefore, data was collected from four organizations to report the findings. The empirical investigation steps have been discussed below. The investigation seeks to find the patterns of collinearrity among multiple metric variables.

## 3.4 Empirical investigation of pillars using factor analysis techniques

Following steps needs to be carried out for investigation of pillars as shown in the form of block diagram in Fig 3.6

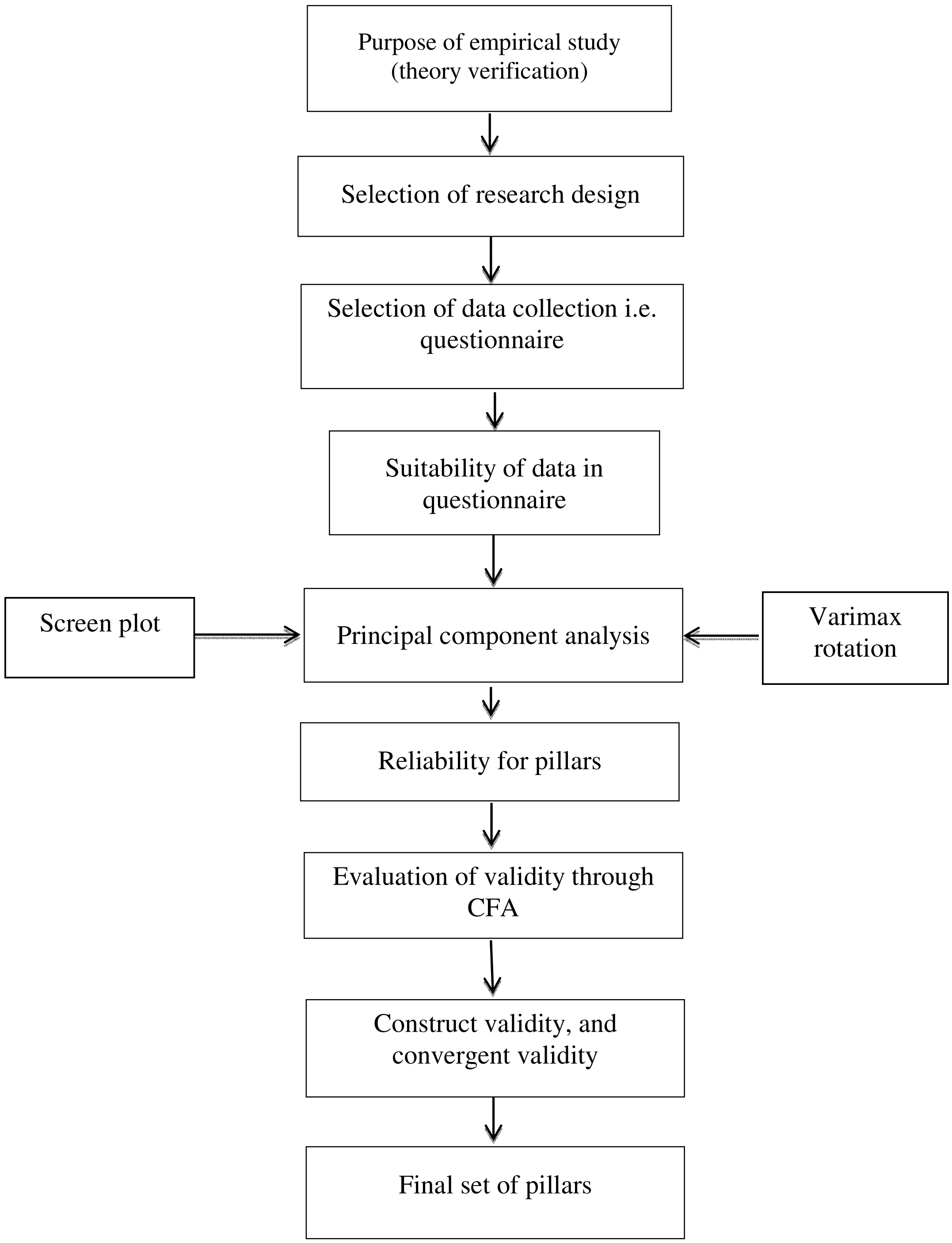



**Fig 3.6: Empirical steps for pillar investigation**

### 3.4.1 Survey instrument

The majority of empirical studies limit their sample to one organization from a very specific sector, casting some doubt about their external validity (Silva et al, 2004). Thus, with the aim of achieving as high a degree of generalization, four large process industries in central India were chosen for the target population (This is the real data and not hypothetical data, the company names are not revealed due to propriety rights). Company F, Company Z, Company V and Company C was selected for questionnaire demonstration. Company F has a worker and staff population of 400, Company Z has a worker and staff population of 2000, Company V has a worker and staff population of 1500, and Company C is having a total of 700.

The sample questionnaire was designed and compiled for each one unit and initially distributed to the safety officers as they have access to all the information. It was found from the discussions that Company F and Company C had a low accident rate as compared to Company V and Company Z due to the following reasons:

a. Automation (DCS enabled processes),
b. Relatively newer processes, and
c. Effective safety management

*The accident rates are not revealed due to the propriety rights of the industry only qualitative and observations are mentioned*

After the management approval, the questionnaire was distributed to supervisors, staff and to workers (personally and through safety officer).The questions were not on a proper sequence and later, according to the content and a pilot study of 10 respondents, the contents were revised. After carrying out pilot study and the dimensionality study of 36 questions which showed poor model fit only 27 were selected systematically after the iterative process in SPSS 20 (Anderson and Gerbing, 1988; Steenkampand Van Trijp, 1991). The response from the four organizations was recorded for further analysis.

**Table 3.1: Response from organizations**

| Organization | No given | No returned | Response % |
|---|---|---|---|
| Company F | 200 | 48 | 24% |
| Company Z | 350 | 67 | 19.14% |
| Company V | 450 | 134 | 29.77% |
| Company C | 125 | 60 | 48% |
| **Total** | **1125** | **309** | **27.46%** |

The reason behind opting for the large sample like this was that the sample selection was looked with apprehension for safety of various departments was related to the statutory requirements of the workers and also they also felt that the top management would identify them and may ask them for clarification and harassment. The questionnaire was measured on the most reliable Likert scale. A Likert scale is a type of symmetric response scale often used scale in survey research (Geller et al., 1996; Grote and Kunzler, 2000). When responding to the Likert questionnaire item, respondents specify their level of agreement with a statement (Likert, 1932). The Likert scores are used to obtain an idea of the relative importance of the characteristics making up the SMS (Reniers et al., 2006). In this research the respondents were asked to note their perceptions ranging from 1 to 5 which is given below. The data chosen is of ordinal scale. The ordinal scale indicates higher level of measurement precision. Variables are ordered and ranked in relation to the amount of attribute possessed. Every subject in the questions can be compared in terms of "less than" or "greater than". The numbers utilized in ordinal scales, however, are really non quantitative because they indicate only the relative positions in an ordered series. The order can be known, but not the amount of difference between the values. Therefore, the respondents were asked to respond on the following Likert scale given below. The survey form is then distributed.

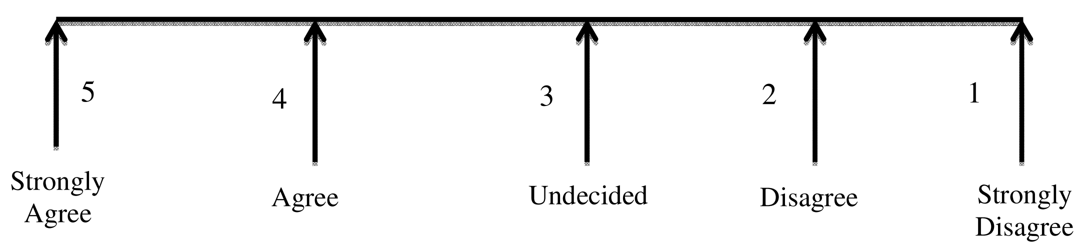



**Table 3.2: Survey form for pillar identification**

| Item No. | Questionnaire | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | Are you satisfied with your safety in the organization? | ○ | ○ | ○ | ○ | ○ |
| 2 | Are you trained for tackling any type of accident? | ○ | ○ | ○ | ○ | ○ |
| 3 | Do you feel lethargic during shifts? | ○ | ○ | ○ | ○ | ○ |
| 4 | Are personal reasons impacting your work? | ○ | ○ | ○ | ○ | ○ |

**Table 3.2: Survey form for pillar identification (contd)**

| Item No. | Questionnaire | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 5 | Do you wear hand gloves while working with jet/chemical etc. | ○ | ○ | ○ | ○ | ○ |
| 6 | Do you talk on mobile during duty hours? | ○ | ○ | ○ | ○ | ○ |
| 7 | How is the cooperation with the supervisors? | ○ | ○ | ○ | ○ | ○ |
| 8 | Safety training plan covers new techniques? | ○ | ○ | ○ | ○ | ○ |
| 9 | Are risks being assessed on regular basis? | ○ | ○ | ○ | ○ | ○ |
| 10 | Workers are provided with information of MSDS of hazardous material? | ○ | ○ | ○ | ○ | ○ |
| 11 | Specific training plan elaborated according to the section or job position? | ○ | ○ | ○ | ○ | ○ |
| 12 | Information systems made available to affected workers prior to modifications and changes in Production processes, job positions or expected investments | ○ | ○ | ○ | ○ | ○ |
| 13 | External audits periodically conducted for validity and reliability of prevention management system. | ○ | ○ | ○ | ○ | ○ |
| 14 | Safety policy is committed to achieve desired objectives and continuous improvement. | ○ | ○ | ○ | ○ | ○ |
| 15 | Tools are in place to identify hazards in your department. | ○ | ○ | ○ | ○ | ○ |
| 16 | Occupational health specialists monitor the health aspects regularly | ○ | ○ | ○ | ○ | ○ |
| 17 | Accidents and incidents reported, investigated, analyzed and recorded | ○ | ○ | ○ | ○ | ○ |
| 18 | Employees are motivated towards improving OHSMS practices | ○ | ○ | ○ | ○ | ○ |
| 19 | Prevention plan based on risks is updated according to the hazards reported by you in the department | ○ | ○ | ○ | ○ | ○ |
| 20 | Absenteeism or lost time is reducing in your department | ○ | ○ | ○ | ○ | ○ |
| 21 | There is a fluent communication embodied in periodic and frequent meetings, campaigns or oral presentations to transmit principles and rules of action | ○ | ○ | ○ | ○ | ○ |
| 22 | Does top management talks with you regarding your safety on a continuous basis | ○ | ○ | ○ | ○ | ○ |
| 23 | Are your aware of the consequences and emergency plan in case the risk is triggered | ○ | ○ | ○ | ○ | ○ |
| 24 | Prevention plans periodically reviewed and updated when job conditions modified or workers' health damaged. | ○ | ○ | ○ | ○ | ○ |
| 25 | Are audit observations being implemented by top management | ○ | ○ | ○ | ○ | ○ |
| 26 | Periodic mock drills carried out in case of risk being triggered or a disaster | ○ | ○ | ○ | ○ | ○ |
| 27 | Accidents/incidents are reducing continuously in your department | ○ | ○ | ○ | ○ | ○ |

The survey questionnaire shown in Table 3.2 consists of 27 questions which were designed and distributed to the workers and the staff through emails, personal collection and through safety officers.

The following questions were then rearranged according to the respective pillar as follows:

TMC (Item No-7,14,22,25), STD (Item No-2,5,8,11), HIRA (Item No-9,15,23,26), WEHMS (Item No-3,4,16), OHSIM (Item No-10,12,6,21), STD (Item No-2,5,8,11) and OHSMS (Item No-1,18,20,27).

The remaining questions were removed as they were suggested by safety professionals and resembled more behavior factors which are difficult to tackle. The questions left are like this

i. Do you delay the work in your department?
ii. Do you pass on your work to another person?
iii. Are you alcoholic?
iv. How frequently you talk about your personal problems at work?
v. Do you listen to your supervisor?
vi. Do you know the emergency SOP?
vii. Do you the location of BA?

#### *3.4.1.1 Sampling adequacy test*

Prior to the extraction of the factors, several tests should be used to assess the suitability of the respondent data for factor analysis. These tests include Kaiser-Meyer-Olkin (KMO), Measure of sampling adequacy (Kaiser, 1970 and Kaiser et al., 1974) and Bartlett's test of sphericity (Bartlett, 1950).

**a KMO**

If two variables share a common factor with other variables, their partial correlation ($a_{ij}$) will be small, indicating the unique variance they share.

$$KMO = \frac{\sum_i \sum_{j \neq i} r_{ij}^2}{\sum_i \sum_{j \neq i} r_{ij}^2 + \sum_i \sum_{j \neq i} a_{ij}^2} \quad \text{where} \quad a_{ij} = -\frac{r_{ij}}{\sqrt{r_{ii} X r_{ij}}}$$

The KMO index, in particular, is recommended when the cases to variable ratio (n:p) are less than 1:5. The KMO index ranges from 0 to 1, with 0.50 considered suitable for factor analysis. The chart for KMO analysis is given below

**Table 3.3: KMO values inference table**

| **KMO value** | **Degree of common variance** |
|---|---|
| 0.90-1.00 | Excellent |
| 0.80-0.90 | Very good |
| 0.70-0.80 | Neutral |
| 0.60-0.69 | Average |
| 0.50-0.59 | Bad |
| 0.00-0.49 | Don't factor |

**b Bartlett's test of sphericity**

It calculates the determinate of the matrix of the sums of products and cross-products (S) from which the intercorrelation matrix is derived. The determinant of the matrix S is converted to a chi-square statistic and tested for significance. The null hypothesis is that the interrelation matrix comes from a population in which the variables are noncollinear (i.e. an identity matrix).And that the non-zero correlations in the sample matrix are due to sampling error. The formula for calculation of it is as follows.

Chi-square

$\chi 2 = - [(n-1) - 1/6\ (2p+1+2/p)]\ [\ln S + p\ln(1/p)\ \Sigma lj\ ]$

p = number of variables

k = number of components

lj = jth eigenvalue of S

df = (p - 1) (p - 2) / 2

Both the KMO and Batrlett's test can be done in the SPSS software version 16. The results will be discussed in the next chapter.

There are variety of extraction methods used in factor analysis which can be done after the sample adequacy test, these are as follows

i. Principle components method
ii. Maximum likelihood method
iii. Principal axis method
iv. Unweighted least-squares method
v. Generalized least squares method
vi. Alpha method
vii. Image factoring

In this methodology the study is using Principal component analysis (PCA ) as it is the simplest of the true eigenvector-based multivariate analysis. The stepwise procedure for PCA is discussed in **Appendix B.1.** Often, its operation can be thought of as revealing the internal structure of the data in a way that best explains the variance in the data.

### 3.4.2 Principal component analysis (PCA)

Broadly, PCA is the principle method used in the factor analysis. Factor analysis is a statistical method used to describe variability among observed, correlated variables in terms of a potentially lower number of unobserved variables called factors.

The EFA is employed to confirm the whether these are the only six pillars with 24 attributes and 3 attributed related to the overall OHSMS.The generalized least squares method, together with the eigen value over 1, factor loading of 0.4, and varimax rotation (the various steps for varimax rotation is discusses in **Appendix B.2**) are used to perform the EFA (Raubenheimer, 2004; Garson, 2009).The first run gives the results which will be displayed in next chapter. The method used is Principal components analysis which is a statistical technique applied to a single set of variables when the researcher is interested in discovering which variables in the set form coherent subsets that are relatively independent of one another. Variables that are correlated with one another, but largely independent of other subsets of variables are combined into factors.' Factors are thought to reflect underlying processes that have created the correlations among variables (Tabachinik and Fidell, 2006).

The sub-space found by principal component analysis is expressed as a dense basis with many non-zero weights which makes it hard to interpret.

Broad steps of PCA used are as follows.

An initial solution using the PCA is followed in the manner shown below

i. In the initial solution, each variable is standardized to have a mean of 0.0 and a standard deviation of ±1.0.
ii. Thus, the variance of each variable = 1.0 And the total variance to be explained is 6, i.e. 6 variables, each with a variance = 1.0,
iii. Since a single variable can account for 1.0 unit of variance.
iv. A useful factor must account for more than 1.0 unit for variance, or have an eigenvalue $\lambda$>1.0 Otherwise the factor extracted explains no more variance than a single variable.

Since the goal of factor analysis is to explain multiple variables by a lesser number of factors. To improve the factor loading (how well one factor relates to other) there are various rotational methods used. The widely used method is the varimax method which is discussed below.

Varimax is so called because it maximizes the sum of the variances of the squared loadings (squared correlations between variables and factors). Preserving orthogonality requires that it is a rotation that leaves the sub-space invariant. Intuitively, this is achieved if, (a) any given variable has a high loading on a single factor, but near-zero loadings on the remaining factors and if (b) any given factor is constituted by only a few variables with very high loadings on this factor while the remaining variables have near-zero loadings on this factor. If these conditions hold, the factor loading matrix is said to have "simple structure," and varimax rotation brings the loading matrix closer to such simple structure (as much as the data allow). From the perspective of individuals measured on the variables, varimax seeks a basis that most economically represents each individual that is, each individual can be well described by a linear combination of only a few basic functions.

One way of expressing the varimax criterion formally is given by this equation.

$$R_{\mathrm{VARIMAX}} = \arg\max_{R} \left( \frac{1}{p} \sum_{j=1}^{k} \sum_{i=1}^{p} (\Lambda R)_{ij}^{4} - \sum_{j=1}^{k} \left( \frac{1}{p} \sum_{i=1}^{p} (\Lambda R)_{ij}^{2} \right)^{2} \right).$$

$R_{ij}$ Communality matrix , p is no of factors and k is the matrix length, inverse sign indicate the transpose of matrix

Another way to determine the number of factors to extract in the final solution is Cattell's screen plot. This is a plot of the eigen values associated with each of the factors extracted, against each factor. The point at which the plot begins to level off, the additional factors explain less variance than a single variable. The plot will be drawn as part of PCA.

After the exploratory structure (factors matrix) determination it is important to find how reliable and valid the set of constructs are to the research objectives. Therefore, the reliability and validity aspects needs to be considered before assessing the statistical model fit.

### 3.4.3 Reliability and validity

The reliability and validity terms can be defined as given below

**(a) Internal consistency measurement (reliability)**

Extent to which a variable or set of variables is consistent in what it is intended to measure. If multiple measurements are taken, the reliable measures will all be consistent in their values (Hair et al., 2006). Now, the internal consistency method (Saraph et al., 1989) was used to evaluate the reliability of each factor (Josheph et al., 1999).Cronbach' s alpha values were estimated for each pillar using the SPSS. Cronbach's alpha is based on "internal consistency" of a test: the degree to which variables in the measurement set are homogeneous. Specifically, it is based on the average correlation of variables within a test (Ngai and Cheng, 1997).

In exploratory research, items with Cronbach's alpha value are higher than 0.6 are considered to exhibit internal consistency. Extent to which a measure or set of measures correctly represents the concept of study the degree to which it is free from any systematic or non-random error.

**(b) Validity**

Validity is concerned with how well the concept is defined by the measures(s), whereas reliability relates to consistency of measures (Hair et al., 2006).To test the validity it is necessary to test the convergent validity which can be done through confirmatory factor analysis. CFA basically tests a hypothesized factor structure (Schumacker and Lomax, 1996, Byrne, 2001). In order to perform CFA, software package for structural equation modeling (SEM), AMOS 20.0 was used. Convergent validity will be useful for the following cases articulating a set of theoretical concepts and their interrelations for OHSMS.

Convergent validity is the way to assess the construct validity of a measurement procedure (Campbell and Fiske, 1959). Convergent validity helps to establish construct validity when the study uses two different measurement procedures and research methods to collect data about a construct. To assess construct validity first establishment of convergent validity is necessary. The idea is that if these scores converge**,** despite the fact that we use two different measurement procedures and research methods, we are measuring the same construct**.** Once, the final sets of pillars are established, the study aims to find the path or the way through which these pillars can be developed. The next section discusses the procedure for the development of such a path.

## 3.5 Path analysis for OHSMS using ISM methodology

The EFA and CFA tools confirm the role of pillars in OHSMS implementation. However, there is lack of clarity about how these pillars needs to be structured for effectiveness. This means, how the pillars correlate with each other and how we can say that if we can develop a particular pillar it will improve OHSMS. Therefore, to structure the pillars a methodology called Interpretative structural matrix (ISM) is used. This methodology is successfully used in supply chain domain and can also be used in OHSMS development for process industries. The tool has the ability to draw the order and direction on the complexity of relationships among pillars/drivers of a system (Sage, 1977). It is evident that ISM is a qualitative tool used by a number of researchers in various environments from literature (Saxena et al., 1992; Pandey et al., 2005; Thakkar et al., 2007; Singh et al., 2007a, b, c; Sahney et al., 2008; Chidambaranathan et al., 2009; Kannan et al., 2010 and Jyoti, 2010). The direct and indirect relationships exists between the critical success factors (CSFs) of OHSMS which will be attempted in this study. The safety manager should know these interrelationships along these CSFs in order to implement OHSMS program accurately.

Therefore, ISM methodology is adopted to know the interrelationships among the CSFs and develop a structural framework for the process industry. The various steps of ISM methodology for used in this work is mentioned below

### 3.5.1 ISM Methodology

ISM analyzes a system of elements and resolves these in a graphical representation of their directed relationships and hierarchical levels. The elements may be objectives of a policy, goals of an organization, factors of assessment, etc. The directed relationships can be in a variety of contexts (referred to as contextual relationships), such as element (i) *"is greater than"; "is achieved by"; "will help achieve"; "is more important than";* Element (j). The following is a brief description of the different steps of ISM:

**(a) Identification of elements**

The elements of the system are identified and listed. This may be achieved through research, brainstorming, etc.

**(b) Contextual relationship**

A contextual relationship between elements is established, depending upon the objective of the modelling exercise. Here the contextual relation is pillar 'i' 'affects' pillar 'j'.

**(c) Structural self-interaction matrix (SSIM)**

This matrix represents the respondents' perception of element-to-element directed relationship. Four symbols are used to represent the type of relationship that can exist between two elements of the system under consideration. These are:

- **V** for the relation from element $E_i$ to $E_j$, but not in the reverse direction
- **A** for the relation from $E_j$ to $E_i$, but not in the reverse direction
- **X** for an interrelation between $E_i$ and $E_j$ (both directions)
- **O** to represent that $E_i$ and $E_j$ are unrelated

**(d) Reachability matrix (RM)**

A reachability matrix is then prepared that converts the symbolic SSIM Matrix into a binary matrix. The following conversion rules are explained stepwise in the next table.

**Table 3.4: Series of steps to obtain final reachability matrix**

| | |
|---|---|
| Step 1 | It starts with identification of CSFs for OHSMS through extensive literature review earlier and brain storming in a specific environment. The relevant CSFs should be shortlisted on the basis of judgment of multiple experts. |

**Table 3.4: Series of steps to obtain final reachability matrix (contd)**

| | |
|---|---|
| Step 2 | The relevant CSFs are considered to develop Structural self-interaction Matrix (SSIM) based on contextual relationships among the CSFs. These contextual relationships show the way their related to each other for OHSMS at GIL where the study is carried out. They are created considering the judgment of experts. Four symbols (A: CSF for "j" leads to CSF "i"; V: CSF for "i" leads to CSF "j"; X: CSF for "i" leads to CSF "j" and CSF "j" leads to CSF "i" and O: No relationship between CSF "i" and CSF "j") are used for the type of the relation that exists between the CSFs ("i" and "j"). |
| Step 3 | The initial reachability matrix (IRM) developed by converting SSIM into the binary matrix is called the initial RM by substituting V, A, X and O by 1 and 0. The substitution of 1s and 0s are as per the following rules<br>➢ If the (i, j) entry in the SSIM is V, then the (i, j) entry in the IRM becomes 1 and the (j, i) entry becomes 0.<br>➢ If the (i, j) entry in the SSIM is A, then the (i, j) entry in the IRM becomes 0 and the (j,i) entry becomes 1.<br>➢ If the (i, j) entry in the SSIM is X, then the (i, j) entry in the IRM becomes 1 and the (j,i) entry also becomes 1.<br>➢ If the (i, j) entry in the SSIM is 0, then the (i, j) entry in the IRM becomes 0 and the (j, i) entry also becomes 0. |
| Step 4 | The Final reachability matrix (FRM) is developed from IRM considering transitivity of the contextual relation of CSFs. Transitivity is carried out which states that if CSF "i" is related to CSF "j" and CSF "j" is related to CSF "k", then CSF "i" is related to CSF "k". Then the (i, k) entry in the FRM becomes 1. |

The FRM can be interpreted as shown below:

**(e) FRM**

FRM with driving and dependence power of each CSF is determined by summing along row and column of FRM respectively. These driving power and dependencies are used to classify the CSFs into four groups (i.e. autonomous having lower dependence and driver power, dependent having higher dependence and lower driver power, linkage having higher dependence and driver power and independent having lower dependence and higher driving power). The level partitions are developed by partitioning FRM into different levels. It starts with developing the reachability and antecedent sets for each CSF from the FRM. The reachability set of a CSF contains factor itself and other factors to which it may reach whereas antecedent set contains CSF itself and other CSFs, which may reach to it. The CSFs for which the reachability and intersection sets are same, is the top-level CSFs in the ISM hierarchy. The top-level CSFs are separated out from the initial set of CSFs and then the process is repeated until all the CSFs are assigned to a level.

**(f) Driving power and dependence**

Based on FRM, a driving power and dependence diagram (diagraph) is drawn and the transitive links are removed.

**(g) Structural model**

Finally, the structural model of CSFs is generated on the basis of level partitions developed in step f and FRM. If there is a relationship between CSFs “i” and “j”, this is shown by an arrow which points from “i” to “j”.

The structural model of CSFs developed in step g is reviewed for conceptual accuracy. If it is not conceptually accurate, then go to step d. again to conceptualize the pillars.(CSF’s are pillars in our case)

## 3.6 Structural equation modelling (SEM) to confirm the ISM path

SEM is the tool to hypotize a conceptual model and find the statistical significance of the model fit parameters and then modify the model accordingly to have a good fit. However, in doing this study we emphasized on getting the ISM model which encompass the views of the experts. It has been done so because it takes the experience of their field work into consideration and it is most appropriate understanding of the case study being investigated. The research being a case study the initial path of OHSMS is taken from ISM. In order to verify the path proposed by ISM, SEM using AMOS 20.0v was performed to check the statistical fit. The inputs for this analysis are respondents data collected from the previous section of study (survey data). The averages of responses for the elements under each pillar were used and the directional relationships among pillars established using ISM method so as to check the goodness of fit. The model fit parameter values of SEM are discussed in the next chapter.

The process of testing the structural model involves the measurement model and the structural model. As discussed previously a measurement model can be developed based on the theory and field observations. Comparing the CFA with EFA illustrates the concept they hold in common. This section will further how to test the theoretical model obtained in CFA and structural model obtained in ISM. Multiple regression does not allow any of the measurement properties that go all with the constructs of OHSMS. Therefore, because of the capability of including both measurement model and structural model, this tool is used in the present research.

The estimation of the structural parameter estimates is same as used in CFA. The concept of direct and indirect effects can also be included in the present study.

### 3.6.1 Assessing the structural model validity

In this analysis the degree to which a specific relationship is supported by the statistical significance of each pillar. In this model respecification can be used without changing the constructs.

The steps for assessing the validity are as follows.

a. Understanding the structural model fit
b. Checking the theoretical constructs
c. Assessing the overall structural model fit
d. Examining the hypotized dependency relatively
e. Examine the model diagnostics

## 3.7 Case Study

After obtaining the structural model of OHSMS, it needs to be researched about its applicability to the case study. Therefore, in-depth analysis of two critical pillars has been discussed. Discussion of all pillars is beyond the scope of the thesis, therefore the focus is given on the practical implications of OHSMS design and improvement in its performance. This will provide statistical as well as practical significance. The next chapter will focus on the results and discussion section wise as highlighted in this chapter.

Chapter - 4

# Results and Discussion

The OHSMS design methodology focussed on the steps required to be used for the development of a model of OHSMS for the process industries. Therefore, the focus of this chapter is to present the statistical tests and results based on the methodology presented sequence wise. The discussion will emphasize the implications of the result in OHSMS design.

## 4.1 Gaps in OHSMS

Systematic gap identification for a process industry (Company, V) from standard requirements has been done. As company V was accessible and necessary permissions from taken for research it was selected for Gap analysis. The gaps are identified by the way of interviews, on field observations, safety manual, log-book records, training data records and audit record book of a single process industry (the industry chosen was more accident prone among the four compared earlier).Since the organization's dynamics changes from one sector to another the research can't specifically say that only these are the gaps in OHSMS program.Therefore, after this initial observation a quick survey to all safety concerned were given and asked to rank the elements (which are the significant gaps) in the process industries. It has been observed that wherever there are manual operations (for example in Company's V critical department, the job requires. changing the jets from which viscose solution is pumped) there is a high degree of occupational risk involved. This control of human error can be eliminated through proper administrative tools used in the OHSMS program. These gaps are identified are shown in Table 4.1 below.

**Table 4 1: OHSMS gap Identification for Company V**

| S.No. | OHSMS Standard requirements | Existing OHSMS at Company V | Gaps in the existing systems |
|---|---|---|---|
| 1 | OHS Policy | The policy has been drafted to cover safety and health aspects of all the employees and workers of Company's V with a thrust on continuous review for hazard and risk reduction. | None |

| S.No. | OHSMS Standard requirements | | Existing OHSMS at Company V | Gaps in the existing systems |
|---|---|---|---|---|
| 2 | Planning | Hazard identification | To establish a system for identification, assessment and control of OHS hazard and risks, for the operational activities or services, intended changes there on and new projects. Risk assessment is done through a matrix. | The planning is based on simple checklists and administrative controls and therefore does not cover the major engineering controls which should be included in the planning process. Risk assessment should be comprehensively covered. |
| | | Legal requirements | Company V complies to the statutory requirements of OHSMS under the schedule XXVI of M.P Factories rule-107 | The plan focuses on legal documentation preparation rather than monitoring tools. Monitoring should be done by formation of the compliance committee's to check the compliance of individual department and cross-audit it for effectiveness. |
| | | Objectives | Objectives include awareness of safety, understanding of safety requirements at the job; enhance awareness of hazard identification and risk assessment | None |
| | | Management Program | The organization shall keep the record of the compliance to which law it complies, it should focus on periodical evaluation. | Periodical evaluation is missing and varies. |
| 3 | Implementation | Implementation of Structure and responsibility | The top management takes the responsibility to allocate resources essential to establish an effective OHSMS, appoint a top executive who will delegate the duties to the other subordinates. | As such there is sufficient support from top management, which is based on observation. However, it needs further analysis for validating it. |
| | | Training, awareness and competence | The training, awareness about the hazards and risks for the workers is done through a training calendar, and make them understand the risks of departure from the standard procedures. | Training module needs to be redesigned by studying the previous incidents and accidents. It should identify the training needs and establish a correlation between training and incidents. |

| S.No. | OHSMS Standard requirements | | Existing OHSMS at Company V | Gaps in the existing systems |
|---|---|---|---|---|
| | | Consultation and communication | All levels of management to work collaboratively to identify the hazards and communicate them to the supervisors and top-management. | Level-wise information requirements to be identified and developed so that each and every hazard is reported and taken for action plan. |
| | | Documentation and data control | Documentation is done to include all the elements of OHSMS to meet all the requirements. | None |
| | | Emergency preparedness and response | The organization responds to the emergency situation and prepares the team to tackle the emergency situation. Company V has a quick response emergency team to handle any emergency. | The responses are measured by mock-drills. Therefore, emergency scenario identification should be done and mock drill effectiveness to be measured. |
| 4 | Checking and corrective action | Performance measurement and monitoring | Company V's OHSMS performance is measured by carrying out an External audit. They rate the audit and quantify in their terms. Also, the action plan is generated to monitor the noncompliance | Most measures taken are reactive in nature, i.e. taken after the incident, therefore OHS work should include proactive measures to tackle the workplace incidents and monitor it for OHS performance. |
| | | Accidents, incidents, non-conformances & corrective actions | Record incidents, accidents and non-conformance to rectify OHS deficiency | Near-miss incidents also need to be recorded as it has significant impact on overall OH&S |
| | | Record and records managements | Records are maintained to conform to OHSMS and to achieve result. Old records to be discarded and new one be retained. | Records are well maintained as per the standard requirement. |
| | | Audit | Audit is performed to check whether there is conformance to the OHSMS requirements or not. At Company V, the audit is carried out externally as well as internally. | All the loopholes on OHSMS should be discussed with the auditor and an action plan should be generated to have an effective and efficient OHSMS |

From the gap analysis, it is evident that each gap should be addressed, redesigned and checked for implementation which can lead to robust OHSMS. Therefore, a quick survey of the sixteen elements of OHSMS was taken to find out the prominent pillars or elements that built OHSMS and the research design steps for this have already been proposed in the previous chapter.

The quick survey was done in the following way. Rating the sixteen elements from 1 to 16 according to the priority and importance in the plant.The opinions of 28 employees from all the four organizations (7 each) was taken for the same. These employees were either the safety captains, safety officers, head of departments and safety committee members. The elements were taken from Redinger and Levine (1998) and CCPS-AIChe (2012) elements of risk based safety

**Table 4.2: Survey for pillars of OHSMS for process industries**

| S.No. | Element | Ranking | Abbrevations |
|---|---|---|---|
| 1 | Compliance with standards | ○ | cosc |
| 2 | Process safety competency | ○ | psc |
| 3 | Training and performance assurance | ○ | std |
| 4 | Management of change | ○ | moc |
| 5 | Operational readiness | ○ | opr |
| 6 | Emergency management | ○ | emm |
| 7 | Hazard identification and risk assessment | ○ | hira |
| 8 | Top management commitment | ○ | tmc |
| 9 | Safe work practices | ○ | swp |
| 10 | Asset integrity and reliability | ○ | asir |
| 11 | Communication (occupational health and safety) | ○ | ohsim |
| 12 | auditing | ○ | aur |
| 13 | Incident investigation | ○ | incii |
| 14 | Measurement and metrics of health | ○ | mmh |
| 15 | Process Knowledge Management | ○ | pkm |
| 16 | Contractor Management | ○ | conm |

When the score of the respondents was plotted as shown below in Fig 4.1. The following observations can be infered

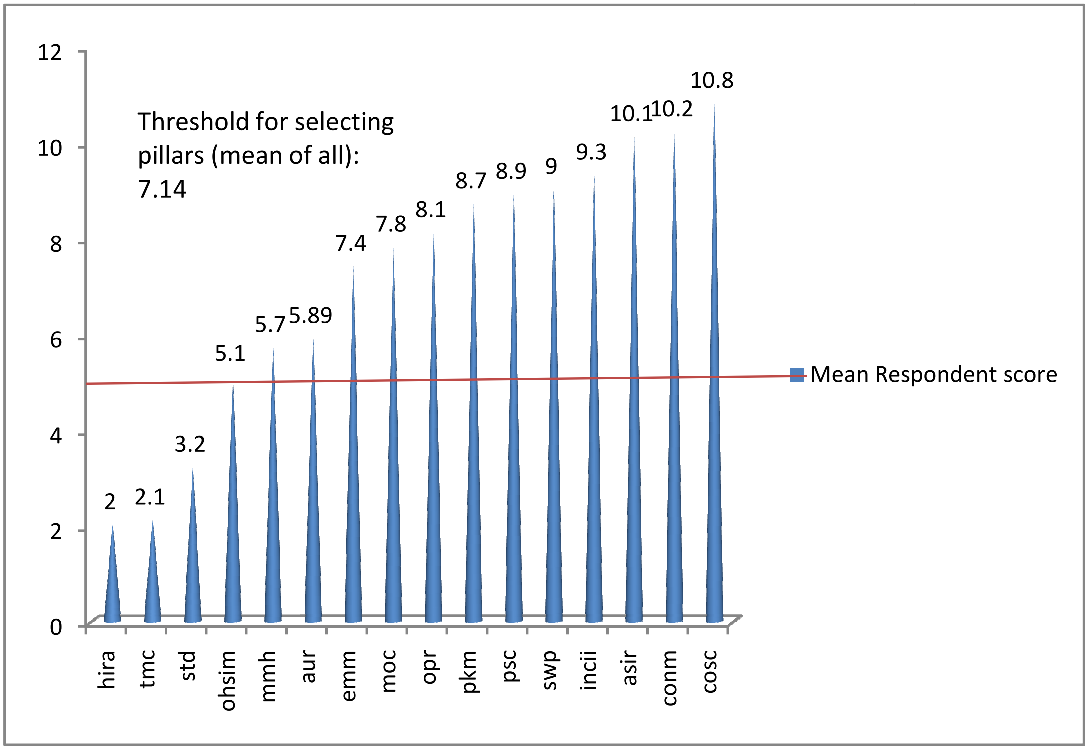



**Fig 4.1: Elements of OHSMS**

The lowest mean score indicates highest priority to that element by the respondent which is plotted in Fig 4.1. Table 4.2 is used to rank 16 elements of Process safety management to find the priority elements whereas Table 3.1 is for variables concerning the 6 hypotized variables governing the OHSMS system. Table 3.1 consists of observed variables which are used to find latent factors. The threshold mean score chosen was 7.143 which is means of all respondent score.

The lowest mean scores means indicate that they are having the most priority, so accordingly the six elements or six pillars,rated by the experts are as follows

1. HIRA (hazard identification and risk assessment
2. TMC (top management commitment)
3. STD (safety training and development)
4. OHSIM (occupational health and safety information management)
5. MMH (measurement of health matrix)
6. AUR (audit and review)

The MMH will be written as work place environment and health monitoring systems as both signifies same concept for further analysis. The abbreviation designated for this is WEHMS. The next step of the investigation is the empirical relevance, which is discussed in section 4.2.

## 4.2 Empirical investigations of pillars using factor analysis techniques

As discussed in the methodology chapter, the survey consisting of the constructs (questions) related to the above six pillars were distributed to a significantly large population to gauge the present structure and propose a framework for such a structure. The response rate percentage was good and the sampling was carried out in the four organizations.

KMO and Bartlett’s test for sampling shown in Table 4.3 indicates that it is fairly significant as significant value is 0. This test was carried out in statistical software (IBM SPSS v20 statistical package for social sciences). The KMO values from Table 3.3 (Chapter 3) suggests that the degree of common variance is very good for further analysis.

**Table 4.3: KMO and Bartlett's test**

| | | |
|---|---|---|
| Kaiser-Meyer-Olkin measure of sampling adequacy | | 0.898 |
| Bartlett's test of sphericity | Approx. Chi-Square | 5147.623 |
| | Df | 351 |
| | Significant value | 0.000 |

The next work is to find out how the factors of each element of OHSMS load on each other i.e. high item loadings on one factor and smaller item loadings on the remaining factor solutions. There are numerous ways to extract factors, this study is using PCA due to its ability of simple and unique representation of factors. The extraction of factors is shown in Table 4.4 , whereas the scree plot in Fig 4.2 represents it.

**Table 4.4: Factor analysis using PCA**

| Component | Initial Eigen values | | | Extraction sums of squared loadings | | | Rotation sums of squared loadings | | |
|---|---|---|---|---|---|---|---|---|---|
| | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 9.117 | 33.765 | 33.765 | 9.117 | 33.765 | 33.765 | 3.279 | 12.145 | 12.145 |
| 2 | 2.516 | 9.318 | 43.083 | 2.516 | 9.318 | 43.083 | 3.177 | 11.765 | 23.910 |
| 3 | 2.185 | 8.092 | 51.175 | 2.185 | 8.092 | 51.175 | 3.168 | 11.734 | 35.644 |
| 4 | 1.864 | 6.903 | 58.078 | 1.864 | 6.903 | 58.078 | 2.867 | 10.618 | 46.262 |
| 5 | 1.710 | 6.335 | 64.413 | 1.710 | 6.335 | 64.413 | 2.678 | 9.919 | 56.182 |
| 6 | 1.414 | 5.239 | 69.652 | 1.414 | 5.239 | 69.652 | 2.577 | 9.545 | 65.727 |
| 7 | 1.026 | 3.801 | 73.452 | 1.026 | 3.801 | 73.452 | 2.086 | 7.726 | 73.452 |
| Extraction method: Principal component analysis | | | | | | | | | |

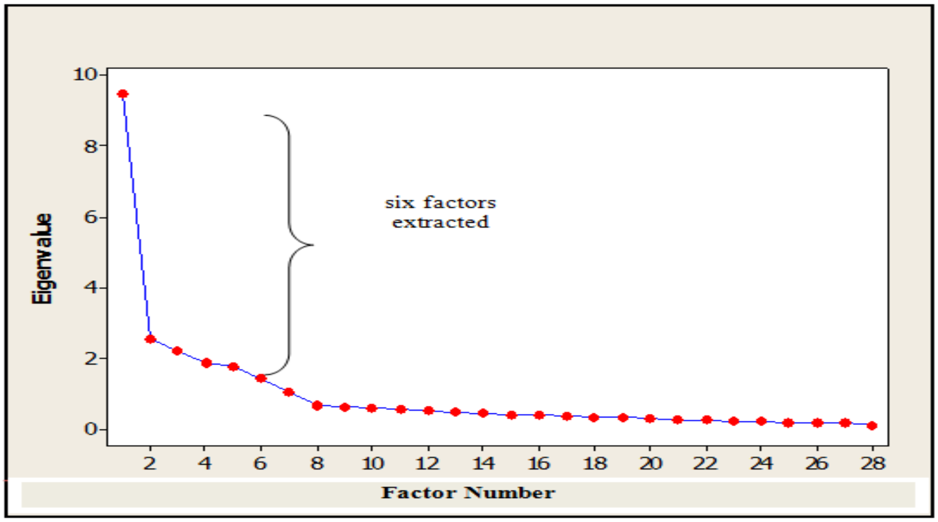



**Fig 4.2: Scree plot**

The idea behind the factor loadings is to convert the 309 respondents 'data by 27 variables which was reduced to 27 variables due to 2 variables cross loaded with each other of WEHMS . This was then converted this into 27 × 27 matrix which represents the interrelation as shown in Table 4.5.

**Table 4.5: Rotated component matrix**

| | Component | | | | | | |
|---|---|---|---|---|---|---|---|
| | **AUR** | **OHSIM** | **TMC** | **OHSAS** | **STD** | **HIRA** | **WEHMS** |
| TMC1 | | | 0.735 | | | | |
| TMC2 | | | 0.841 | | | | |
| TMC3 | | | 0.816 | | | | |
| TMC4 | | | 0.828 | | | | |
| WEHMS1 | | | | | | | 0.737 |
| WEHMS2 | | | | | | | 0.741 |
| WEHMS3 | | | | | | | 0.690 |
| HIRA1 | | | | | | 0.741 | |
| HIRA2 | | | | | | 0.777 | |
| HIRA3 | | | | | | 0.792 | |
| HIRA4 | | | | | | 0.700 | |
| STD1 | | | | | 0.783 | | |
| STD2 | | | | | 0.822 | | |
| STD3 | | | | | 0.767 | | |
| STD4 | | | | | 0.642 | | |

| | Component | | | | | | |
|---|---|---|---|---|---|---|---|
| | AUR | OHSIM | TMC | OHSAS | STD | HIRA | WEHMS |
| OHSIM1 | | 0.820 | | | | | |
| OHSIM2 | | 0.842 | | | | | |
| OHSIM3 | | 0.878 | | | | | |
| OHSIM4 | | 0.851 | | | | | |
| OHSAS1 | | | | 0.606 | | | |
| OHSAS2 | | | | 0.828 | | | |
| OHSAS3 | | | | 0.857 | | | |
| OHSAS4 | | | | 0.766 | | | |
| AUR1 | 0.794 | | | | | | |
| AUR2 | 0.826 | | | | | | |
| AUR3 | 0.871 | | | | | | |
| AUR4 | 0.863 | | | | | | |
| Extraction method: Principal component analysis<br>Rotation method: Varimax with kaiser normalization | | | | | | | |
| a. Rotation converged in 6 iterations | | | | | | | |

The next part of the investigation is to check the reliability and validity issues which are discussed in Section 4.2.1

### 4.2.1 Reliability and validity

Now, the internal consistency method (Saraph et al., 1989) was used to evaluate the reliability of each factor (Joseph et al., 1999) and results are shown in Table 4.6.

**Table 4.6: Internal consistency of OHSMS pillars**

| Pillar | No of items | Cronbach's Alpha |
|---|---|---|
| TMC | 4 | 0.892 |
| WEHMS | 3 | 0.806 |
| HIRA | 4 | 0.793 |
| STD | 4 | 0.845 |
| OHSMS | 4 | 0.900 |
| AUR | 4 | 0.927 |

Cronbach' s alpha values were estimated for each pillar using the SPSS. Cronbach's alpha is based on "internal consistency" of a test: the degree to which variables in the measurement set are homogeneous. Specifically, it is based on the average correlation of variables within a test (Ngai and Cheng, 1997). In exploratory research, items with Cronbach's alpha value or higher than 0.6 are considered to exhibit internal consistency. However, in the present case the lowest alpha value detected was 0.793, which is completely acceptable. It also shows that a maximum alpha value of 0.927 that the final alpha value ranges between 0.793 to 0.927, which indicate that the instrument can be considered reliable and internally consistent.

The next part is see the extent to which these sets of measures correctly represent the concept of the study undertaken and the degree to which it is free from any systematic or non-random error. To test the validity it is necessary to test the construct validity and convergent validity which can be done through confirmatory factor analysis discussed in the next section.

### 4.2.2 Confirmatory factor analysis

This analysis is done to confirm and examine the details of an assumed factor structure obtained from EFA. EFA is used to explore all the factors but if don't know clearly how they factors manifest the variables, whereas in CFA we know clearly which are manifest variables for the particular factor. Confirmatory factor analysis is reckoned as a best-known statistical procedure for testing a hypothesized factor structure (Schumacker and Lomax, 1996; Byrne, 2001). It is performed to establish, construct validity (Hair et al., 2006). In order to perform CFA, a software package for structural equation modeling (SEM), AMOS 20.0 is used. Correlation matrix is used in AMOS

#### *4.2.2.1 Construct validity*

The analysis was carried out in multiple stages, initially all 378 data set were considered. For six factors (or principle component) model, the model fit indices were

**(a) Relative/normed chi-square ($\chi2/df$)**

**Table 4.7: Relative/normed chi-square ($\chi2/df$) value**

| $\chi2$ chi square | df degree of freedom | $\chi2/df$ |
|---|---|---|
| 384.584 | 301 | 1.278 |

The chi square statistic is in essence a statistical significance test, it is sensitive to sample size, which means that the chi-square statistic nearly always rejects the model when large samples are used (Bentler and Bonnet, 1980; Jöreskog and Sörbom, 1993). On the other hand, where small samples are used, the chi-square statistic lacks power and because of this may not discriminate between good fitting models and poor fitting models (Kenny and McCoach, 2003). Due to the restrictiveness of the model chi-square, researchers have sought alternative indices to assess model fit. One example of such a statistic that minimizes the impact of sample size on the model chi-square is Wheaton et al's (1977) relative/normed chi-square ($\chi 2$/df). Although there is no consensus regarding an acceptable ratio for this statistic, recommendations range from as high as 5.0 to as low as 2.0 (Tabachnick and Fidell, 2007)

**(b) Goodness-of-fit statistic (GFI)**

The value calculated for GFI = 0.917, GFI calculates the proportion of variance that is accounted for by the estimated population covariance (Tabachnick and Fidell, 2007). By looking at the variances and covariances accounted for by the model it shows how closely the model comes to replicating the observed covariance matrix (Diamantopoulos and Siguaw, 2000). This statistic ranges from 0 to 1 with larger samples, increasing its value. When there are large number of degrees of freedom in comparison to sample size, the GFI has a downward bias (Sharma et al, 2005). Traditionally, an omnibus cutoff point of 0.90 has been recommended for the GFI therefore our values of 0.917 is well within the range.

**(c) Adjusted goodness of fit (AGFI)**

The value calculated for AGFI = 0.896, related to the GFI is the AGFI which adjusts the GFI based upon the degrees of freedom, with more saturated models reducing fit (Tabachnick and Fidell, 2007). Thus, more parsimonious models are preferred while penalizing for complicated models. In addition to this, AGFI tends to increase with sample size. As with the GFI, values for the AGFI also range between 0 and 1 and it is generally accepted that values of 0.90 or greater indicate well fitting models.

**(d) Root mean square error of approximation (RMSEA)**

The calculated value for RMSEA = 0.030, RMSEA predicts how well the model, with unknown but optimally chosen parameter estimates would fit the population covariance matrix (Byrne, 1998). In recent years, it has been regarded as 'one of the most informative fit indices' (Diamantopoulos and Siguaw, 2000: 85) due to its sensitivity to the number of estimated parameters in the model. In other words, the RMSEA favors parsimony in that it will choose the model with the lesser number of parameters. Recommendations for RMSEA cutoff points have been reduced considerably in the last fifteen years. Up until the early nineties, an RMSEA in the range of 0.05 to 0.10 was considered an indication of fair fit and values above 0.10 indicated poor fit (MacCallum et al, 1996). It was then thought that an RMSEA of between 0.08 to 0.10 provides a mediocre fit and below 0.08 shows a good fit (MacCallum et al., 1996). However, more recently, a cutoff value close to 0.06 (Hu and Bentler, 1999) or a stringent upper limit of 0.07 (Steiger, 2007) seems to be the general consensus amongst authorities in this area.

**(e) Root mean square residual (RMR)**

The calculated value of RMR = 0.025

The RMR is the square root of the difference between the residuals of the sample covariance matrix and the hypothesized covariance model. The range of the RMR is calculated based upon the scales of each indicator, therefore, if a questionnaire contains items with varying levels (some items may range from 0 1 – 0 5 while others range from 0 1 – 0 7 the RMR becomes difficult to interpret (Kline, 2005). Values for the RMR range from zero to 1.0 with well fitting models, obtaining values less than 0.05 (Byrne, 1998; Diamantopoulos and Siguaw, 2000) however values as high as 0.08 are deemed acceptable (Hu and Bentler, 1999).

Therefore, after this discussion, it can seen that model fit parameters are well within the range and can, therefore one can move forward with the desired objective.The detailed analysis is mentioned in **Appendix C**-.These values clearly indicate that the original model is respecified to fit with sample data. The model specification was done using following guidelines (Wang and Ahmed, 2004).

- Items with poor square multiple correlations and low regression weights were deleted;
- Items with high error variance and which does not degrade the goodness of fit were deleted;
- Items with high factor loading were not deleted

#### *4.2.2.2 Convergent validity*

It is the extent to which indicators of a specific construct converge or share a high proportion of variance in common (Hair et al., 2006). Anderson and Gerbing (1988) stated that the convergent validity of a model is assessable by determining the path estimates between the measurement items and the significance of their respective latent constructs. Using AMOS output the standardized estimates of all the measured variables were found to be significant. The standardized estimates of all the measured variables are given in Table 4.8. Each variable exhibited significant loadings which supported the convergent validity. In Table 4.8 S.E. represents standard estimate and C.R. (critical ratio for regression weight). The *** in the p column indicates that the values are significant.

**Table 4.8: Convergent validity**

| | | | **Estimate** | **S.E.** | **C.R.** | **P** |
|---|---|---|---|---|---|---|
| TMC1 | <--- | TMC | 1.000 | | | |
| TMC2 | <--- | TMC | 1.249 | 0.085 | 14.708 | *** |
| TMC3 | <--- | TMC | 1.120 | 0.080 | 13.963 | *** |
| TMC4 | <--- | TMC | 1.058 | 0.072 | 14.700 | *** |
| HIRA1 | <--- | HIRA | 1.000 | | | |
| HIRA2 | <--- | HIRA | .994 | 0.094 | 10.538 | *** |
| HIRA3 | <--- | HIRA | .969 | 0.097 | 10.027 | *** |
| HIRA4 | <--- | HIRA | 1.033 | 0.103 | 10.067 | *** |
| WEHMS1 | <--- | WEHMS | 1.000 | | | |
| WEHMS2 | <--- | WEHMS | .968 | 0.091 | 10.652 | *** |
| WEHMS3 | <--- | WEHMS | .938 | 0.083 | 11.281 | *** |
| SAD1 | <--- | SAD | 1.000 | | | |
| SAD2 | <--- | SAD | 1.339 | 0.105 | 12.697 | *** |
| SAD3 | <--- | SAD | 1.247 | 0.103 | 12.113 | *** |
| SAD4 | <--- | SAD | 1.135 | 0.100 | 11.329 | *** |
| OHSIM1 | <--- | OHSIM | 1.000 | | | |
| OHSIM2 | <--- | OHSIM | 1.071 | 0.068 | 15.665 | *** |
| OHSIM3 | <--- | OHSIM | .953 | 0.055 | 17.341 | *** |
| OHSIM4 | <--- | OHSIM | 1.039 | 0.063 | 16.549 | *** |

| | | | Estimate | S.E. | C.R. | P |
|---|---|---|---|---|---|---|
| AUR1 | <--- | AUR | 1.000 | | | |
| AUR2 | <--- | AUR | 1.106 | 0.059 | 18.825 | *** |
| AUR3 | <--- | AUR | 1.010 | 0.079 | 12.712 | *** |
| AUR4 | <--- | AUR | 1.001 | 0.077 | 12.982 | *** |
| OHMAS1 | <--- | OHMAS | 1.000 | | | |
| OHMAS2 | <--- | OHMAS | 1.163 | 0.090 | 12.922 | *** |
| OHMAS3 | <--- | OHMAS | 1.237 | 0.094 | 13.174 | *** |
| OHMAS4 | <--- | OHMAS | 1.017 | 0.094 | 10.812 | *** |

#### *4.2.2.3 Discriminant validity*

It is the extent to which a construct is truly distinct from other constructs (Hair et al., 2006). According to Fornell and Larcker (1981), average variance explained (AVE) must be greater than 0.5 (or 50%). Average variance explained is given in Table 4.9. It can be seen from the tables that AVE’s are greater than 0.5 which supports the discriminant validity.

**Table 4.9: Average variance**

| **Pillars** | **AVE** |
|---|---|
| Hazard identification and risk assessment (HIRA) | 0.735 |
| Top management commitment (TMC) | 0.685 |
| Audit and review (AUR) | 0.509 |
| Work environment and health management system (WEHMS) | 0.535 |
| Safety training and development | 0.584 |
| Occupational health and safety information management (OHSIM) | 0.702 |
| Overall OHSMS effectiveness (OHMAS) | 0.632 |

The CFA model fit, confirms that there is an underlying structure among pillars of OHSMS and therefore there exists a correlation among the pillars which is being highlighted in **Appendix C**. Though, the study undertaken have the confirmations of model fit parameters from CFA but the path of implementation is still unclear. Therefore, ISM tool whose methodology has been described in the previous chapter is discussed in the next subsection 4.3.

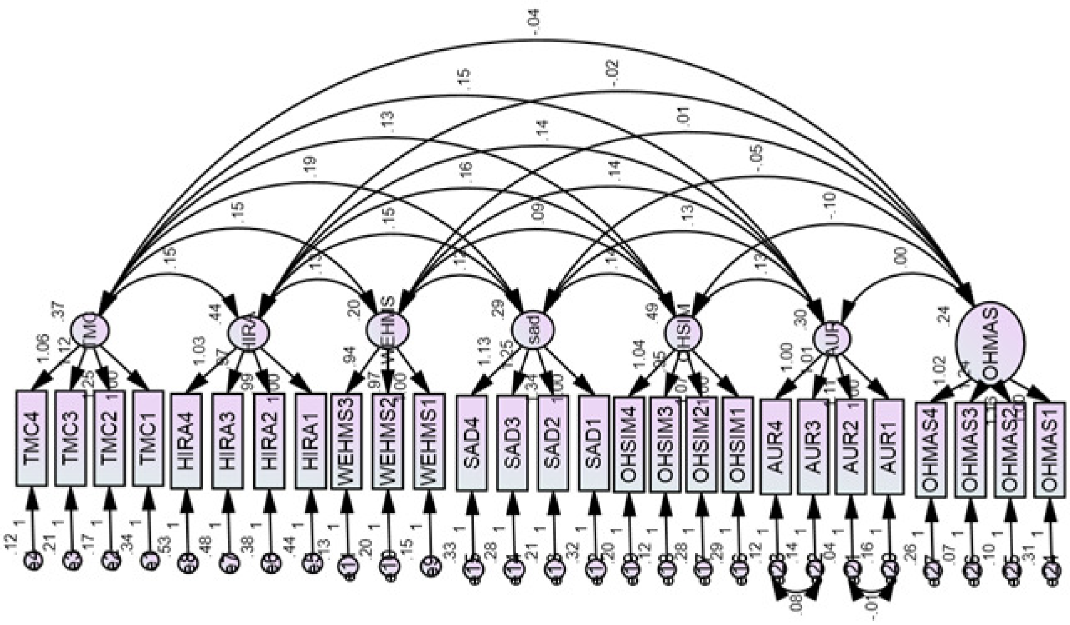



**Fig 4.3: CFA Path diagram**

## 4.3 Path analysis of OHSMS using ISM

As discussed in the ISM methodology the aim is to find the CSF (critical success factors) for OHSMS. The CSF's are the pillars identified from the empirical investigation discussed in the previous subsection. CSF's for OHSMS can be converted into the matrix form to determine the structure for OHSMS implementation

**Table 4.10: CSF's for OHSMS**

| S.No. | Critical factors | Abbreviation | Notation in Matrix |
|---|---|---|---|
| 1 | Top management commitment | TMC | A |
| 2 | Hazard identification and risk assessment | HIRA | B |
| 3 | Training and development (safety) | STD | C |
| 4 | OHSMS information systems | OHSIM | D |
| 5 | Health monitoring systems (workplace environment) | WEHMS | E |
| 6 | Safety auditing (audit and review) | AUR | F |

**Rules of ISM**:

- **V** -for the relation from element $E_i$ to $E_j$, but not in the reverse direction
- **A** -for the relation from $E_j$ to $E_i$, but not in the reverse direction
- **X** -for an interrelation between $E_i$ and $E_j$ (both directions)
- **O** -to represent that $E_i$ and $E_j$ are unrelated
- IRM developed by converting SSIM into binary matrix is called IRM
  - If the (i, j) entry in the SSIM is V, then the (i, j) entry in the IRM becomes 1 and the (j, i) entry becomes 0.
  - If the (i, j) entry in the SSIM is A, then the (i, j) entry in the IRM becomes 0 and the (j,i) entry becomes 1.
  - If the (i, j) entry in the SSIM is X, then the (i, j) entry in the IRM becomes 1 and the (j,i) entry also becomes 1.
  - If the (i, j) entry in the SSIM is 0, then the (i, j) entry in the IRM becomes 0 and the (j, i) entry also becomes 0.

- The Final reachability matrix (FRM) is developed from IRM considering transitivity of the contextual relation of CSFs. If CSF "i" is related to CSF "j" and CSF "j" is related to CSF "k", then CSF "i" is related to CSF "k". Then the (i, k) entry in the FRM becomes 1.

**Table 4.11: SSIM for OHSMS**

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | - | X | A | X | A | X |
| B | | - | A | A | A | V |
| C | | | - | X | A | V |
| D | | | | - | X | X |
| E | | | | | - | V |
| F | | | | | | - |

**Table 4.12: IRM for CSFs of OHSMS**

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | - | 1 | 0 | 1 | 0 | 1 |
| B | 1 | - | 0 | 0 | 0 | 1 |
| C | 1 | 1 | - | 1 | 0 | 1 |
| D | 1 | 1 | 1 | - | 1 | 1 |
| E | 1 | 1 | 1 | 1 | - | 1 |
| F | 1 | 0 | 0 | 1 | 0 | - |

**Table 4.13: FRM for CSFs for OHSMS**

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| A | - | 1 | 1* | 1 | 1* | 1 |
| B | 1 | - | 0 | 1* | 0 | 1 |
| C | 1 | 1 | - | 1 | 1* | 1 |
| D | 1 | 1 | 1 | - | 1 | 1 |
| E | 1 | 1 | 1 | 1 | - | 1 |
| F | 1 | 1* | 1* | 1 | 1* | - |

**Table 4.14: FRM with driving and dependence power for CSFs of OHSMS**

| | A | B | C | D | E | F | DRIVING |
|---|---|---|---|---|---|---|---|
| A | 1 | 1 | 1* | 1 | 1* | 1 | 6 |
| B | 1 | 1 | 0 | 1* | 0 | 1 | 4 |
| C | 1 | 1 | 1 | 1 | 1* | 1 | 6 |
| D | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| E | 1 | 1 | 1 | 1 | 1 | 1 | 6 |
| F | 1 | 1* | 1* | 1 | 1* | 1 | 6 |
| DEPENDENCY | 6 | 6 | 5 | 6 | 5 | 6 | |

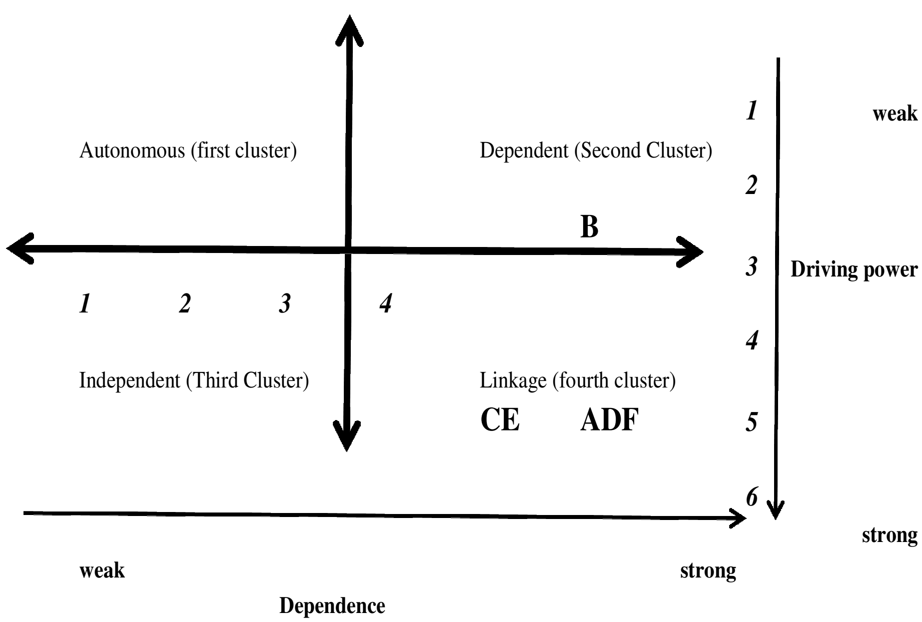



**Fig 4.4: Driving power and dependence diagram of pillars for OHSMS**

**Table 4.15: Level partition-iteration 1 for CSFs of OHSMS**

| | | | |
|---|---|---|---|
| A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | I |
| A,B,D,F | A,B,C,D,E,F | A,B,D,F | I |
| A,B,C,D,E,F | A,C,D,E,F | A,C,D,E,F | |
| A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | I |
| A,B,C,D,E,F | A,C,D,E,F | A,C,D,E,F | |
| A,B,C,D,E,F | A,B,C,D,E,F | A,B,C,D,E,F | I |
| C,E | C,E | C,E | II |
| C,E | C,E | C,E | II |

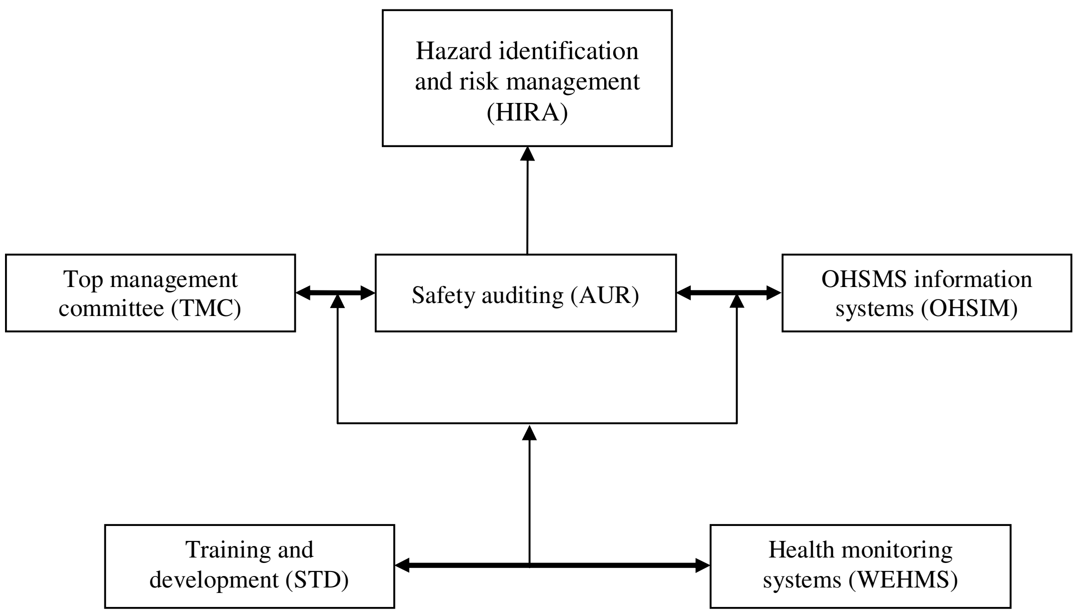



**Fig 4.5: Structure of pillars for OHSMS of process industries**

### 4.3.1 Path analysis of pillars and discussion

The following are the key findings obtained from the ISM study. Driving power-dependence diagram is shown in Fig 4.5 and it classifies all the 6 pillars into four clusters. The first cluster includes autonomous pillar that has a weak driving power and weak dependence. These pillar if present, is relatively disconnected from the overall

OHSMS process. It is found that no identified pillar is in this autonomous cluster. The second cluster (as shown in Fig 4.5) consists of the dependent criteria that have weak driving power but strong dependence. One pillar related to Hazard identification and risk assessment (HIRA) is found in this category. It is put at the top of the ISM hierarchy (see Fig 4.5).Therefore, OHSMS should adopt strong techniques in HIRA for development of safety technology which if implemented properly will be successful in long run.The third cluster includes independent pillars with strong driving power and weak dependence. In this case, five pillars are placed and two pillars that should be focused first are Safety training and development (STD) and workplace health monitoring systems (WEHMS). The "STD and "WEHMS" are placed at the base of the hierarchy of structural framework (see Fig 4.5). This concludes that

"STD" or equally "WEHMS" is the driver for successful adoption of the OHSMS practice in the process industries. Therefore, it is suggested to design and implement many STD plans in coordination with the workers and supervisors so that the all of them should get motivated towards OHSMS process. These STD plans should be clear, transparent and innovative and also have the capability to create a win-win situation for both. The fourth cluster includes linkage pillars that have strong driving power and dependence. However, in this methodology we could get any of the pillars in this cluster so our focus is to understand the overall OHSMS process, its critical elements and develop a safety training and development module first if this statistically validated also. This validation can be done in the structural measurement model which is described later. Before testing this model it is also necessary to test the research hypothesis stated in the objectives. The results of the hypothesis are discussed in the next section.

## 4.4 Testing hypothesis

After the path determination of pillars using the ISM there is a need to test the hypothesis as stated in the methodology. For testing the hypothesis bivariate analysis has been carried out with SPSS. The construct of each pillar is summed as the one pillar for eg. TMC1 the value is 4 and TMC2 is 5 TMC3 4 and TMC 2 is added in one variable TMC = 15, similarly it is done for other pillars and bivariate corelations have been calculated and checked whether they are significant. If they are significant the hypothesis is correct otherwise alternate hypothesis is correct.

**Table 4.15 Bivariate correlations**

| | | TMC | WEHMS | HIRA | STD | OHSIM | OHSMS | AUR |
|---|---|---|---|---|---|---|---|---|
| TMC | Pearson Correlation | 1 | 0.430** | 0.310** | 0.509** | 0.282** | 0.417** | 0.413** |
| | Sig. (2-tailed) | | 0 | 0 | 0 | 0 | 0 | 0 |
| WEHMS | Pearson Correlation | 0.430** | 1 | 0.310** | 0.428** | 0.282** | 0.626** | 0.475** |
| | Sig. (2-tailed) | 0 | | 0 | 0 | 0 | 0 | 0 |
| HIRA | Pearson Correlation | 0.310** | 0.310** | 1 | 0.345** | 0.302** | 0.275** | 0.320** |
| | Sig. (2-tailed) | 0 | 0 | | 0 | 0 | 0 | 0 |
| STD | Pearson Correlation | 0.509** | 0.428** | 0.345** | 1 | 0.345** | 0.337** | 0.384** |
| | Sig. (2-tailed) | 0 | 0 | 0 | | 0 | 0 | 0 |
| OHSIM | Pearson Correlation | 0.282** | 0.282** | 0.302** | 0.345** | 1 | 0.292** | 0.304** |
| | Sig. (2-tailed) | 0 | 0 | 0 | 0 | | 0 | 0 |
| OHMAS | Pearson Correlation | 0.417** | 0.626** | 0.275** | 0.337** | 0.292** | 1 | 0.475** |
| | Sig. (2-tailed) | 0 | 0 | 0 | 0 | 0 | | 0 |
| AUR | Pearson Correlation | 0.413** | 0.475** | 0.320** | 0.384** | 0.304** | 0.475** | 1 |
| | Sig. (2-tailed) | 0 | 0 | 0 | 0 | 0 | 0 | |

** Correlation is significant at the 0.01 level (2-tailed)

As per the hypothesis discussed in the methodology, the following observations can be made

Hypothesis $H_1$: TMC positively affects OHSMS is valid and true

Hypothesis $H_2$: STD positively affects OHSMS is valid and true

Hypothesis $H_3$: HIRA positively affects OHSMS is valid and true

Hypothesis $H_4$: WEHMS positively affects OHSMS is valid and true

Hypothesis $H_5$: OHSIM positively affects OHSMS is valid and tru

Hypothesis $H_6$: AUR positively affects OHSMS is valid and true

The final analysis is now to find whether the ISM path is statistical fit or not. Therefore, the structural model needs the measurement. These measurements criteria are same as the CFA model

## 4.5 Structural model for OHSMS

This is a structural model where each pillar of OHSMS model are tested for their covariances. The ISM model, whether fits statistically or not. Although some have severely criticized the practice, others have argued that the process is substantively meaningful and cause practical as well as statistical significance can be taken into account. If the model is rejected, the problem is determining what is wrong with the model and how the model would be verified to fit the data better. The procedure is followed by summing all the observed variables of the particular pillars and then using the path for statistical significance. In improving the significance the higher regression weights in the covariance of the pillars were removed. The results of the run obtained is as shown in the table below and the diagraph of the path in Fig 4.7. The parameters of statistical fit model are same as discussed in the CFA model.

**Table 4.16: Parameters of the structural model**

| CMIN/DF | GFI | CFI | FMIN | RMSEA |
|---|---|---|---|---|
| 4.617 | 0.956 | 0.867 | 0.105 | 0.108 |

The values of all the statistical fit are measured and are found to be in conformance of the statistical fit values. However, the RMSEA values to be lower than the observed value as for better the values to be less than 0.05, however in trying so the practical significance is distorted, therefore this model of OHSMS for process industries framework can be significantly used to improve the existing framework.

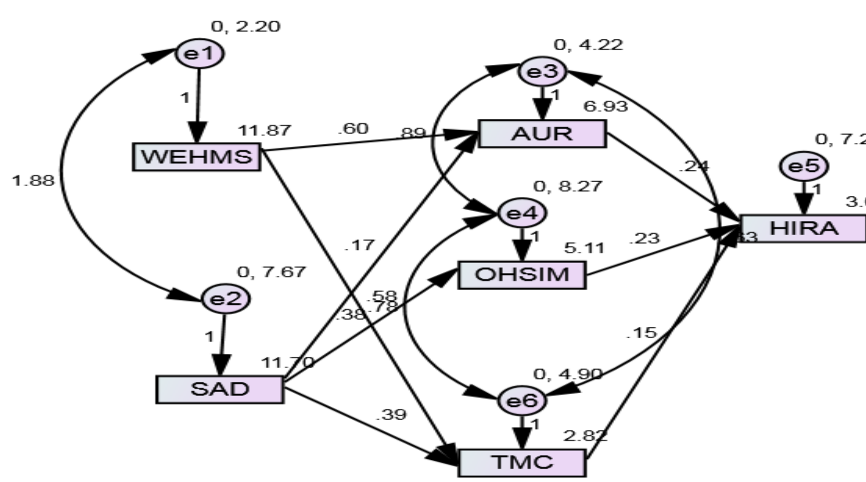



**Fig 4.6: Structural model for OHSMS in process industries**

The regression weight of WEHSM with OHSIM was high and therefore removed for statistical significance, this has done to achieve statistical significance.

Since it has been established that these pillars are practically correlated with OHSMS development significantly. These pillars will improve the effectiveness. The first pillar to be developed significantly is STD as discussed in ISM also.

In order to estimate the correlations and its effect on OHSMS, they are correlated as follows. Either direct effect and indirect effect on OHSMS. For this the study summed the HIRA variable and OHSMS variable and the correlations was found as shown in 4.8.

Considering $Y_{OHSAS}$ as the output variable and the Path coefficients can be calculated by summing the path

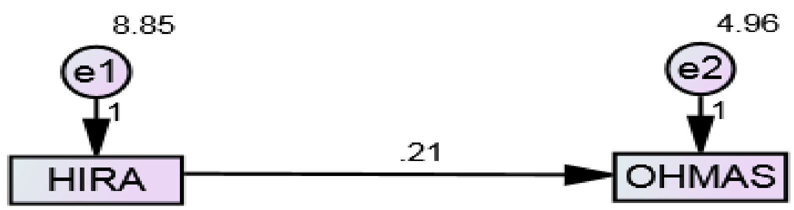



**Fig 4.7: Path diagram from HIRA to OHMAS**

Path from STD to OHMS can be calculated like this

$$Path_{std} \longrightarrow Path_{tmc} \longrightarrow Path_{HIRA} \longrightarrow Y_{ohsms}$$

Therefore the path coefficients for developing OHSMS requires to develop STD, TMC and HIRA respectively.

($Path_{std}$: 0.39) + ($Path_{tmc}$: 0.15) + ($Path_{hira}$: 0.21) = 0.75 which is significantly correlated and will improve OHSMS.

The reason for choosing STD with respect to WEHMS as HMS is something difficult to gauge without extensive medical investigations and survey and more ever, the workers move from one location to another so to know what chemicals and exposures are affecting them needs to monitor over 5-15 years which requires a exhaustive survey which is beyond our scope.Therefore, the research investigates the safety training and development and hazard identificantion and risk assessment pillar which was found to directly impacting OHSMS implementation as per ISM also.Therefore, Company V, which is Grasim Industries Limited(GIL ) is taken for the base case research

Now, that the study have qualitatively and statistically modeled the pillars of OHSMS using ISM and SEM, it is imperative to understand the process and develop/suggest steps for implementation of theses pillars of OHSMS at GIL. Therefore, process description will help us to map our work forward. This implementation issues at GIL would be addressed in the next chapter.

Chapter - 5

# OHSMS case study: Grasim industries limited (GIL)

As highlighted in results and discussion chapter that the derived structural model of OHSMS will improve its effectiveness. Effectiveness can be measured through accidents, incident, health data and morale of the workers. It is the set of the measures that are positively impacting in reduction of incidents, accidents and provides a healthy workplace eenvironment. Therefore, with this emphasis the chapter is dedicated to the background of the specific GIL process, occupational accidents and incidents occurring in the process, and the role of the significant pillars to reduce the incidents and accident.

The base case study taken is of GIL, Nagda unit because it is the largest unit of viscose staple fiber production in the world and out of the four process industries surveyed most vulnerable to incidents due to the manual operations involved in the process. The process background and the incidents are discussed in the next section.

## 5.1 GIL background and process description

GIL is the flagship Company of the prestigious Aditya Birla Group. The VSF plants are located at Nagda (M.P), Harihar (Karnataka) and Kharach (Guj). The total production capacity of GIL is approximately 980 TPD. VSF, Nagda unit production capacity is 450 TPD and the production capacity of byproduct sodium sulphate is 250 TPD. The capacities of carbon –disulphide and sulphuric acid are 60 TPD and 320 TPD respectively .The capacity of captive power plant is 110 MW which meets the demand of the above units.The stepwise process of manufacting VSF is discussed in the next section. It consists of two parts, first part is viscose preparation and the second part is spinning and aftertreatment.

### a. Viscose preparation

The starting point of fibre manufacturing process is viscose preparation. Pulp in the form of sheets or crumbs is flash dried, and pulp slurry is converted into alkali cellulose first and then to viscose solution employing the xanthation process. The xanthation process includes conversion of alkali cellulose, xanthation and filtration of viscose. The caustic received is settled to remove iron-free caustic. This caustic is further diluted to 18% (% refers concentration) strength. Pulp with alpha cellulose content of 94% is hydrolyzed using 18 % caustic in a slurry mixer. Manganese salt and other chemicals are added, as catalyst to ensure required degree of polymerization. Excess alkali is drained in slurry press and the separated alkali cellulose is shredded and matured at a temperature of 35-45 $^0$C in a maturing drum. The recovered alkali is filtered in rotary filters to remove impurities. The temperature of the matured alkali cellulose is brought down to about 30$^0$ C prior to batchwise treatment using NaOH and $CS_2$ and chilled water. This process is known a xanthation. $CS_2$ is added under vacuum and after completion of reaction, the excess $CS_2$ is exhausted. The viscose solution is thereafter transferred to dissolver, disintegrator and blender for uniform composition. The filtered viscose is finally deaerated using four stage vacuum flash deaerator.

**b. Spinning of fibre**

The viscose solution is continuously pumped through spinneret's using gear pumps and regenerated into cellulosic fibre in contact with continuously running spin bath media. The spinning machines have cluster type spinneret's (each with 8000 - 23000 holes for Filament formation) numbering 120-180 per machine. The regenerated cellulose from each spinneret is continuously drawn as tow and cut to requisite staple length in a cutter. Tow washings and squeezing serve to recover carryover spin bath within the spinning machine and are returned to spin bath bottom tank. It is then subjected to after-treatment process where it is washed, bleached, and dried to get the desired product. The governing reaction for the process is highlighted below.

The governing reactions for VSF is as follows.

**Alkcell formation**

$$\underset{\text{Cellulose}}{C_6H_9O_4OH} + \underset{\text{Alkali}}{NaOH} \rightarrow \underset{\text{Alkali Cellulose}}{C_6H_9O_4ONa} + \underset{\text{Water}}{H_2O}$$

(equipments involved: homogenizer, slurry press, hopper, maturing drum)

**Xanthation**

$$\underset{\text{Alkali Cellulose}}{C_6H_9O_4ONa} + \underset{\text{Carbon Disulfide}}{CS_2} \rightarrow \underset{\text{Alkali Cellulose Xanthate}}{C_6H_9O_4O - C = S - NaS}$$

(equipments involved: xanthator, dissolver, three stage filtration unit and refrigeration unit)

**Regeneration of Cellulose**

$$\underset{\phantom{Cellulose}}{C_6H_9O_4O\text{-}C=S\text{-}NaS} + H_2SO_4 \rightarrow \underset{\text{Cellulose}}{C_6H_9O_4OH} + \underset{\text{Sodium Sulfate (by product)}}{Na_2SO_4} + H_2O$$

(equipment involved: spinning machine, $CS_2$ recovery unit, after treatment section, dryer etc. $Na_2SO_4$ is obtained as a byproduct and requires a separate plant)

In the above process spinning department is handles much of manual work required as per the process demand. Therefore, it is necessary to understand the potential process points where the incident/accident cases are more.

The data was collected with the permission and as per the procedure. The data is shared for any study only after 3 years. The study undertaken has used the data from the year 2004-2011 consistently.

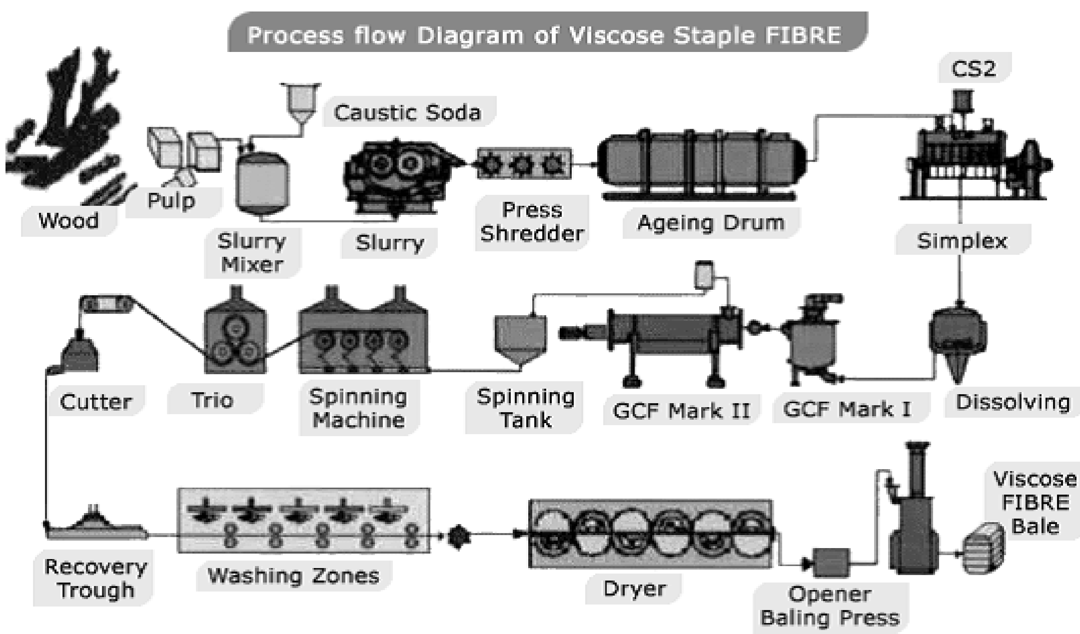



**Fig 5.1: Process description of GIL (GIL safety manual, 2001)**

## 5.2 Accident description at GIL

The number of incident have been taking place in various departments of GIL. Some of these accidents have been described in Table 5.1. The objective is to analyze the role of OHSMS and which intervention can prevent these type of incidents.

**Table 5.1: Selected accidents at GIL in recent years**

| Year | Name of Equipment | Accident | | | Reference (propriety rights of GIL) |
|---|---|---|---|---|---|
| | | Description | Cause | Nature | |
| 2007 | Spinning machine-2 | While the worker was cutting tow, he got injury by a hook | Lack of precaution | Minor cut on the left ankle | Logbook of spinning machine 2 |
| 2008 | Spinning machine-4 | The worker slipped and fell into the tow waste pit during shifting machine Fiber reinforced plastic (FRP) cover | Lack of precaution | Internal back | Logbook of spinning machine-4 |
| 2008 | Spinning machine-7 | The worker slipped and fell into the tow waste pit during shifting the machine's FRP cover | Lack of precaution | Minor cut on thumb | Logbook of spinning machine-7 |
| 2008 | Spinning machine-1 | The worker got trapped between the tow and the roller | Unsafe behavior | Elbow fractured | Logbook of spinning machine-1 |
| 2008 | Spinning machine-4 | The worker got a cut by a knife during tow cutting | Lack of precaution | Minor cut on right ankle | Logbook of spinning machine-4 |
| 2009 | Dryer-5 | The worker got struck to the beam at the dryer's wet end | Lack of precaution | Cut on ankle | Log book of after-treatment section-5 |
| 2009 | Spinning machine-8 | While putting the tow into the cutter, the wooden guide fell down from the platform | Unsafe practice | Internal injury on foot | Logbook of spinning machine-4 |
| 2009 | Dryer-8 | Chain block hook came out from the dryer fan assembly | Maintenance failure | No injury reported | Log book of after-treatment section-5 |
| 2010 | Spinning machine-3 | While the worker was coming down after the job completion from godet gear box, he slipped and fell down | Unsafe practice | Fracture on the back | Logbook of spinning machine-3 |
| 2010 | Spinning machine-3 | Worker got injured while cutting the tow wrap on the feed roller by a knife | Unsafe practice | Minor cut on the thumb | Logbook of spinning machine-3 |
| 2010 | Spinning machine-5 | Worker slipped and fell into the tow waste pit during shifting the machine FRP cover | Unsafe act | Injury on internal back | Logbook of spinning machine-5 |
| 2010 | Sulphur recovery pit | While he was working at pit, he slipped and fell down. | Unsafe act | Fracture right hand, slip and Fall | Logbook of $CS_2$-acid log book |
| 2010 | Acid plant | While pulling a grill by chain block on settling pit, he slipped and fell into pit due to chain block lifting pipe got loose | Unsafe act | Minor cut un head, struck with | Unsafe act-lifting equipment Not fixed |

After the observations of the incidents it is clear that majority of the incidents falls in the unsafe act category. The general analysis of an accident anatomy can be best understood from a fault tree diagram as follows.

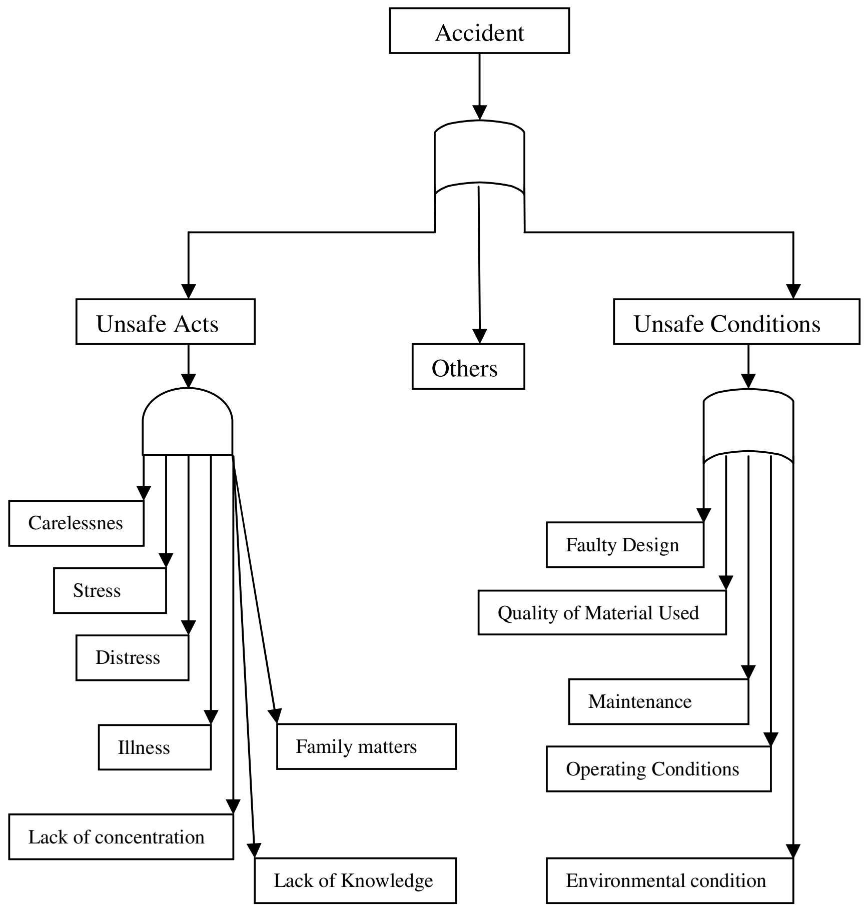
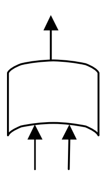
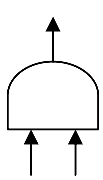



**Fig 5.2:Fault tree of an accident**



**AND Gate**: This gate can allow more then one event at a time



**OR Gate**: This gate will allow only one event at a time

The accident data in Fig 5.1 was selective so the analysis can't be comprehensive. Therefore, comprehensive accident data was collected from the safety officer for all the departments. Special permissions and approvals were taken for the same.

**Table 5.2: Accident data year wise**

| **Department** | **2004-2005** | **2005-2006** | **2006-2007** | **2007-2008** | **2008-2009** | **2009-2010** | **2010-2011** | **Total** | **Mean** | **Standard deviation** |
|---|---|---|---|---|---|---|---|---|---|---|
| Viscose-1 | 18 | 2 | 3 | 4 | 3 | 3 | 3 | 26 | 3.71 | 1.97 |
| Spinning-1 | 14 | 27 | 8 | 8 | 7 | 8 | 12 | 84 | 12.00 | 7.09 |
| After-treatment-1 | 18 | 8 | 2 | 3 | 9 | 8 | 6 | 54 | 7.71 | 5.25 |
| Auxiliary-1 | 4 | 2 | 4 | 1 | 2 | 4 | 1 | 18 | 2.57 | 1.39 |
| Viscose-2 | 6 | 5 | 4 | 2 | 4 | 3 | 1 | 25 | 3.57 | 1.71 |
| Spinning-2 | 2 | 4 | 4 | 3 | 2 | 2 | 1 | 18 | 2.57 | 1.13 |
| After- Treatment- 2 | 6 | 3 | 1 | 0 | 1 | 2 | 1 | 14 | 2.00 | 2.00 |
| Auxiliary-2 | 0 | 5 | 1 | 2 | 1 | 1 | 1 | 11 | 1.57 | 1.61 |
| $CS_2$ | 4 | 3 | 1 | 7 | 1 | 1 | 1 | 18 | 2.57 | 2.29 |
| $H_2SO_4$ | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 3 | 0.42 | 0.53 |
| **Total accidents per year** | **63** | **60** | **29** | **30** | **30** | **32** | **32** | **276** | **39.42** | **15.14** |

Accident data was collected from various departments from 2004-2011. The accidents include both major and minor accidents. Major accident is termed as having a fatality or a disability whereas minor accident is referred to as an injury wherein worker reports to the workplace after some time. The data mostly covers minor accidents. Table 5.2 shows the accident data year wise from 2004-2011.The causewise analysis data of the accidents have been shown in **Appendix E**. The average mean and standard deviation is also calculated for the data, which shows that spinning-1 and 2 contributes to approximately half of the total accidents. The accident frequency becomes half mostly due to large initiatives by the new management and more emphasis on PPE's during occupational work.The pareto-chart of accident contribution of various departments is shown in Fig 5.4 which confirms that 62.7% accidents are in spinning and after-treatment. Therefore, the focus and attention should be based on the spinning and after-treatment department.

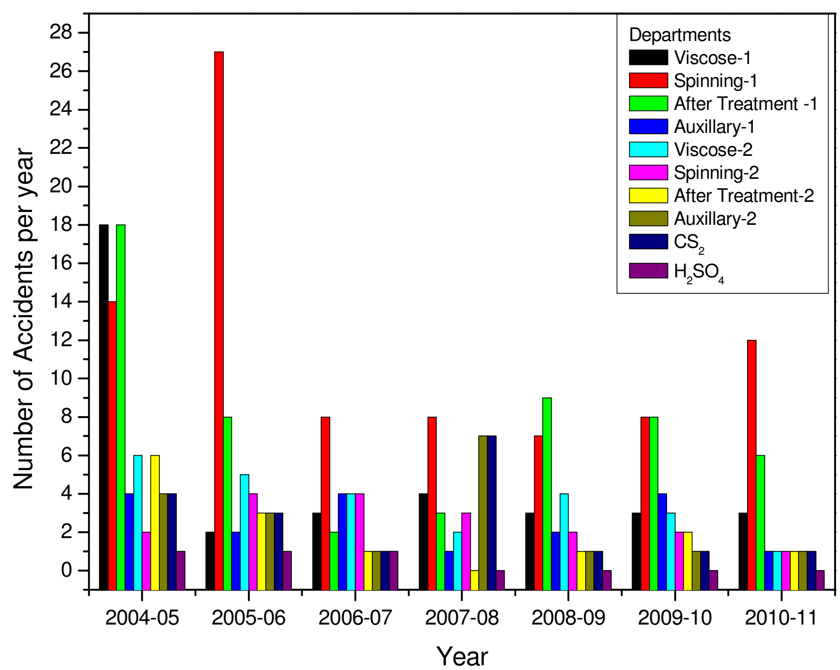



**Fig 5.3: Year wise and department wise accidents**

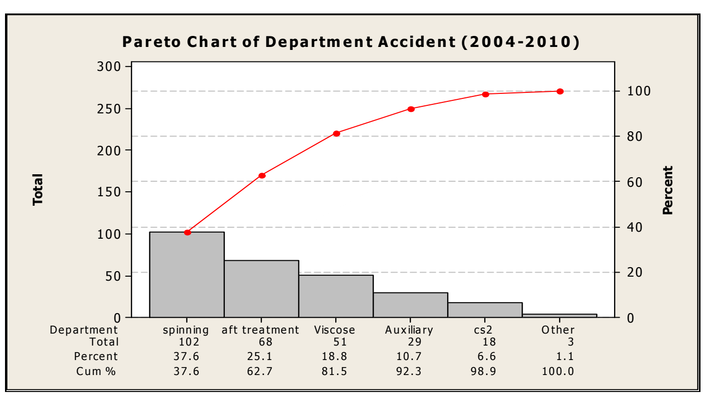



**Fig 5.4**: **Pareto diagram for accident contribution department wise**

### 5.2.1 Relationship of accidents with safety training and development at GIL

Although there is a formal OHSMS at GIL, but the accidents are not reducing to a large extent. One of the reason may be that, as confirmed from structural model also that the variables in the safety training and development pillar are not functioning properly. As discussed in the framework this pillar will lead to a robust OHSMS.

From accident data it is clear that spinning, after treatment and viscose are the most vulnerable departments with respect to accidents as evident from the records of 2004-2011. Therefore, the number of accidents occurred in these departments were segregated equipment/areawise, injury wise, category-wise and cause-wise (**Appendix-E**). However, injury and its type have been broadly taken rather than specific to cater to the most occurring accidents. An unsafe act contributes to more than 90% of accidents at VSF, which can be reduced and mitigated through continuous effort in enhancing the training effectiveness module. Therefore, the review of existing training modules is warranted, its relation to accidents, and the prediction of future accidents will help in better planning of the training module .

The data was collected for all the incidents and accidents in the major departments of VSF and the observations are made as shown in Table 5.3. It was found that 90.4% accidents were due to unsafe acts, some of the reasons of such acts are shown in Fig 5.2. These acts can be minimized though not completelty eliminated as its beyond scope to control the human nature, and his emotions, but definitely there is a general acceptance among researchers that a train mind is less vulnerable to mistakes than an untrained one. Therefore, the pattern of training and accident needs to be studied in detail.The corresponding training data with respect to the accident was also collected for the same period.

**Table 5.3 : Percentage of accidents due to unsafe Acts (2004-2011)**

| Department | Total accident | Accidents due to unsafe acts | % of accidents due to unsafe acts |
|---|---|---|---|
| Viscose | 51 | 43 | 84.31 |
| Spinning | 102 | 98 | 96.08 |
| After-Treatment | 68 | 59 | 86.76 |
| **Total** | **221** | **200** | **90.4%** |

**Table 5.4: Training data year wise (2004-2011)**

| Types of Training | 2004-2005 | 2005-2006 | 2006-2007 | 2007-2008 | 2008-2009 | 2009-2010 | 2010-2011 | Total hours | Mean training hours (7 years) | Standard deviation |
|---|---|---|---|---|---|---|---|---|---|---|
| OJT | 198 | 203 | 197 | 215 | 230 | 240 | 265 | 1548 | 221.14 | 25.31 |
| WDP | 230 | 215 | 267 | 278 | 298 | 302 | 310 | 1900 | 271.43 | 36.72 |
| VBT | 56 | 58 | 57 | 55 | 52 | 61 | 63 | 402 | 57.43 | 3.69 |
| CT | 245 | 255 | 267 | 271 | 285 | 290 | 304 | 1917 | 273.86 | 20.56 |
| FAT | 78 | 68 | 81 | 84 | 85 | 86 | 92 | 574 | 82 | 7.55 |
| ET | 89 | 91 | 90 | 92 | 94 | 96 | 97 | 649 | 92.71 | 3.04 |
| EST | 52 | 55 | 57 | 59 | 58 | 59 | 60 | 400 | 57.14 | 2.79 |
| PPE | 48 | 53 | 54 | 55 | 51 | 58 | 58 | 377 | 53.86 | 3.63 |
| HAZOP | 34 | 36 | 37 | 39 | 42 | 45 | 49 | 282 | 40.29 | 5.35 |
| **Total** | **1030** | **1034** | **1107** | **1148** | **1195** | **1237** | **1298** | **8049** | **1149.86** | **101** |
| **Mean of all training types** | **147.14** | **147.71** | **158.14** | **164.00** | **170.71** | **176.71** | **185.43** | | | |

OJT = On the job training; WDP = Workmen development program; VBT = Video based training; FAT = First aid training; ET = Emergency training; EST = Electrical safety training; PPE = Personal protective equipment training; HAZOP = Hazard and operability.

The training methods used in GIL can be briefly described as follows.

| | |
|---|---|
| OJT | The workers are trained in their job field which helps them to perform the job safely. |
| WDP | Developmental training with respect to standard operating procedure, process changes is delivered through classroom lectures |
| VBT | Video clips of safe and unsafe jobs are shown to the workers. |
| FAT | First aid procedure training for various injuries, accidents is provided |
| ET | Emergency training is provided through mock drills, department camps etc. A trigger event using historical experience is taken |
| EST | Procedure for hot electrical job work is taught along with the necessary precautions |
| CT | Contractor Training |
| PPE | Workers and employees are trained in proper usage of PPE's |
| HAZOP | Generation of various deviation parameters for the critical equipment using hazard analysis and operating procedure are taught. |

### 5.2.2 Hypothesis of training versus accident prediction

To test this hypothesis that increase training hours reduces the aciident rate, the study used the paired sample t test to find whether the relationship is significant

Hypothesis $H_1$: There is strong relationship between training and accident. Test run result was found to be significant. The results are shown in Table 5.5. The relationship was found to be significant and therefore the null hypothesis was found be to true and valid. Thus, with the data available for both training and accident, the use of forecasting tools can be made to see the impact of increase in training hours with respect to accidents.

Therefore, the next part of the study is to find what part of training should be emphazied more to reduce the accidents. Therefore, the forecasting of accidents was done which is shown in Figure 5.5.

Linear forecasting was carried to find the accidents in coming years (the accidents was available upto 2011 only). Thus, from the Figure 5.5 it can be inferred that the accidents will remain constant unless and until a major transformation will take place in training and development. Therefore, it was thought to ask the safety incharge in the plant to suggest what steps can be taken in training to reduce the future accidents. Also, the data upto 2015 also found that there is only a 10% error in the prediction. So, more or less the forecasting can be assumed to be correct.

Therefore, it was thought to survey the Head of departments, workers and management to see what steps can be taken to reduce the accidents. Before taking the survey the existing training gaps were found out through observations and scientific review of safety literature.

**Table 5.5: t test to test significance of accidents and training**

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. deviation | Std. error mean | 95% Confidence interval of the difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | training - accident | 1.11043E3 | 112.85515 | 42.65524 | 1006.05496 | 1214.80218 | 26.033 | 6 | .000 |

**Table 5.6: Prediction of accidents**

| Model | Number of predictors | Model fit statistics | | Ljung-box Q(18) | | | Number of outliers |
|---|---|---|---|---|---|---|---|
| | | Stationary R-squared | MaxAPE | Statistics | DF | Sig. | |
| Aaccident-model_1 | 0 | -.197 | 106.897 | . | 0 | 0.000 | 0 |

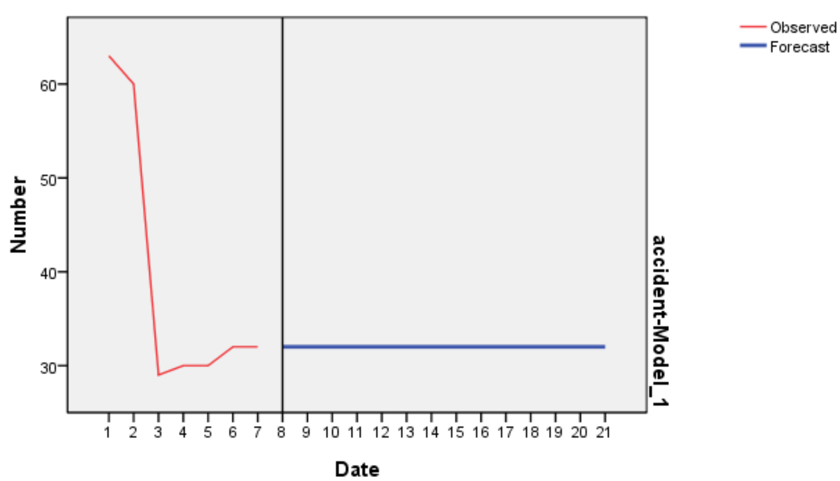



**Fig 5.5 Accident prediction model**

Number: No of accidents

Date: year (data available upto 8 after 8 it is the predicted value, read 1 value as year 2004)

### 5.2.3 Gaps in training

According to the observations the following are the training gaps at GIL which can be addressed

(a) Competent and experienced trainer: It has been observed that the trainer is chosen from the plant by the supervisor and HR (Human Resource) department without testing his competence and experience in the department.

(b) Training should be given depart wise with increased training hours: Most accident prone department have the same training hours compared to the other departments, therefore feedback and survey from supervisors of the department should be taken.

(c) Train the trainer: supervisor and external faculty are not resourced in training the trainer with advanced safety techniques.

(d) Behavioral training: Behavioral training does not involve top management

(e) Job rotation: Job rotation practice is not adopted to remove monotony of work.

(f) Training competition: Inter-department safety training competitions are held only quarterly

Further, to enhance the existing training it is necessary to survey the shop floor employees and workers with parameters that are responsible for workplace accidents.

## 5.3 Survey to design the safety training and development module

The training need of the workers is most valid when the knowledge and the skills being taught are practiced. The equipment and the facilities to be maintained will help in determining the needs of the safety training program. The basic steps in establishing a good safety training program is to survey the shop floor workers and the supervisors. The accident data and training data suggests that increased hours in training programs reduces the accident likelihood, therefore to enhance the training program effectiveness following parameters were identified and questions related to those parameter were asked to the shop floor workers and employees.The survey referred to a similar research work done by Sinclair et al. (2011).

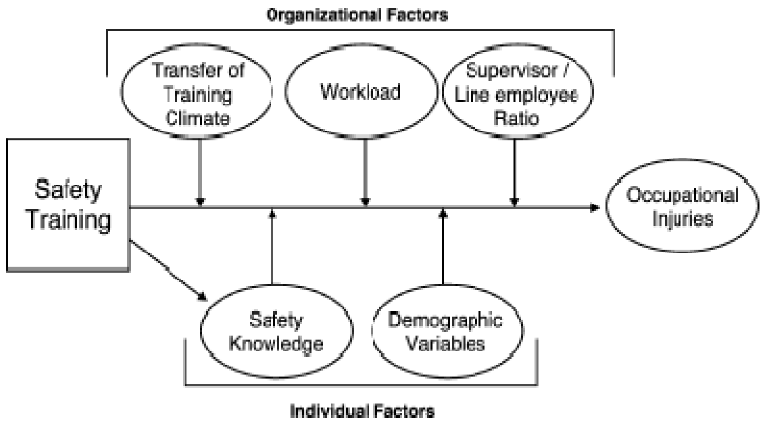



**Fig 5.6: Study variable for safety training (adapted from R.C. Sinclair et al., 2011)**

Thus, from Fig 5.6 it can be inferred that the essential organizational and individual factors that are responsible for the intervention and correction in training will avoid the occupational accidents. Based on this experience and experts view the variables for GIL were take as follows

a. Workers attitude, W
b. Management commitment, MC
c. Trainers skill, TS

### 5.3.1 Survey of shop floor workers

The survey was carried out randomly with a sample size of 50 workers including 3 shifts in spinning and after- treatment departments by asking them the following questions. It is almost never the case that the sampling frame you use is a perfect match to the population you are trying to understand, so this error is present on most studies

The researcher bias, sampling bias, response bias, overdoing bias were removed using appropriate measures such as maintaining randomness in sample.

The following question were asked to shop floor workkers

a. Which type of training is most critical for your department?
b. Is the trainer effective in giving you on-the job training?
c. Is the management committed to provide continuous safety training and support?
d. How responsible are you in performing critical job?
e. Are the training hours sufficient to learn?

46 (92%) workers including contractor workers respondent to the above questions and the following results were obtained. The results are shown by the way of bar diagrams from Fig 4.7 to Fig 4.11.

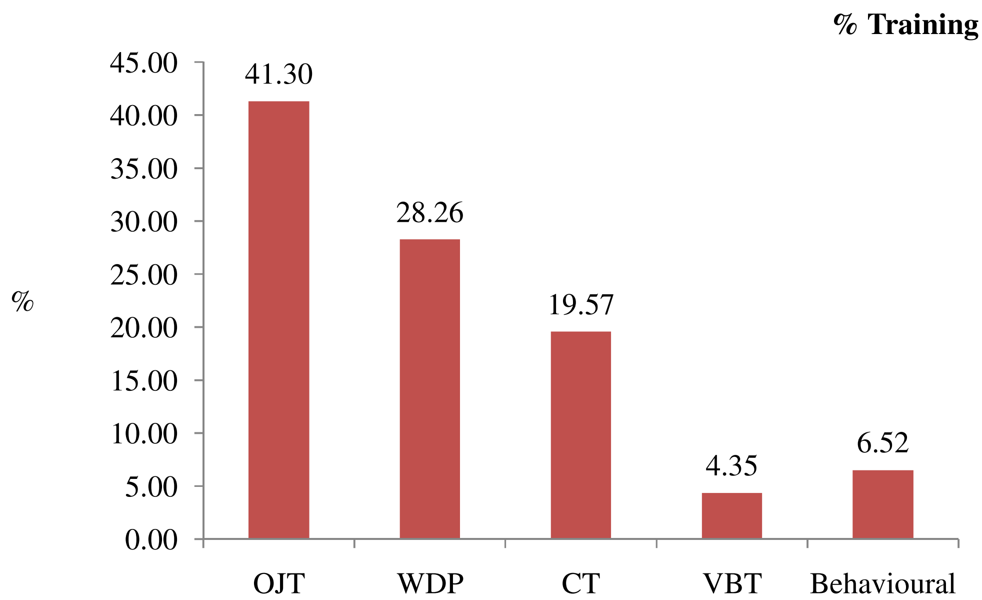



**Fig 5.7: Response to question (a)**

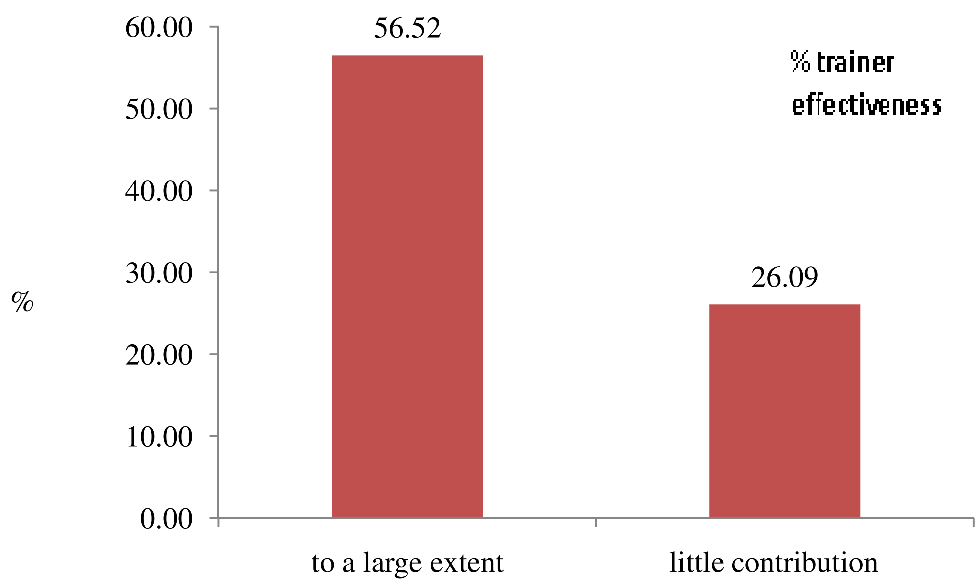



**Fig 5.8: Response to question (b)**

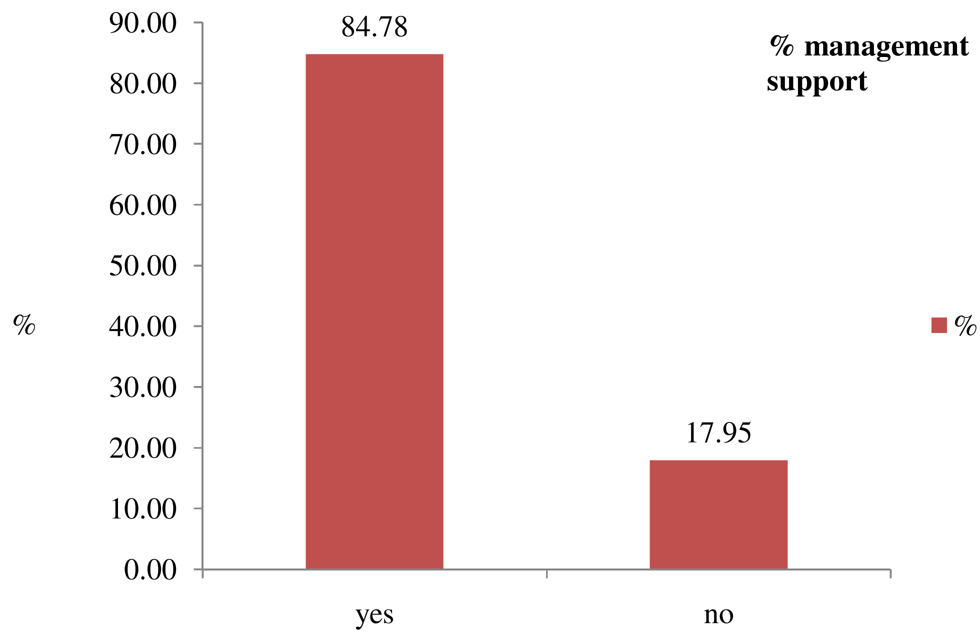



**Figure 5.9: Response to question (c)**

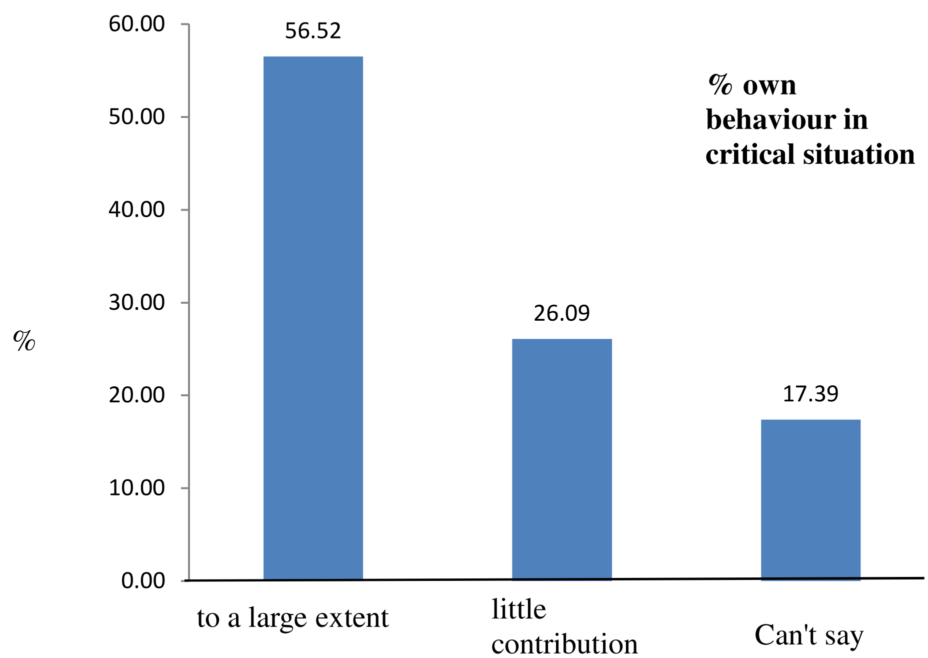



**Figure 5.10: Response to question (d)**

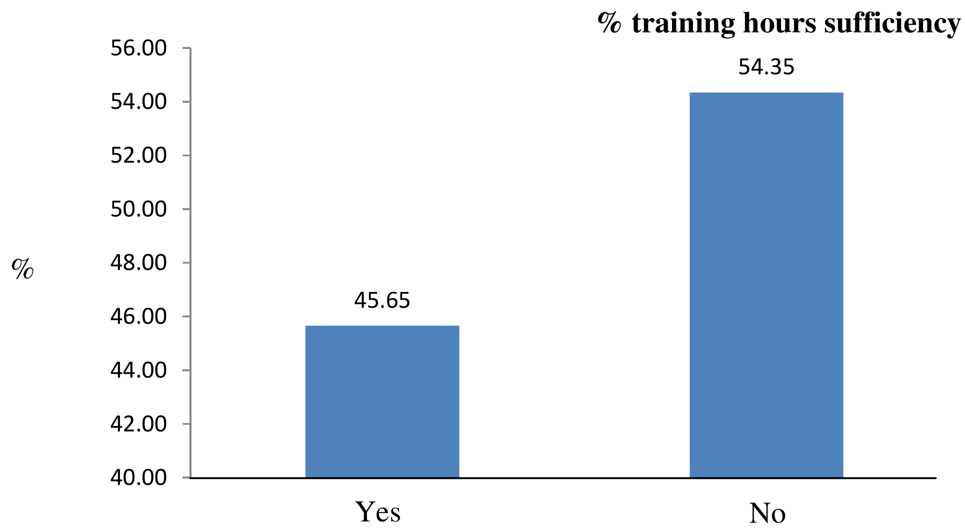



**Fig 5.11: Response to question (e)**

The five questions given to the shop floor workers will help to focus in preparation and gauging the training requirements for them and how other factors would be helpful in the training effectiveness. The majority of workers are satisfied with the management commitment but they feel that the present training hours need to be increased, also they feel that On the job training is more important tool for them to be trained. With these aspects, the survey was further extended to the supervisors and the Head of department to implement their suggestions in the training plan for workers and employees.

### 5.3.2 Supervisory and Head of department (HOD) survey

Supervisor and HOD play a pivotal role in maintaining the process conditions and workplace safety. Therefore, the survey of 2 supervisors and 1 HOD from each department of VSF were taken and their responses were recorded.

Each department within VSF has its own parameter for reducing accidents. Therefore, the responses are different, for example training is most important in spinning department whereas process conditions are important in $CS_2$/ $H_2SO_4$. Therefore, the survey results also varies department wise. The training and development program at VSF is designed based on the recommendation/ suggestion of the Middle level management represented by the supervisors and the HOD's. Therefore, the following questions were posed to them in order to redesign the existing training program.

(a) Is safety training sufficient to mitigate the accidents in your department?

(b) Are the training hours sufficient?

(c) Does the training cover all the workmen?

(d) Is the top management supportive to your training suggestions?

**Table 5.7 : Survey of supervisors and HOD for training program improvement**

| **Department** | **Supervisor (Deputy manager and manager)** | **HOD (AGM/DGM)** |
|---|---|---|
| Viscose-1 | 2 | 1 |
| Spinning-1 and aftertreatment 1 | 4 | 1 |
| Viscose-2 | 2 | 1 |
| Spinning-2 and aftertreatment-2 | 2 | 1 |
| Auxiliary-1 | 2 | 1 |
| Auxiliary-2 | 2 | 1 |
| $CS_2/H_2SO_4$ | 2 | 1 |
| **Total** | **16** | **7** |

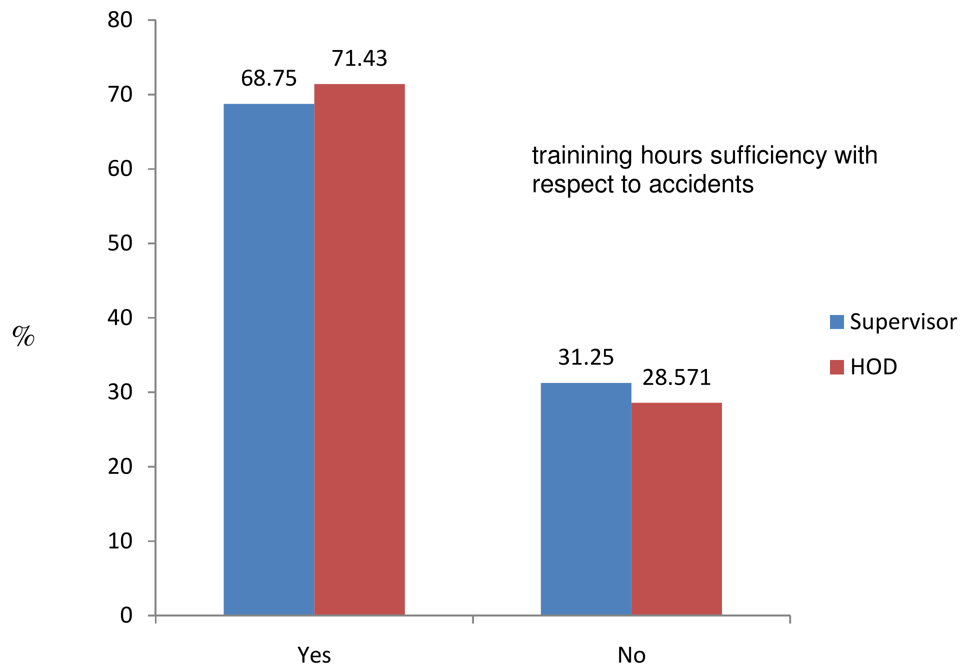



**Fig 5.12: Response to question (a)**

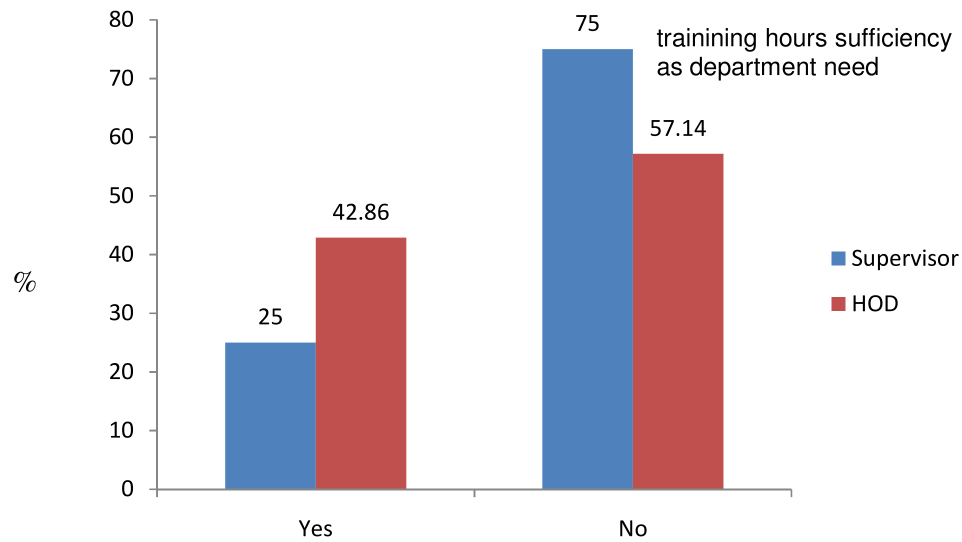



**Fig 5.13: Response to question (b)**

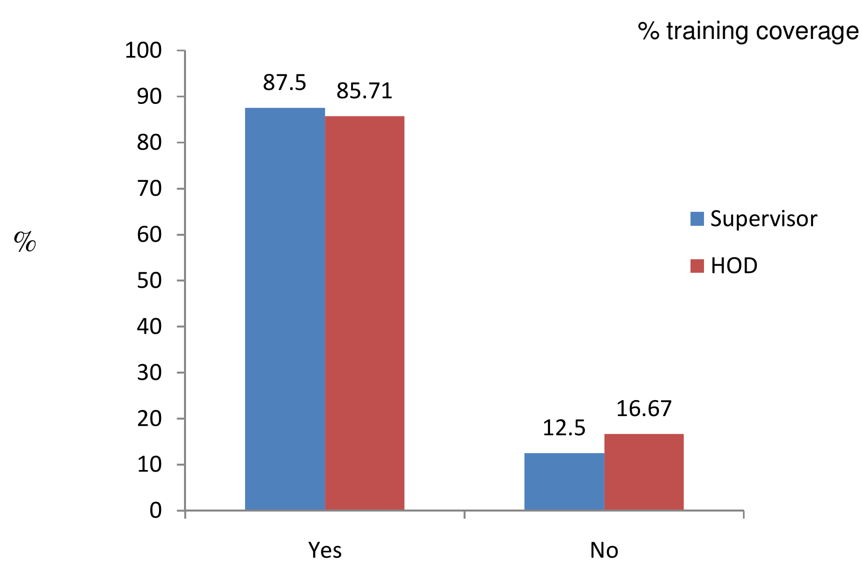



**Figure 5.13: Response to question (c)**

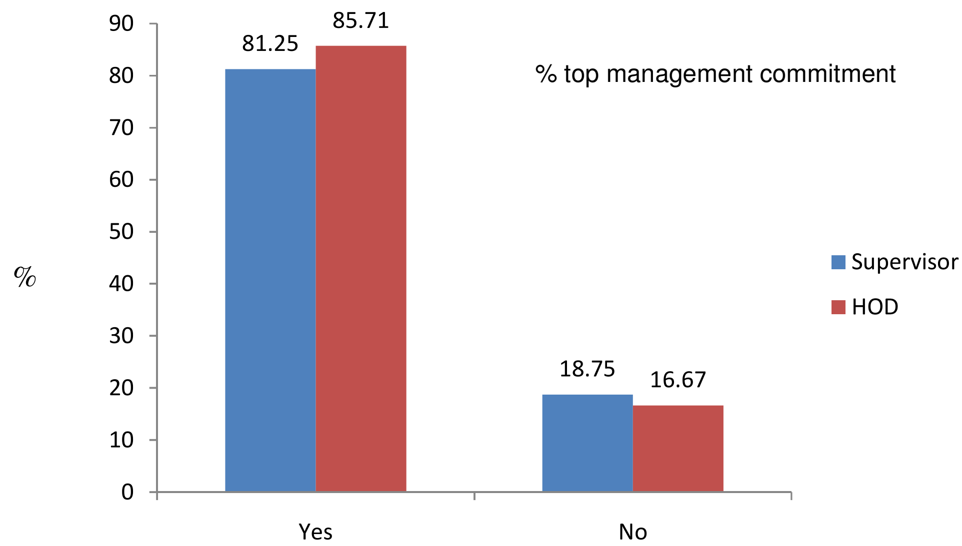



**Fig 5.14: Response to question (d)**

### 5.3.3 Observations and training design plan

As evident from the response of both workers and middle level management they were found to be satisfied with the top management commitment towards the safety training. However, from the survey of both categories it can be inferred that the training hours are not sufficient to the current department and the critical job. Therefore, observation based training plan can be prepared. Some of the recommendation for are as follows.

a. Safety training is very critical for spinning and after-treatment department as nearly 62% of all accidents at SFD occur in this department. This means that if training hours are increased exponential a better result can be expected.
b. Behavioral training is not given to the shop floor workers which should be introduced as revealed during the interviewing process.
c. Refresher training hours to be increased
d. Top management to work constantly to implement management of change i.e. change the process technology to eliminate unsafe conditions.
e. Department should have daily training session for their department so that maximum coverage is possible.
f. As revealed from the data analysis that the training hours reduces the mean accident rate, however this increase in training hours should be done only after proper forecasting.

## 5.4 Training design plan

As evident from the accidents and the forecasting method that more training hours will reduce the accidents, but under what category of training the hours to be increase can only known through the survey of the workers and middle level management which has been discussed before.

The training design plan was based on the exponential trend, so as to reduce the accidents exponentially rather than linearly which was found to be constant over a period of time. Therefore, the accident and training hours were plotted exponential to obtain a training function.

Thus, the calculation of the training function for total training and the other types of training was done by plotting the accidents and the training hours for each function yielded the following results as shown in Table 5.8.

where *x* represents the accidents, thus to make this accident zero, how much total training is required can be calculated by putting x=0

**Table 5.8: Training function for GIL**

| **Total training** | **Function** | **Training hours requirement (put *x* = 0 which represent zero accidents)** |
|---|---|---|
| $Y_{total\ training}$ | $975.3e^{0.040x}$ | 975 hours |
| $Y_{OJT}$ | $181e^{0.048x}$ | 181 hours |
| $Y_{WDP}$ | $211.6e^{0.060}$ | 211 hours |
| $Y_{VBT}$ | $54.43e^{0.012x}$ | 54.43 hours |
| $Y_{CT}$ | $237.8e^{0.034x}$ | 237.8 hours |
| $Y_{FAT}$ | $70.68e^{0.036x}$ | 70.68 hours |
| $Y_{ET}$ | $87.41e^{0.014x}$ | 87.41 hours |
| $Y_{EST}$ | $52.49e^{0.021x}$ | 52.49 hours |
| $Y_{PPE}$ | $48.69e^{0.024x}$ | 48.69 hours |
| $Y_{hazop}$ | $30.43e^{0.066x}$ | 30.43 hours |

The results show that when by substituting $x = 0$ i.e. zero accidents the result is less training hours, therefore it can be inferred that rather than simply increasing the training hours it is necessary to put in place priority based training function which can be prepared by taking in account the survey details.

**Table 5.9: Priority based training Program**

| Department | Assigned priority | Present training hours | Suggestion |
|---|---|---|---|
| Spinning and after-treatment | 1 | Data not available as it is clubbed together | Nearly 604 hours of training should be given to the workers of spinning amd after-treatment (975 hours is optimum hours and 62% accidents in spinning & after-treatment therefore 975×0.62 =604 hours) |
| Viscose | 2 | Data not available as it is clubbed together | Similarly calculations for viscose gives 975×0.188 = 183 hours |
| Auxiliary | 3 | Data not available as it is clubbed together | 975×0.11 = 107 hours |
| $CS_2$ & $H_2SO_4$ | 4 | Data not available as it is clubbed together | 975×0.077 = 75 hours |

The training hours should be distributed according to the survey analysis of shop floor workers of spinning and after-treatment in in which 41% says that OJT is the most critical training in their department. Therefore, the calculations are according to % of the response of each training type, for example 41% believe that OJT is the most critical training in their department therefore OJT training hours should be=0.41*604= 247 hours. Each year the number of training hours to be made productive rather than merely increasing the hours. That is optimum but effective training is needed for GIL

**Table 5.10: Training wise priority**

| Department | OJT | WDP | CT | VBT | Behavioral |
|---|---|---|---|---|---|
| Spinning and after-treatment, 604 hours | 247 hours | 168 hours | 115 hours | 26 hours | 39 hours |

The above training hours have been suggested based on survey carried for shop floor workers. Also, in the supervisor and HOD survey there was a suggestion to include department safety refresher training for 3 hours every week. That means 144 hours should be spent on refresher training which can include behavioral training, new employee training and management of change training The following suggestion are given for developing training and development pillar.

a. Trainers pool must be created to provide adequate technical and managerial training with respect to HAZOP, risk assessment, root cause analysis and mitigation strategies so that maximum employees and workers are covered.

b. Top management should encourage and provide impetus to the training module.

After the discussion and suggestions about safety training and development, the next pillar discussed is Hazard identification and risk assessment (HIRA), this pillar should also be meticulously built as past events suggest the vulnerabilities of the process industries for the disasters and first step to prevent such distasers rests on the HIRA pillar.

Morever, even from the SEM model the study has inferred that the path of implementation of OHSMS is as suggested, STD→TMC→HIRA which has the maximum correleation to OHSMS, TMC is always handeled and managed by the board of directors and therefore this pillar is very judgemental. Therefore, the focus should be on HIRA and an indpth analysis of HIRA with respect to GIL is discussed in the next section.

## 5.5 Hazard identification, risk assessment and consequence analysis

This is the central pillar for many process industries to conduct its safety program. A hazard means anything that results in injury or harm to the health of a person i.e. it can be activity or condition which poses threat of loss or harm. Risk can be defined as the probability of the hazardous situation resulting into an accident. Hazard identification can help correcting accident by providing proactive situations at every stage of a product's manufacturing cycle, from design to dispatch. There are number of ways to discover hazards in the workplace. Monitoring and data collection along with plant inspections, job safety analysis, are useful tools for hazard identification and control in process industry. Hazard identification and risk assessment are sometimes combined into a general category called hazard evaluation. The Fig 5.15 given below describes the normal procedure of HIRA. It can be performed at any stage during the initial design, it should be done as early as possible (Crowl and Louvar, 2002).

There are several hazards in the life cycle of the process. Therefore, there is a need to identify the critical equipment from the past experience, nature of the operation, and the material being handled. In the VSF process there are chances of explosion in the xanthator, leakage in the $CS_2$ plant, leakage in $CS_2$ recovery tank etc. A study has been undertaken to identify which are critical equipment at various department of GIL. The first step is to undertstand the material safety data sheet (MSDS) of $CS_2$ at all instances which is described in **Appendix F.**

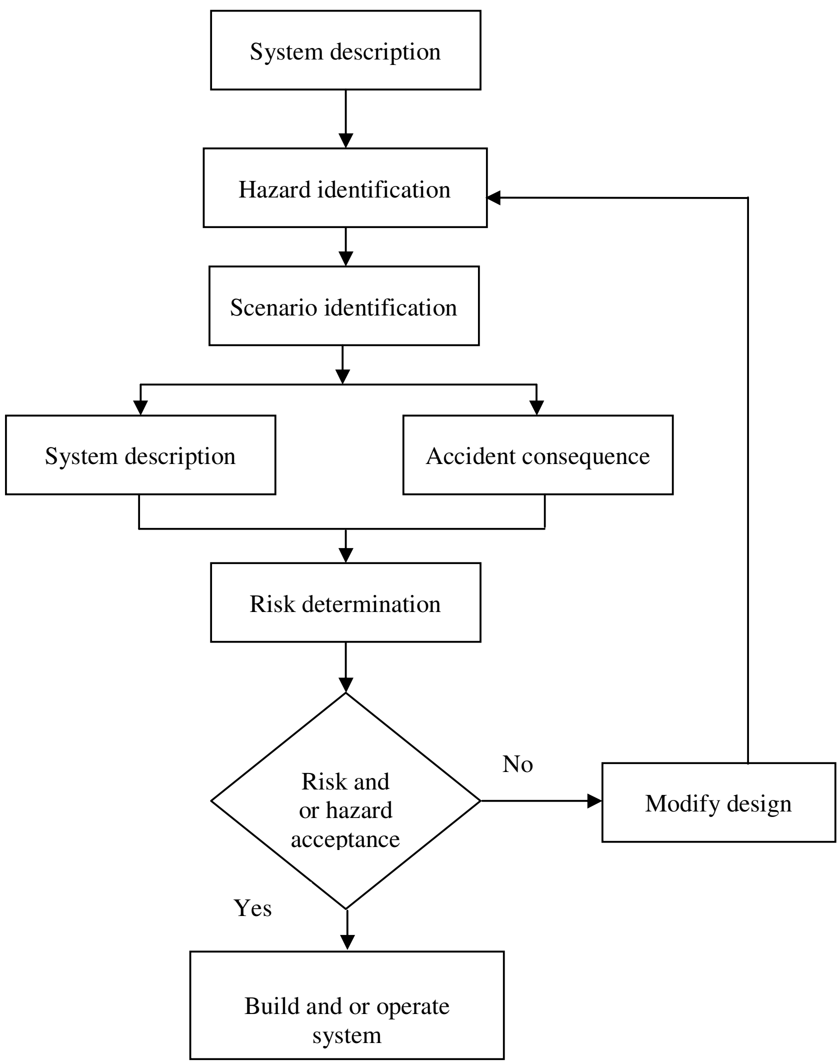



**Fig 5.15: Hazard identification and risk assessment procedure (Crowl, 2002)**

### 5.5.1 Critical equipments identification

A department wise study revealed the following equipment as critical and the reasoning for the same has been described below.

**a. Viscose department**

According to the operation and past incidents, xanthator is the critical equipment in this department. Here, the alkcell reacts with $CS_2$ vapor to produce sodium cellulose xanthate. The reaction is performed under vacuum to ensure vaporization of the $CS_2$ ($CS_2$ is a liquid at room temperature). Mass transfer rates hold the key to xanthation, as the reaction is heterogeneous. In this process wet churning of the xanthate is done. In this process the cellulose xanthate which is in the form of dry crumbs is dumped into the dissolver. In this operation little $CS_2$ will come out in the atmosphere at any time of xanthate dumping, But, it is very essential to have a powerful exhaust in the churn room. Caustic soda is added to the xanthate in xanthator and the liquid solution is fed to the dissolver. This eliminates the possibility of open dumping.

**b. Spinning department**

In the spinning department the viscose solution reacts with the spin bath to regenerate the cellulose in fiber form. Therefore, environmental norms suggest recovering of $CS_2$ and $H_2S$ vapors. Also, this will have an economic benefit for the process. The key to achieving an efficient level of recovery is to establish as high as concentration of $CS_2$ in the waste air stream as possible. $CS_2$ is highly inflammable with a wide explosive range (1.3%-50%) and hence any streams falling in this range must be made inert by replacing air with steam or nitrogen as the ventilation gas. Therefore, $CS_2$ recovery section is critical for the spinning process.

Condensation is used to recover $CS_2$ from the more concentrated process exhaust gases. However, condensation is insensitive to $H_2S$ recovery therefore it is commonly scrubbed using NaOH solution. Now, it is suggested that adsorption to be used in place of absorption to increase the recovery efficiency.

**c. $CS_2$/Acid department**

$CS_2$ is produced by the reaction of molten sulphur and charcoal in the $CS_2$ arc furnace.Electric current of about 2500 Ampere is maintained and temperature of 900ºC is maintained inside the furnace. Safety measures and their strict follow-up is necessary to ensure safe working related to $CS_2$ furnace. The vapors from the furnace are condensed in a series of condensers by indirect heat exchange with ordinary cooling water and then with chilled water at 5ºC. Crude $CS_2$ received is refined in a series of distillation columns, condensed and stored under water. Thus, the $CS_2$ furnace and the $CS_2$ tanks in the refinery are the critical equipment and therefore needs meticulous hazard identification and control. After analyzing the critical equipment there is a need to suggest steps for control of these hazards and risks. The extensive application of these techniques is discussed in this chapter.

#### *5.5.1.1 Checklist approach*

Checklist represents the simplest method used for hazard identification. A checklist is a list of questions about plant, organization, operation, maintenance and other areas of concern to verify that various requirements have been fulfilled and nothing is neglected or overlooked. The main limitations of this methodology is that it takes a longer time to develop a checklist but it yields only qualitative results, with no insights into the system. It merely provides the status of each item in yes and no.The checklist approach has been applied to the critical equipment and is detailed in **Appendix G** as per the table shown below.

**Table 5.11: Checklist approach for critical equipment**

| Equipment | Refer (Appendix-G) | Comments |
|---|---|---|
| Xanthator | Table G.1.1 | Instructional and qualitative but useful operational for operators to check the various parameters. It is most widely used in GIL due to its simplicity. Its limitation being it does not identify the potential problems and risks |
| $CS_2$ furnaces | Table G.1.2 | |
| $CS_2$ condensers | Table G.1.3 | |
| $CS_2$ measuring vessel | Table G.1.4 | |
| $CS_2$ refinery | Table G.1.5 | |

### *5.5.1.2 HAZOP*

Various real life experiences indicate that HAZOP is the widely used tool for safety aspects The Hazard and operability studies is applied to all new designs, but hazard analysis should only be used selectively. Only the serious hazards need to be quantified. It is necessary to keep in mind that HAZOP and HAZAN are concerned with hazards; not with operating problems.HAZOP study includes streams which handle hazardous materials, process which handle high temperatures and pressures, places where toxic and inflammable materials are stored. The technique of HAZOP study aims at identifying hazardous situation and to arrive at agreeable options to rectify design deviations and anomalies.

**Table 5.12: HAZOP approach for critical equipment**

<table>
<tr><th>Equipment</th><th>Refer (Appendix-G)</th><th>Comments</th></tr>
<tr><td>Jacket water circulation of xanthator</td><td>Table G.2.1</td><td rowspan="5">Qualitative which covers technical aspects and is considered the most effective tool with respect to process conditions. It applicability is wide due to its ability to predict with ease the various devations in the process equipment and suggest effective control for it. The various control strategies for these critical equipment is given in the sheets. However, it is not used widely as they mostly rely on simple qualitative tools. Each of these HAZOP for critical equipment was carried out after extensive study and technical interviews with all the concerned</td></tr>
<tr><td>Hopper room</td><td>Table G.2.2</td></tr>
<tr><td>$CS_2$ measuring vessel</td><td>Table G.2.3</td></tr>
<tr><td>$CS_2$ storage tank in spinning area</td><td>Table G.2.4</td></tr>
<tr><td>$CS_2$ overflow tank</td><td>Table G.2.5</td></tr>
</table>

### *5.5.1.3 Dow index*

The Dow Fire and Explosion (F&EI) index was first issued by the renowned Dow Chemical Company in 1964 based upon the Factory Manuals. Its original purpose was to help in the selection of fire protection methods. The Dow guide applies only to process units, not to auxiliary units such as power generating stations, plant water systems, control rooms, laboratories etc. However it is applicable to tank farms, warehouses and to pilot plants. The Dow Guide is not applicable to explosives such as TNT, nitroglycerine, dynamite, and tetryl etc. since their handling and processing is a very specialized subject. The degree of Hazard determination is done by the procedure highlighted by Crowl and Louvar (2002).

The dow index was applied to the critical equipment and the degree of hazard was determined.

**Table 5.13: Guideline for degree of hazard (Dow index)**

| F and E index range | Degree of hazard |
|---|---|
| 1-60 | Light |
| 61-96 | Moderate |
| 97-127 | Intermediate |
| 128-158 | Heavy |
| 159-up | Severe |

The procedure discussed in **Appendix G** is applied to all the critical equipment of the process. The sheets contain the calculation of the degree of hazard from the Dow's guide. The Material factor for all the calculation is also taken from the Dow's guide which is shown in Table 5.13

**Table 5.14: Material factor for all the materials involved in the GIL process**

| Compound | MF | H, BTU/lb×10 | NFPA classification | | | Flash point | Boiling point |
|---|---|---|---|---|---|---|---|
| | | | NH | NF | NR | deg F | deg F |
| Ammonia | 4 | 8 | **3** | **1** | **0** | Gas | -28 |
| Carbon disulphide | 21 | 6.1 | **3** | **4** | **0** | -22 | 115 |
| Hydrogen disulphide | 21 | 6.5 | **4** | **4** | **0** | Gas | -76 |

**Table 5.15: Fire and explosion index calculation (Dow) for critical equipment of GIL**

| Equipment | Refer (Appendix-G) | Comments |
|---|---|---|
| Xanthator | Table G.4.1 | For xanthator the degree of hazard was found to be severe. For $CS_2$ storage tank, $CS_2$ refinery the degree of hazard was found to be severe and for $CS_2$ furnace it was found to be intermediate |
| $CS_2$ Storage tank | Table G.4.2 | |
| $CS_2$ Refinery | Table G.4.3 | |
| $CS_2$ furnace | Table G.4.4 | |

### *5.5.1.4 Failure mode effect analysis (FMEA)*

FMEA does not only rely on product design changes to overcome weaknesses in the process, but does take into consideration a product's design characteristics relative to the planned manufacturing to assure that, to the extent possible the product meets customer needs and also able to overcome unsafe practices in the process

**Table:5.16 FMEA for critical equipments of GIL**

| Equipment | Refer (Appendix-G) | Findings |
|---|---|---|
| Xanthator | Table G.4.1 | The RPN (risk priority number) of the equipment is calculated in the Appendix. RPN highlights the priority given to a particular failure of the equipment. The bottom valve of the xanthator has the highest RPN, therefore the first priority is bottom valave. Also, it is a predictive maintenance tool which will guide about the health status of the equipment. For example $CS_2$ furnace is hot surface equipment, thermal analysis will reveal the internal material structure of such equipment.Thus, a very important tool to take decision and actions |
| $CS_2$ furnaces | Table G.4.2 | |
| $CS_2$ refinery | Table G.4.3 | |

All the Hazard identification and risk assessment tools and techniques have been applied to the critical equipment. It has been observed that all the safety measures are being taken to avoid any incident/accident, but the risk level is somewhat high due to the handling of the hazardous chemical $CS_2$. This chemical can be completely be eliminated in the new-process developed in-house, this process is called as solvent spinning process wherein the solvent is recovered 99% and is relatively safer. All the HIRA tools should be reviewed once a year and modifications and actions to be taken based on the result.

HIRA will mitigate the disasters probability or risk at GIL. Thus, the outcomes of both the pillars will make OHSMS effective. One aspect also needs to be seen is what happens in case the disaster, what can be the consequence, what distance the gases will travel. Therefore, consequence modeling of the critical equipment was done, which is highlighted in the next section.It is one part of risk analysis technique.

### 5.5.2 Consequence analysis

Consequence analysis deals with the study of the physical effects of potential dangers associated with the hazardous chemicals, their storage and operation etc. The best way of understanding and quantifying the physical effects of any accidental release of any hazardous chemical from their normal containment is by means of mathematical modeling. The consequence modeling for different release incidents for Grasim Industries Ltd (GIL) has been done with the help of Pasquill-Gillford model (Crowl and Louvar, 2002).

Consequence analysis for any accidental release scenario depends on several factors viz., physical and chemical properties, inventory, storage temperature and pressure, meteorological and topographical conditions etc. For flammable materials, consequences on animals and structures are studied in terms of radiation and overpressures. Concentration and dose-response relationship are used to study the consequences of toxic chemicals. The physical impact of heat radiation, exposure time necessary to reach the threshold value, physical impact of overpressure due to explosion/blast wave, physical impact on concentration levels and atmospheric stability classes are shown in **Appendix-H** (H.1.1, H.1.2, H.1.3, H.1.4 H.1.5)

Consequence analysis are based on maximum loss scenarios arising from maximum credible accidents. A maximum credible accident (MCA) can be characterized as an accident with a maximum damage potential, which is believed to probable. Practically it is not possible to indicate exactly a level of probability that is believed to be credible.

Hence the selection of MCA is somewhat arbitrary. The selection of accident scenarios representative for an MCA analysis is done on the basis of engineering judgement and expertise in the field of risk analysis studies.

The following main hazardous chemicals at GIL have been considered for the consequence estimation of carbon disulphide

The MCA for $CS_2$ can be assumed as follows

- Catastrophic failure of one tank in storage area (inventory = 55 MT)
- Catastrophic failure of one tank in spinning unit 1 (inventory = 10 MT)
- Catastrophic failure of all tanks in spinning unit 2 (inventory = 17 MT)
- Rupture in $CS_2$ line (furnace to tank)
- Rupture in $CS_2$ line (tank to refinery)

#### *5.5.2.1 Description of the consequence scenarios*

The event description will identify the events that can lead the MCA

##### *a. $CS_2$ pool vaporization and formation of vapor cloud*

$CS_2$ is a flammable liquid and is stored under ambient temperature and pressure. If it is released from container in considerable amount, it forms a pool in the dyke area. The pool so formed vaporizes entrapping some liquid droplets and considerable amount of moisture and it forms a vapor cloud. Depending upon the meteorological and topographical conditions, the vapor cloud may travel to a considerable distance. While moving downwind, if the vapor cloud encounters any ignition source within the flammability range (1.3% to 50 % by volume of air), it can cause flash fire and explosion. If the $CS_2$ liquid pool exists and still in touch of the vapor cloud, the flash fire can ignite the whole mass of pool. However, in absence of any ignition source for a considerable period, the cloud may get diluted to such a level that the mixture of $CS_2$ and air is no longer in the flammability range.

##### *b. $CS_2$ liquid pool fire*

The pool formed after the spillage of $CS_2$ liquid causes a pool fire, if ignited. In the pool fire, it burns throughout the pool diameter and radiates intense heat, which can cause severe damage to the adjoining structures, especially the storage tanks, which are placed side adjacent to each other. In extreme case of direct contact of fire with other tanks for a longer period, the situation may lead to the formation of BLEVE (Boiling Liquid Expanding Vapor Explosion). The diameter, tilt and the physical impact of the pool fire depend upon the rate of evaporation of $CS_2$ from the pool and the prevailing meteorological conditions especially the wind direction and the wind speed.

***c. Jet fire***

Since $CS_2$ is stored under ambient pressure; the release from storage tanks does not have any chance of formation of jet fire. However, in case of inlet and outlet flow of $CS_2$, there is a water pressure of around 3 Kgf/cm$^2$. Hence in case of rupture of flow line, there is a chance of formation of jet fire. If the emerging jet is in touch with flashing cloud of $CS_2$, it can take the form of a jet flame. The shape, length and tilt that decides its physical impact in form of heat radiations greatly depends upon the release rate of $CS_2$ from the line, wind direction with respect to release point, wind velocity etc. The physical damages in case of such jet fires, is restricted within the plant boundary. However, if this jet flame has the direct impingement on the storage tanks of $CS_2$, it can cause BLEVE.

***d. Vapor cloud explosion (VCE)***

An unconfined (i.e., in open space) explosion is possible only when a large amount ($\geq$ 1MT) of $CS_2$ comes from a rupture of line/leak with large hole and accumulates in the open space as a cloud while moving along the wind. If the mixture of cloud and air is in the flammability range and some ignition source is available on its way, it ignites and subsequently releases the energy on the point of ignition in the form of a blast wave. The loss in case of VCE depends upon the mass involved in the explosion and the location of the center of explosion.

***e. Boiling liquid expanding vapor explosion (BLEVE)***

In general, BLEVE occurs due to direct overheating on the vapor portion of pressurized storage vessel and results in fireball. In case of $CS_2$, which is stored under ambient pressure with water overlying on it and water filled dyke below, there is no possibility of the occurrence of BLEVE. The extreme case of direct impingement of flame on a storage tank of $CS_2$ or the engulfment of that tank in the pool fire can cause failure of the containment of $CS_2$ due to overheating and can result in to the fireball.

***f. Dispersion of vapor cloud***

When a hazardous chemical escapes from its normal containment for some reason or other, it can lead to formation of a gas, vapor or two phase cloud depending on the storage and environmental conditions. Indirect cloud formation occurs through evaporating pools of liquid resting on the substrate. If the escaping fluid is flammable (say, $CS_2$) and an ignition source is present, various fire scenarios may occur. Combustion of vapor cloud may lead to shock waves also. If the source of ignition is not present, then the cloud gets diluted gradually.

***5.5.2.2 Representation of consequence results***

The probable vulnerable zones because of accidental releases will depend on various factors viz., the amount of quantity stored, storage temperature and pressure, atmospheric stability classes, wind speed and direction etc. For the present analysis, the average weather conditions of Nagda have been assumed. Prevailing atmospheric conditions at the time of accident largely controls the extent of vulnerable zones. Keeping this fact in mind, three different types of atmospheric conditions represented by Pasquill stability classes with varying surface wind speeds have been considered in the present analysis (**Table H.1.5**):

- Very stable (F class) atmosphere with low wind speed (1.5 m/s);
- Neutral (D class) atmosphere with wind speed of 4.0 m/s; and
- Very unstable atmosphere (A class) with wind speed of 3.0 m/s.

Here neutral class of atmosphere has been considered as the most representative case because it describes the conditions for the major parts of a day. Very stable and very unstable conditions are present only for a short duration in a particular time of a day.

The consequence results for carbon disulphide ($CS_2$) vapor cloud for various release scenarios are shown in Table 5.16. The table shows the maximum downwind distances of vapor cloud due to catastrophic rupture of storage tanks (main area and spinning units), rupture of liquid lines (from furnace to tank and tank to refinery). In the main storage area, release of liquid due to catastrophic rupture of one tank of $CS_2$ with capacity of 55 MT has been considered. It is seen from the table that a $CS_2$ vapor cloud with concentration level of $LC_{50}$ (1009 ppm) can be felt within the maximum downwind effect distance of 371 m from release point when a catastrophic rupture of $CS_2$ tank occurs with the release of 55 MT $CS_2$. This distance is for the very stable atmospheric condition (F class). It is 338 m and 253 m respectively from release point for stability classes of D and A. The vapor cloud with concentration of 500 ppm (IDLH) would reach to slightly higher distances for the respective stability classes.

In spinning units, there are two types of storage tanks with capacity of 10 MT and 7 MT. In PC-1 there are 7 tanks with total capacity of 70 MT. For catastrophic failure of a tank with inventory of 10 MT, the vapor cloud with concentration of 500 ppm would reach to a distance of 133 m from release point under neutral stability condition, and these distances are 261 m and 101 m respectively for very stable and very unstable conditions. The impact distances for vapor clouds with concentrations of $LC_{50}$ are also shown.

In case of rupture of line running from furnace to tank, an inventory of 1300 Kg (length: 150 m; diameter = 100 mm) and of line running from tank to refinery, an inventory of 325 Kg (length: 150 m; diameter = 50 mm) have been considered. The consequence distances corresponding to various stability classes are within 117 m from release point for LC50 and IDLH values.

Since $CS_2$ is a flammable liquid, the other major release scenarios besides the vapor cloud dispersion are various types of fire and explosion. Since the atmospheric stability conditions have little impact on the distances for various fire and explosion scenarios, only a representative class (D) of neutral atmosphere with wind speed of 4.0 m/s has been considered. It is seen from the Table 5.16 that there is no chance of occurrence of BLEVE under normal situation. Also the occurrence of jet fire is nil and only a maximum distance of 61 m from the pool will be associated with radiation level of 4.0 $Kw/m^2$ for line rupture scenarios. The impact distances of pool fire with various radiation levels are in the range of 53 m to 99 m from the pool for catastrophic rupture of tanks. In case of catastrophic rupture of tanks, the furthest extent of the flash fire is within 185 m from the ignition point of vapor cloud. This extent is the least in case of rupture of $CS_2$ line. Vapor cloud explosion overpressures with moderate impact are within the range of 60 m to 90 m from the point of explosion.

Thus, in the OHSMS case of GIL discussed in this chapter, safety training and development will take care or mitigate the unsafe acts of the workers and provide occupational discipline to protect them from hazards whereas HIRA and consequence analysis will mitigate disaster consequences and in case of consequences provide the appropriate emergency plan based on the representation of the consequence results. The other four pillars of OHSMS have been briefly described in **Appendix I**. Each pillar have been studied for existing practices and some improvement plans have been suggested. The focus of the thesis was limited to the two pillars discussed extensively in this chapter. The next chapter will summarize the conclusion and the contributions of the research work.

**Table 5.16 : Maximum downwind effect distances for various fire and explosion scenarios of carbon disulphide ($CS_2$) (based on a representative stability class D with wind speed of 4.0 $ms^{-1}$**

| S. No. | Scenarios | Maximum affected distances for various fire and explosion scenarios of carbon disulphide ($CS_2$) (in meter) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pool fire | | | Jet fire | | | BLEVE | Flash fire | Overpressures for vapour cloud explosion | | |
| | | For thermal radiation (in $Kw/m^2$) levels of | | | | | | | | | | |
| | | 4.0 | 12.5 | 37.5 | 4.0 | 12.5 | 37.5 | | | 0.0207 bar (g) | 0.1379 bar (g) | 0.2068 bar(g) |
| 1 | Catastrophic rupture of one tank (Inventory = 55 MT) | 99 | 68 | 47 | No | No | No | No | 185 | 207 | 90 | 81 |
| 2 | Catastrophic rupture of one tank (Inventory = 10 MT) | 53 | 37 | 26 | No | No | No | No | 67 | 94 | 62 | 59 |
| | Catastrophic Rupture of All Tanks (Inventory = 17 MT) | 83 | 56 | 40 | No | No | No | No | 96 | 139 | 73 | 68 |
| 3 | Line rupture: Furnace to tank: (Inventory = 1.3 MT, L = 150 m, D = 100 mm) | 87 | 59 | 42 | 61 | NR | NR | No | 64 | 97 | 62 | 59 |
| 4 | Line rupture: Tank to refinery: (Inventory = 325 Kg, L = 150 m, D = 50 mm) | 47 | 33 | 23 | 56 | NR | NR | No | 53 | 88 | 60 | 58 |

NR: Not rated

Chapter - 6

# Conclusions

The field of occupational health and safety management system (OHSMS) has gained significance over the last three decades due to its potential for reducing work related injuries and illnesses. The research choice of OHSMS, which itself is a very broad topic was done because of its wide applicability to organizations and society at large. The need of research was felt after observing that the rate of incidents and accident reoccur after a given time, which casts doubt about the existing framework of OHSMS present and its effectiveness.

OHSMS effectiveness has been developed and implemented by many major organizations, but studies of their implementation and effect have rarely been carried out. Research should be aimed to see how the intervention affects the OHSMS effectiveness. The best way is to incorporate theoretical constructs into the intervention itself and the kind of measurement tools that should be developed to assess the change in the constructs.

The present research work focused on studying the OHSMS practices of Indian process industries through observations, field trips and company's manual. The research question is how to develop the OHSMS framework for these industries. It was broadly done by analyzing OHSMS gaps from current practices, and methodology was designed to understand these gaps with statistical as well practical implications.

The stepwise methodogy consists of a survey instrument, the reason being it is the best way to capture the cross sectional studies and provide generalization to the research work as compared to other measurement metrics such as auditing techniques where a sense of biasness seems to creep in. Other measurement criteria for OHSMS were also discussed in Chapter 3, but it was found that such measurement criteria lack the real life implications and therefore the empirical investigation was found to deemed fit for the given research problem.

The industries chosen for the survey were the major hazard industries classified according to the national safety council of India (Company V, Company C, Company F and Company Z as discussed in Chapter 3). These industries have already their different policies and procedures for OHSMS but the repetitive incidents cast the doubts on the validity. Therefore, cross sectional studies of these employees was gauged to see how they perceive the OHSMS, so that design based on their thoughts and ideas can be empirically tested and validated through the empirical steps.

Initial survey and observation from 28 indepth interviews (Chapter 4) revealed that there are six elements of OHSMS which are critical to these industries. These elements are top management commitment, safety training and development, hazard identification and risk assessment, workplace environment analysis and health monitoring systems, occupational health and safety information systems, and audit and review. These elements are referred to as pillars which are useful for building OHSMS.

The constructs (questions) pertaining to these pillars were distributed among the population of these four industries and a response rate of 27.46% which was 309 total responses received. The sampling adequacy test was performed to see whether the sample size is adequate for analysis in SPSS, the KMO and the Bartlett's test of sphericity concluded that the sample size was adequate and significant. Therefore, the next part of the research was to extract the dominant factors using principal component analysis. Six factors were extracted using PCA and Scree plot criterion.

The next statistical check was to perform whether all these constructs for the pillars identified are consistent, reliable and valid. Therefore, reliability and validity tests were performed which found out that the internal consistency values of all pillars were in conformance of the norm and the cronbach's alpha values were much higher that 0.6, therefore it was concluded that the constructs are consistent with the pillars.

The construct validity, convergent validity and discriminant validity confirmed by checking the normed values for all the model fit parameters by running the AMOS program. The validity was found to be significant which can infer that the measurement parameters are valid and therefore there is a need to find the causal relationship between the pillars.

The causal relationship for the pillars was found by the ISM methodology, this methodology predicts what is the path for the pillars to develop OHSMS. The methodogy used is successful in supply chain method and was applied for the given research problem. The four clusters were found by using the driving power dependency diagram. The inference from the ISM structure is that The “STD and “WEHMS” are placed at the base of the hierarchy of structural framework (see Fig 4.6). This concludes that “STD” or equally “WEHMS” is the driver for successful adoption of the OHSMS practice in the process industries.

Many researchers use the literature model to validate the structure, but this research attempts to find it through ISM which caters to the practical significance for the same workplace rather than a different workplace which changes according to the number of variables (country, legislations, human tendency, demographics).

To test whether this structural model is significant, the model fit parameters were again comprehended. This was done by summing the scores of each construct in that particular pillars and then covarying the error variables to make the model fit better. The higher values of modification indices were removed to improve the model fit values, but major changes were not done for the sake of a good fit, as it may loose the practical significance which is the major objective of the research problem.

The hypothesis testing for this summed pillars was carried out and it was found that the hypothesis, design for the research problem was valid. Bivariate correlation using 2 tailed t-test was used to confirm the validity that the pillars positively develop OHSMS.

The structural path model was found to be valid and significant for major parameters (normed values). Thus, the structural model for OHSMS was found from the empirical investigations discussed above. Thus, the key to improving the framework is developing STD or WEHMS which is at the base of the structure . The reason for choosing STD with respect to WEHMS, as WEHMS is something difficult to gauge without extensive medical investigations and survey and more ever, the workers move from one location to another, so to know what chemicals and exposures are affecting them needs to monitor over 5-15 years which requires a exhaustive survey which is beyond the scope of the study.

Therefore, to consider the direct impact of these pillars on OHSMS, the path coefficient of top pillar HIRA to OHSMS was found out . And finally it was thought app that to develop a such OHSMS framework which will follow the path from STD to HIRA , as they have high degree of correlation with OHSMS.

After confirming the structural OHSMS framework for process industries through empirical investigations there was a strong case to use this design to a process industry. The base case study of GIL of OHSMS design was thought to be appropriate due to the repetitive nature of accidents occurring at GIL even though there is a presence of formal OHSMS . Therefore, based on the framework proposed for OHSMS it can be inferred to work on indepth analysis of two pillars i.e. Safety training and development (STD) and hazard identification and risk assessment (HIRA).

While analyzing STD and its relation to accidents (a measure of OHSMS effectiveness), the accident data and the corresponding training data for 7 years was collected (2004-2011) for various departments of GIL. Spinning and after-treatment was the most vulnerable department with respect to accidents. The present training component comprises of OJT (on the job training), WDP (workmen development program), VBT (video based training), FAT (first aid training), HAZOP (hazard and operability studies), ET( emergency training), PPE (personal protective training), EST (electrical safety training) and CT (contratctor training).

The hypothesis was checked for strong correlation of STD with accidents using 2-tailed t test which was found to be significant. It was inferred here that increasing the training hours reduces the accidents which is also evident from the data. However, after performing forecasting it was found that the accidents more or less remain constant and there is no decreasing trend after a certain period. Therefore, based on this forecasting data it was though to have a training function with each type of training. The training function was determined and the values of accidents were substituted to zero for each function, here it was found that without drastically increasing only the training hours the accidents won't be reduced, therefore it was appropriate to design a priority based training program. Based on the inputs of the shop floor workers and middle level management it was concluded that OJT hours to be more as compared to other training programs, this is practically significant due to the representation of real life phenomenon. Also, the priroty based training program concludes that the training should be more focused on spinning and after treatment department. The next pillar for analysis of OHSMS is HIRA. Various tools such as Checklists, HAZOP, DOW index and FMEA were applied to the critical equipment of VSF process. The critical equipment identification was done on the basis of the past historical events and the nature of hazardous chemical being handled by these equipment. It can be concluded that the tools should be used for analysis and troubleshooting of operational errors. After the risk analysis of the critical equipment, consequence analysis of the maximum credible scenarios was modeled using the Pasquill-Gifford model, for these the atmospheric conditions of GIL, Nagda, heat radiation levels and material properties were taken as input and the various distances from the events was calculated in the event of mishap.

Thus, the thesis contributes to develop the existing OHSMS framework and provide guidelines for the managers and top level management for their deliberation and improve the effectiveness of the present structure.

## 6.1 Major contributions

The major contribution of the research work is highlighted below

- Identification of gaps for OHSMS from standard requirements
- Identification of pillars for the OHSMS of process industries
- Empirical investigations of the pillars and confirmations of correlations between the pillars and the hypothesis validation
- Structural model development for OHSMS using ISM
- Path validation using structural equation modelling
- OHSMS effectiveness path of various pillars for process industries
- Indepth analysis of two pillars (STD and HIRA) for GIL case study
- Design of priority based training program
- Critical equipment identification for GIL
- Applied various hazard identification tools for the critical equipment to aid in rectifying the operational errors
- Generate maximum credible scenarios for carbon disulphide
- Modelling of this scenario for emergency preparedness

## 6.2 Limitations

The research work is mostly studied in 3-4 process industries and therefore the model is process industries centric and can't be universally adopted across all sectors of organizations.The reason being the dynamics of each and every varies according to location, demographics, management commitment. Also, the behavior aspects of the workers and its impact on accidents are not studied. Each pillar requires too much deliberation through meetings and conferences, therefore it should be discussed on national and international forums which is not allowed due to industrial restrictions. Also, consequence analysis for other compound which are equally hazardous as $CS_2$ such as $H_2S$ should also be modeled on the lines of $CS_2$.

## 6.3 Scope for future research

The future scope for research in OHSMS should include behavioral pattern analysis of workers and the psychological reasons behind accident and incidents, designing a safety culture wherein the workers take their ownership and responsibility to act and perform in the safe manner. Also, perform maximum credible consequence analysis for critical equipment of GIL and inculcate a information system network among the workers of GIL.

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# Appendix-A

## A.1- Company F (CFCL) EHS policy

The company has a well-defined safety and occupational health program conforming to OHSAS 18001:2007. The Company's integrated EHS Management System includes an onsite disaster management plan, mock-drills, safety audits and workshops, an onsite medical centre, health awareness programmes and regular health assessment of employees. A corporate EHS (Environment, Health and Safety) policy and a site EHS Policy provides the framework and guidelines for environment, health and safety. The company believes in building and maintaining excellent safety culture among its employees and contractor workforce. The aim is to prevent/ minimize all incidents and injuries, investigate all incidents including first aid injuries and near misses followed by implementation of 'Corrective and Preventive actions'. The Company ensures that all jobs are adequately supervised, using necessary 'Personnel Protective Equipment' and strictly follow safety precautions.

Fertilizer plants in India are classified as hazardous by the Government of India since they carry the risk of spillage/leakages of chemicals like naphtha, chlorine and ammonia. The company’s commitment to 'zero accidents' on account of spills of any hazardous material confirms that safety is an area of paramount importance for the Company. Over the years, it has been able to practically eliminate usage of naphtha except in emergency situations. It continuously reviews and upgrades its technologies and other safety measures to control accidental spills and ammonia leakages.

The Company has implemented the process safety management (PSM) system developed by Occupational Safety and Health Administration (OSHA), USA across its operations. Unlike USA, the PSM system is not mandatory in India but the Company has adopted it to focus on excellence through continual improvement of existing systems and employee involvement in safe operation of plants.

## A.2- Company Z (HZL) HSE policy

**a. Health**

The Company Z, constantly endeavor to provide a workplace free from occupational health risks and hygiene hazards. Occupational health experts are present across all mines and smelters for regular health check-ups of permanent and contractual employees. Specific examinations, like blood lead test, audiometric tests, spirometry test, ECG and chest X-rays are carried out regularly. Our internal system periodically monitors medical health of our workforce. During the year, 10,330 persons including contract workmen have undergone periodic medical examination. No occupational disease case has been reported in the recent years.

**b. Safety**

The Company believes that they can avoid fatalities, serious injuries or occupational illnesses and firmly consider that every accident is preventable. The company feels that primary health and safety goal will have zero harm to people. They are committed to providing safe work conditions and have effective management systems in place to ensure the well-being of permanent and contractual employees and others who may be affected by their operations. They believe that continual improvement in this aspect is essential for the Company's sustainable success.

**c. Environment**

The company's environment vision frames the commitment to be the world-class zinc and lead producer by developing technology to maximize metal extraction, operate responsibly with least footprint for water, carbon, land and hazardous wastes and caring for people and surrounding bio-diversity. The Company's environmental initiatives and performance have been discussed in detail under principal 6 of Business Responsibility Report, forming part of this annual report.

## A.3-Company C (GRCD) policy

**a. Safety**

At Company's C, excellence is not confined to high-quality products and services. The safety and health of their employees is also a top priority for the company. They understand the importance of providing a safe working environment for their team. They have a policy of promoting safe and healthy attitude at work, thereby effectively reducing the number of accidents, injuries and illnesses.

Taking cognizance of the safety aspect, the group has gone a step ahead of regulatory standards and entered into a strategic collaboration with DuPont to implement safety initiatives across all chemical units as well as the chlor-alkali and viscose filament yarn facilities in India.zero accidents and zero losses is their mantra.

## B.1- Principal component factor analysis

The prime applications of factor analysis techniques are to reduce the number of variables and to detect structure in the relationships between variables, i.e. to classify variables. Therefore, factor analysis is applied as a data reduction or structure detection method.

**Terminologies of factor analysis**

**a. Factor loadings, $L_i(j)$**

It is the matrix representing the correlation between different combinations of variables and factors. $L_i(j)$ is the factor loading of the variable j on the factor i ,where i = 1,2,3 ….. n and j =1,2,3,…..n .

**b. Communality, $h_i^2$**

It is the sum of squares of the factor loadings of the variable i on all factors

$$h_i^2 = \sum_{j=1}^{n} L^2{}_{ij}$$

**c. Eigen value**

It is the sum of squares of the factor loadings of all variables on a factor.

Eigen value of the factor

$$j = \sum_{i=1}^{n} L^2{}_{ij}$$

The sum of the eigen values of all factors (if no factor is dropped) is equal to the sum of the communalities of all variables

**d. Factor rotation**

Since the original loadings may not be readily interpretable, the usual practice is to rotate them until a 'simple structure' is achieved. A simple structure means that each variable has very high factor loadings (as high as 1) on one of the factors and very low factor loadings (as low as 0) on the other factors. The communalities of each variable before and after factor rotation will be the same

**e. Significant number of factors**

The main objective of factor analysis is to group the given set of input variables into minimal number of factors with the maximum capability of extracting information with the reduced set of factors. There are basically two criteria to determine the number of factors to be retained for future study

**f. Minimum Eigen value criterion**

If the eigen value (sum of squares of the factor loadings of all variables on a factor) of a factor is more than or equal to 1, then that factor is to be retained; otherwise, that factor is to be dropped.

**g. Scree plot criterion**

It is a plot of the eigen values of the factors by taking the factor number on X-axis and the eigen values on Y-axis. Then, identify the factor number at which the slope of the line connecting the points changes from steep to a gradual trailing off towards the right of the identified factor number. Such change in slope in the graph is known as ‘scree’ and the point is known as ‘scree point’. The factors which are marked up to the right of the scree point are to be dropped from the study

**h. Factor scores**

Though a factor is not visible like an original input variable, it is still a variable which can be used to find the scores for respondents. At the initial stage, the respondents assign scores for the variables. After performing factor analysis, each factor assigns a score for each respondent. Such scores are called ‘factor scores’. The expression to compute the factor score of a respondent by the factor k is shown below. By substituting the standardized values of the input variables assigned by a respondent in this expression, the factor score of that respondent can be obtained by the following equation

$$F_{k=}w_{1k}X_1 + w_{2k}X_2 + w_{3k}X_3 + \cdots \ldots . w_{nk}X_{n=}\sum_{i=1}^{n} w_{ik}X_i$$

where w is the weight of the input variable $X_i$ in the linear composite of factor , k for k=1,2,3, …n

## B.2- Steps of Principal component analysis

This method maximizes the sum of squares of loadings of each identified factor. This is a popular technique which determines loadings of variables on different factors by using the standard normal values of the observations of the original (input) variables. The steps of the principal components analysis are summarized as follows:

| | |
|---|---|
| Step 1 | In the original sets of observation $[a_{ij}]$ i=1,2,3 …….m and j=1,2,3,……n |
| Step 2 | Find the standardized sets of observations $[Z_{ij}]$ from $[a_{ij}]$ using the following formula<br>$$Z_{ij} = \frac{a_{ij} - \bar{X}}{\sigma_j}$$<br>i=1,2,3 …….m and j=1,2,3,……n<br>where $Z_{ij}$ is the standardized observation of the $i^{th}$ original observation under the variable j and $\sigma_j$ is the standard deviation of the original observations of the variable j |
| Step 3 | Determine the weights of the different linear composites of factors $[w_{ij}]$ such that the variance of the un standardized factor scores of the entire set of observations is maximal. These weights are nothing but directional cosines of the respective vectors |
| Step 4 | Find the unstandardized factor scores using the following formula<br>$$[f_{ij}]_{m\times n}=[z_{ij}]_{m\times n} \times [w_{ij}]_{m\times n}$$ |
| Step 5 | Find the loadings of the variables on the factors $L_{ij}$ is the correlation coefficient between the values in column **i** of matrix $Z_{ij}$ and that of column j of the matrix $[f_{ij}]$ for i = 1,2,3,…..n and j =1,2,3,…… n |

| | |
|---|---|
| Step 6 | Find the standardized factor scores using the following formula<br>$S_{ij}=\frac{f_{ij}-\overline{M}_{iJ}}{s_j}$   i = 1,2,3,…..n and j =1,2,3,…… n<br>where $S_{ij}$ is the standardized factor score of the i$^{th}$ set of observations on the factor j ,$\overline{M}$ is the mean of the un standardized factor scores of the factor j and $S_j$ is the standard deviation of the unstandardized factor scores of the factor j . |
| Step 7 | Find the prediction of the standardized original observations using the following formula<br>$\left[Z_{ij}\right]_{m\times n}=\left[S_{ij}\right]_{m\times n}\times\left[L_{ij}\right]_{m\times n}$ |
| Step 8 | Find the sum of squires of loadings of each column j<br>(principal component-j) /(factor- j ) which is known as eigen value of that column j . |
| Step 9 | Drop insignificant principal components which have eigen values less than 1.<br>Let the number of principal components retained be X |
| Step 10 | Perform the rotation of the retained principal components for better interpretation. The rotation can be done by ‘varimax rotation method |
| Step 11 | Assign each variable to the principal component (factor), with which it has the maximum absolute loading (irrespective of sign). |
| Step 12 | Find the sum of squares of loadings for each variable i (row i ). It is denoted by $h_i^2$ . Also, find the common variance, whose formula is given below:<br>Common variance = $\sum_{i=1}^{n}\boldsymbol{h_i}^{2}$ |
| Step 13 | For each retained principal component, k (k =1,2,3,K,X) , find the following and state inferences<br>Proportion of total variance of the principal component<br>$k=\frac{\text{Eigenvalue of principal component k}}{\text{Total variance}}$<br>where the total variance is equal to the number of variables, n . Also,<br>Proportion of common variance of the principal component<br>$k=\frac{\text{Eigenvalue of principal component k}}{\text{Common variance}}$ |

## B.3- Varimax method of factor rotation

Varimax rotation is the most popular form of factor rotation was developed by Kaiser (1958). For varimax a simple solution means that each factor has a small number of large loadings and a large number of zero (or small) loadings. This simplifies the interpretation because, after a varimax rotation, each original variable tends to be associated with one (or a small number) of factors, and each factor represents only a small number of variables. In addition, the factors can often be interpreted from the opposition of few variables with positive loadings to few variables with negative loading

**Steps of varimax method of factor rotation**

Formally varimax searches for a rotation (i.e., a linear combination) of the original factors such that the variance of the loadings is maximized, which a mounts to maximizing

$$v = -\frac{1}{p}\sum_{j=1}^{m}(\text{varianceof squares of (scaled) loadings for jth factor})$$

where p´x m is a matrix of estimated factor loadings obtained. The steps of varimax rotation method for two factors are presented below:

| | |
|---|---|
| Step 1 | Input the factor loading matrix. number of variables = n . number of principal components (factors) = 2 . Angle of rotation = q |
| Step 2 | Plot the factor loadings on a two-dimensional space, $F_1 – F_2$ plane, where $F_1$ and $F_2$ are factor 1 and factor 2 respectively. Let q be the angle between the nearest axis $F_1$ or $F_2$ and each vector of factor loadings. |
| Step 3 | Rotate the $F_1 – F_2$ plane by an angle such that the factor loadings are revised to have a simple structure. A simple structure means that each variable has very high factor loading (as high as 1) on one of the factors and very low factor loading (as low as 0) on other factors. Let the rotated plane be $F_1 – F_2$ |
| Step 4 | Set variable number i =1. |
| Step 5 | Let $a_i$ and $b_i$ be the factor loadings of the variable i on $F_1$ and $F_2$ respectively. Find the magnitude of the vector $C_i$ of the factor loadings of the variable i , using the following formula: $Ci \square\square( a_i^2 + b_i^2 )^{0.5}$ Let the angle of the vector of factor loadings with the nearest part (positive side and negative side) of $F_1$ axis be α |
| Step 6 | Find cos $\theta$ and treat it as the factor loading on the nearest axis ( $a_i$ if the nearest axis as explained in step-1 is $F_1$ axis, $b_i$ if the nearest axis is $F_2$ axis). Fix the sign of the revised loading depending on the side of the factor (plus for positive side and minus for negative side) |
| Step 7 | Find cos (90 - $\theta$ ) and treat it as the factor loading on the other axis ($b_i$ if the nearest axis as explained in step-1 is $F_1$ axis, $a_i$ if the nearest axis is $F_2$ axis). Fix the sign of the revised loading depending on the side of the factor (plus for positive side and minus for negative side) |
| Step 8 | i □□i □1 |
| Step 9 | If i < n , then go to step 5; or else go to step 10 |
| Step 10 | Print the revised factor loading matrix |
| Step 11 | Group variables into factors and make inferences |

## Confirmatory model results

**Table C.1: CMIN: The minimum discrepancy**

| Model | NPAR | CMIN | DF | P | CMIN/DF |
|---|---|---|---|---|---|
| Default model | 77 | 384.584 | 301 | 0.001 | 1.278 |
| Saturated model | 378 | 0.000 | 0 | | |
| Independence model | 27 | 5165.259 | 351 | 0.000 | 14.716 |

**Table C.2: Root mean square residual (RMR), goodness of fit (GFI)**

| Model | RMR | GFI | AGFI | PGFI |
|---|---|---|---|---|
| Default model | 0.025 | 0.917 | 0.896 | 0.730 |
| Saturated model | 0.000 | 1.000 | | |
| Independence model | 0.182 | 0.288 | 0.234 | 0.268 |

**Table C.3: Baseline comparisons**

| Model | NFI Delta1 | RFI rho1 | IFI Delta2 | TLI rho2 | CFI |
|---|---|---|---|---|---|
| Default model | 0.926 | 0.913 | 0.983 | 0.980 | 0.983 |
| Saturated model | 1.000 | | 1.000 | | 1.000 |
| Independence model | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table C.4: Parsimony-adjusted measures**

| Model | PRATIO | PNFI | PCFI |
|---|---|---|---|
| Default model | 0.858 | 0.794 | 0.843 |
| Saturated model | 0.000 | 0.000 | 0.000 |
| Independence model | 1.000 | 0.000 | 0.000 |

**Table C.6: Minimum discrepancy function (FMIN)**

| Model | FMIN | F0 | LO 90 | HI 90 |
|---|---|---|---|---|
| Default model | 1.249 | 0.271 | 0.121 | 0.448 |
| Saturated model | 0.000 | 0.000 | 0.000 | 0.000 |
| Independence model | 16.770 | 15.631 | 14.887 | 16.396 |

**Table C.7: RMSEA**

| Model | RMSEA | LO 90 | HI 90 | PCLOSE |
|---|---|---|---|---|
| Default model | 0.030 | 0.020 | 0.039 | 1.000 |
| Independence model | 0.211 | 0.206 | 0.216 | 0.000 |
| Independence model | 16.946 | 16.202 | 17.711 | 16.963 |

**Table C.8: Covariances: (Group number 1 - Default model)**

| | | | M.I. | Par Change |
|---|---|---|---|---|
| e25 | <--> | sad | 4.207 | -0.021 |
| e20 | <--> | OHMAS | 6.211 | 0.029 |
| e19 | <--> | e27 | 8.843 | -0.046 |
| e18 | <--> | HIRA | 4.642 | -0.034 |
| e17 | <--> | WEHMS | 4.330 | -0.028 |
| e16 | <--> | AUR | 5.017 | -0.034 |
| e15 | <--> | sad | 6.425 | -0.041 |
| e15 | <--> | HIRA | 5.584 | 0.056 |
| e15 | <--> | TMC | 11.624 | 0.062 |
| e14 | <--> | WEHMS | 4.285 | -0.028 |
| e13 | <--> | TMC | 6.890 | -0.042 |
| e12 | <--> | TMC | 4.564 | -0.037 |
| e12 | <--> | e15 | 4.137 | -0.043 |
| e12 | <--> | e13 | 7.017 | 0.050 |

| | | | M.I. | Par Change |
|---|---|---|---|---|
| e11 | <--> | e27 | 5.786 | -0.031 |
| e10 | <--> | OHMAS | 5.142 | -0.030 |
| e10 | <--> | e17 | 9.786 | -0.051 |
| e9 | <--> | e21 | 4.274 | -0.017 |
| e8 | <--> | e9 | 4.537 | -0.043 |
| e7 | <--> | e21 | 4.164 | -0.028 |
| e6 | <--> | e15 | 7.697 | 0.069 |
| e5 | <--> | e27 | 6.773 | -0.059 |
| e4 | <--> | e17 | 5.302 | 0.032 |
| e3 | <--> | AUR | 4.071 | 0.027 |
| e3 | <--> | sad | 9.057 | -0.041 |
| e3 | <--> | e27 | 4.248 | 0.032 |
| e3 | <--> | e26 | 5.301 | -0.024 |
| e3 | <--> | e13 | 8.158 | -0.046 |
| e2 | <--> | e17 | 7.303 | -0.044 |
| e2 | <--> | e15 | 6.613 | 0.045 |
| e2 | <--> | e12 | 5.171 | -0.039 |
| e1 | <--> | e4 | 8.637 | -0.042 |
| e1 | <--> | e3 | 6.081 | 0.043 |

**Table C.9: Standardized regression weights: (Group number 1 - Default model)**

| | | | Estimate |
|---|---|---|---|
| TMC1 | <--- | TMC | 0.718 |
| TMC2 | <--- | TMC | 0.876 |
| TMC3 | <--- | TMC | 0.829 |
| TMC4 | <--- | TMC | 0.876 |

| | | | **Estimate** |
|---|---|---|---|
| HIRA1 | <--- | HIRA | 0.706 |
| HIRA2 | <--- | HIRA | 0.731 |
| HIRA3 | <--- | HIRA | 0.682 |
| HIRA4 | <--- | HIRA | 0.685 |
| WEHMS1 | <--- | WEHMS | 0.750 |
| WEHMS2 | <--- | WEHMS | 0.693 |
| WEHMS3 | <--- | WEHMS | 0.750 |
| SAD1 | <--- | sad | 0.689 |
| SAD2 | <--- | sad | 0.843 |
| SAD3 | <--- | sad | 0.789 |
| SAD4 | <--- | sad | 0.729 |
| OHSIM1 | <--- | OHSIM | 0.794 |
| OHSIM2 | <--- | OHSIM | 0.815 |
| OHSIM3 | <--- | OHSIM | 0.886 |
| OHSIM4 | <--- | OHSIM | 0.852 |
| AUR1 | <--- | AUR | 0.810 |
| AUR2 | <--- | AUR | 0.946 |
| AUR3 | <--- | AUR | 0.825 |
| AUR4 | <--- | AUR | 0.847 |
| OHMAS1 | <--- | OHMAS | 0.661 |
| OHMAS2 | <--- | OHMAS | 0.872 |
| OHMAS3 | <--- | OHMAS | 0.912 |
| OHMAS4 | <--- | OHMAS | 0.697 |

**Table C.10: Covariances: (Group number 1 - Default model)**

| | | | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|---|---|
| TMC | <--> | HIRA | 0.148 | 0.031 | 4.825 | *** | par_21 |
| TMC | <--> | WEHMS | 0.147 | 0.023 | 6.449 | *** | par_22 |
| TMC | <--> | sad | 0.186 | 0.028 | 6.607 | *** | par_23 |
| TMC | <--> | OHSIM | 0.128 | 0.029 | 4.436 | *** | par_24 |
| TMC | <--> | AUR | 0.147 | 0.024 | 6.010 | *** | par_25 |
| TMC | <--> | OHMAS | -0.039 | 0.019 | -2.046 | 0.041 | par_26 |
| HIRA | <--> | WEHMS | 0.127 | 0.025 | 5.183 | *** | par_27 |
| HIRA | <--> | sad | 0.146 | 0.029 | 5.054 | *** | par_28 |
| HIRA | <--> | OHSIM | 0.158 | 0.034 | 4.605 | *** | par_29 |
| HIRA | <--> | AUR | 0.140 | 0.027 | 5.117 | *** | par_30 |
| HIRA | <--> | OHMAS | -0.022 | 0.022 | -1.007 | 0.314 | par_31 |
| WEHMS | <--> | sad | 0.125 | 0.021 | 6.034 | *** | par_32 |
| WEHMS | <--> | OHSIM | 0.093 | 0.022 | 4.154 | *** | par_33 |
| WEHMS | <--> | AUR | 0.137 | 0.020 | 6.785 | *** | par_34 |
| WEHMS | <--> | OHMAS | 0.010 | 0.015 | 0.653 | 0.514 | par_35 |
| Sad | <--> | OHSIM | 0.144 | 0.028 | 5.158 | *** | par_36 |
| Sad | <--> | AUR | 0.133 | 0.023 | 5.862 | *** | par_37 |
| Sad | <--> | OHMAS | -0.050 | 0.018 | -2.793 | 0.005 | par_38 |
| OHSIM | <--> | AUR | 0.133 | 0.026 | 5.096 | *** | par_39 |
| OHSIM | <--> | OHMAS | -0.104 | 0.024 | -4.416 | *** | par_40 |
| AUR | <--> | OHMAS | -0.002 | 0.016 | -0.112 | 0.911 | par_41 |
| e20 | <--> | e21 | -0.006 | 0.018 | -0.310 | 0.757 | par_42 |
| e22 | <--> | e23 | 0.077 | 0.018 | 4.347 | *** | par_43 |

**Table C.11: Correlations: (Group number 1 - Default model)**

| | | | Estimate |
|---|---|---|---|
| TMC | <--> | HIRA | 0.368 |
| TMC | <--> | WEHMS | 0.548 |
| TMC | <--> | sad | 0.568 |
| TMC | <--> | OHSIM | 0.304 |
| TMC | <--> | AUR | 0.445 |
| TMC | <--> | OHMAS | -0.131 |
| HIRA | <--> | WEHMS | 0.433 |
| HIRA | <--> | sad | 0.407 |
| HIRA | <--> | OHSIM | 0.341 |
| HIRA | <--> | AUR | 0.385 |
| HIRA | <--> | OHMAS | -0.068 |
| WEHMS | <--> | sad | 0.518 |
| WEHMS | <--> | OHSIM | 0.302 |
| WEHMS | <--> | AUR | 0.564 |
| WEHMS | <--> | OHMAS | 0.044 |
| Sad | <--> | OHSIM | 0.380 |
| Sad | <--> | AUR | 0.448 |
| Sad | <--> | OHMAS | -0.189 |
| OHSIM | <--> | AUR | 0.349 |
| OHSIM | <--> | OHMAS | -0.307 |
| AUR | <--> | OHMAS | -0.007 |
| e20 | <--> | e21 | -0.069 |
| e22 | <--> | e23 | 0.593 |

**Table C.12: Variances: (Group number 1 - Default model)**

| | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|
| TMC | .365 | .052 | 7.058 | *** | par_44 |
| HIRA | .440 | .069 | 6.392 | *** | par_45 |
| WEHMS | .197 | .028 | 6.915 | *** | par_46 |
| Sad | .293 | .045 | 6.520 | *** | par_47 |
| OHSIM | .488 | .060 | 8.128 | *** | par_48 |
| AUR | .298 | .039 | 7.551 | *** | par_49 |
| OHMAS | .238 | .038 | 6.294 | *** | par_50 |
| e1 | .343 | .031 | 11.124 | *** | par_51 |
| e2 | .172 | .021 | 8.259 | *** | par_52 |
| e3 | .209 | .022 | 9.698 | *** | par_53 |
| e4 | .124 | .015 | 8.281 | *** | par_54 |
| e5 | .443 | .047 | 9.399 | *** | par_55 |
| e6 | .380 | .043 | 8.933 | *** | par_56 |
| e7 | .475 | .049 | 9.782 | *** | par_57 |
| e8 | .530 | .054 | 9.730 | *** | par_58 |
| e9 | .153 | .018 | 8.544 | *** | par_59 |
| e10 | .199 | .021 | 9.668 | *** | par_60 |
| e11 | .135 | .016 | 8.546 | *** | par_61 |
| e12 | .324 | .030 | 10.722 | *** | par_62 |
| e13 | .215 | .028 | 7.780 | *** | par_63 |
| e14 | .277 | .030 | 9.265 | *** | par_64 |
| e15 | .334 | .032 | 10.286 | *** | par_65 |
| e16 | .286 | .028 | 10.288 | *** | par_66 |
| e17 | .282 | .028 | 9.924 | *** | par_67 |
| e18 | .121 | .016 | 7.774 | *** | par_68 |

| | **Estimate** | **S.E.** | **C.R.** | **P** | **Label** |
|---|---|---|---|---|---|
| e19 | .200 | .022 | 9.053 | *** | par_69 |
| e20 | .156 | .023 | 6.752 | *** | par_70 |
| e21 | .043 | .019 | 2.214 | .027 | par_71 |
| e22 | .142 | .020 | 7.222 | *** | par_72 |
| e23 | .118 | .018 | 6.493 | *** | par_73 |
| e24 | .307 | .027 | 11.407 | *** | par_74 |
| e25 | .101 | .013 | 7.518 | *** | par_75 |
| e26 | .074 | .013 | 5.544 | *** | par_76 |
| e27 | .261 | .023 | 11.178 | *** | par_77 |

## Structural model fit results

**Table D.1: CMIN: The minimum discrepancy**

| Model | NPAR | CMIN | DF | P | CMIN/DF |
|---|---|---|---|---|---|
| Default model | 24 | 12.506 | 3 | 0.006 | 4.169 |
| Saturated model | 27 | 0.000 | 0 | | |
| Independence model | 6 | 370.030 | 21 | 0.000 | 17.620 |

**Table D.2: Baseline comparisons**

| Model | NFI Delta1 | RFI rho1 | IFI Delta2 | TLI rho2 | CFI |
|---|---|---|---|---|---|
| Default model | 0.966 | 0.763 | 0.974 | 0.809 | 0.973 |
| Saturated model | 1.000 | | 1.000 | | 1.000 |
| Independence model | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

**Table D.3:Parsimony-Adjusted Measures**

| Model | PRATIO | PNFI | PCFI |
|---|---|---|---|
| Default model | 0.143 | 0.138 | 0.139 |
| Saturated model | 0.000 | 0.000 | 0.000 |
| Independence model | 1.000 | 0.000 | 0.000 |

**Table D.4: Minimum discrepancy function (FMIN)**

| Model | FMIN | F0 | LO 90 | HI 90 |
|---|---|---|---|---|
| Default model | 0.041 | 0.031 | 0.007 | 0.081 |
| Saturated model | 0.000 | 0.000 | 0.000 | 0.000 |
| Independence model | 1.225 | 1.156 | 0.961 | 1.375 |

**Table D.5: Root mean square error of approximations (RMSEA)**

| Model | RMSEA | LO 90 | HI 90 | PCLOSE |
|---|---|---|---|---|
| Default model | 0.102 | 0.048 | 0.164 | 0.055 |
| Independence model | 0.235 | 0.214 | 0.256 | 0.000 |

**Table D.6: Regression Weights: (Group number 1 - Default model)**

| | | | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|---|---|
| TMC | <--- | SAD | 0.391 | 0.055 | 7.048 | *** | par_1 |
| OHSIM | <--- | SAD | 0.382 | 0.064 | 5.960 | *** | par_2 |
| AUR | <--- | SAD | 0.171 | 0.051 | 3.331 | *** | par_3 |
| AUR | <--- | WEHMS | 0.597 | 0.095 | 6.280 | *** | par_4 |
| TMC | <--- | WEHMS | 0.584 | 0.103 | 5.674 | *** | par_5 |
| HIRA | <--- | AUR | 0.238 | 0.077 | 3.090 | .002 | par_6 |
| HIRA | <--- | OHSIM | 0.231 | 0.057 | 4.047 | *** | par_7 |
| HIRA | <--- | TMC | 0.153 | 0.066 | 2.305 | .021 | par_8 |

**Table D.7: Intercepts: (Group number 1 - Default model)**

| | Estimate | S.E. | C.R. | P | Label |
|---|---|---|---|---|---|
| SAD | 11.696 | 0.171 | 68.367 | *** | par_13 |
| WEHMS | 11.875 | 0.092 | 129.589 | *** | par_14 |
| AUR | 6.932 | 1.018 | 6.812 | *** | par_16 |
| TMC | 2.815 | 1.100 | 2.558 | .011 | par_17 |
| OHSIM | 5.105 | 0.771 | 6.626 | *** | par_18 |
| HIRA | 3.059 | 1.233 | 2.480 | .013 | par_15 |

**Table D.8: Variances: (Group number 1 - Default model)**

| | **Estimate** | **S.E.** | **C.R.** | **P** | **Label** |
|---|---|---|---|---|---|
| e1 | 2.201 | 0.192 | 11.448 | *** | par_19 |
| e2 | 7.672 | 0.670 | 11.448 | *** | par_20 |
| e3 | 4.216 | 0.368 | 11.448 | *** | par_21 |
| e4 | 8.265 | 0.722 | 11.448 | *** | par_22 |
| e6 | 4.902 | 0.428 | 11.448 | *** | par_23 |
| e5 | 7.211 | 0.630 | 11.448 | *** | par_24 |

# Appendix-E

## Causewise analysis of accidents in various departments of GIL

**Table E.1: Cause wise analysis of accidents of viscose section (I &II combined) 2004-2011**

| Equipment/ Area | Summary of accidents (2004-2011) –unsafe act | | | | |
|---|---|---|---|---|---|
| | **Accidents** | **Injury** | **Category** | **Type** | **Cause** |
| Hopper room | 2 | Irritation (Eye) | minor | flying particles | unsafe Act |
| Slurry mixer-A side | 6 | Irritation (Eye) | minor | chemical contact | unsafe Act |
| Bale charging | 2 | Internal (leg) | minor | fall of object | unsafe Act |
| Ripening room | 10 | Internal (forehead) | minor | struck with | unsafe Act |
| Caustic tanks | 8 | Minor Cut (foot) | minor | chemical contact | unsafe Act |
| Slurry mixer-B side | 10 | Irritation (Eye) | minor | caught in between | unsafe Act |
| Refrigeration | 5 | Minor Cut (Eye) | minor | slip/fall | unsafe Act |
| | **43** | | | | |
| The no of accidents are different in both the viscose departments, but general causes with respect to unsafe act are same and therefore the data has been clubbed together | | | | | |

**Table E.2: Cause wise analysis of accidents of spinning section (I &II combined) 2004-2011**

| Equipment/ Area | summary of accidents (2004-2011) –unsafe act | | | | |
|---|---|---|---|---|---|
| | **Accidents** | **Injury** | **Category** | **Type** | **Cause** |
| Spinning machine | 43 | cuts (hand) | minor | sharp edge | unsafe Act |
| Jet room | 10 | leg/knee | minor | slip | unsafe Act |
| Tow cutting | 13 | minor cut(hand) | minor | sharp edge | unsafe Act |
| Godet side | 10 | minor cut(hand) | minor | sharp edge | unsafe Act |
| Trio roller | 4 | hand | major | caught in between | unsafe Act |
| Cutter area | 8 | minor Cut (hand) | minor | chemical contact | unsafe Act |
| Floor | 10 | leg | minor | caught in between | unsafe Act |
| | **98** | | | | |
| The no of accidents are different in both the departments, but general causes with respect to unsafe act are same and therefore the data has been clubbed together | | | | | |

**Table E.3: Cause wise analysis of accidents of after-treatment section (I &II combined) -2004-2011**

| **Equipment/ Area** | **summary of accidents (2004-2011) –unsafe act** | | | | |
|---|---|---|---|---|---|
| | **Accidents** | **Injury** | **Category** | **Type** | **Cause** |
| Baling Press-3 | 16 | Mainly palm, leg, foot,eye, wrist etc | minor | struck by & caught between | unsafe Act |
| Baling Press-9 | 14 | Mainly palm, leg, foot,eye, wrist etc | minor | struck by & caught between | unsafe Act |
| Baling Press-6 | 8 | Mainly palm, leg, foot,eye, wrist etc | minor | struck by & caught between | unsafe Act |
| Baling Press-4 | 4 | Mainly palm, leg, foot,eye, wrist etc | minor | struck by & caught between | unsafe Act |
| Baling Press-7 | 3 | Mainly palm, leg, foot,eye, wrist etc | minor | Struck by & caught between | unsafe Act |
| Baling Press-8 | 2 | Mainly palm, leg, foot,eye, wrist etc | minor | Struck by & caught between | unsafe Act |
| Dryers (all) | 12 | Finger, Foot etc | One accident major i.e. due to electric shock rest all were minor | Struck by & caught between | unsafe Act |
| | **59** | | | | |
| The no of accidents are different in both the departments, but general causes with respect to unsafe act are same and therefore the data has been clubbed | | | | | |

## F.1 Material safety data sheet-Carbon disulphide

| | | |
|---|---|---|
| 1 | **Chemical identity** | Carbon disulphide |
| | Chemical name | $CS_2$ |
| | | Hazchem code:3 WE |
| | | U.N.No: 1131 |
| 2 | **Physical/Chemical data** | |
| | Boiling point | $45^0$C |
| | Vapor density | 2.64 (Air = 1) |
| | Specific gravity | 1.26 at 20°C (liq.) (Water = 1) |
| | Odour | Rotten Eggs to Sweet odour |
| 3 | **Fire/Explosion data** | |
| | Explosive limits | 1.3% to 50% |
| | Flash point | $-30^0$C |
| | Auto ignition Temperature | $125^0$C |
| 4 | **Health hazard data** | |
| | Effects of exposure/symptoms | Mild irritation of eyes and skin |
| | Emergency treatment | Inhalation - Shift the victim from exposure to fresh air immediately and then arrange |
| | | Skin - Remove the contaminated clothing and shoes and wash the affected area |
| | | Ingestion - Induce vomiting and arrange medical treatment. |
| | TLV | 10 ppm |
| 5 | **Preventive measures** | |
| | Personal protective equipment | Avoid contact with liquid or vapors. |
| | | Do not eat or drink at work place. |

| | | |
|---|---|---|
| | | Use safety goggle / face shield, PVC hand Gloves, gas mask, breathing apparatus, |
| | | Clothing and helmet while working. |
| | Handling and storage precautions | Store under water and keep away from direct heat. |
| | | Container should be earthed properly |
| 6 | **Emergency/First aid measures** | Fire Extinguishing media - Dry chemical powder, fog, water spray, $CO_2$ and foam |
| | | Special Procedure - Keep the containers cool by spraying water if exposed to fire |
| | | First aid measures - Eyes - Immediately wash with plenty of water for 15 Minutes |
| | | Skin - Remove the soaked clothes and shoes. Wash the affected area with plenty of water and soap |
| | | Inhalation - Shift to fresh air and get medical help |
| | | Steps to be taken - Shut off leaks without risk. Contain the leakage on sand or earth. |
| | | Knock down the vapors with water spray. Do not allow liquid to enter sewer. |
| 7 | **Additional Information** | A dangerous fire hazard, when exposed to heat, flame, sparks friction or oxidising materials. Due to its low flash point and high specific gravity, $CS_2$ should be stored. Severe explosion hazard when exposed to heat or flame |

## Hazard identification and risk assessment

**Table G.1.1: Check-list for xanthator**

| S.No | Check Points |
|---|---|
| 1 | Physical condition of xanthator |
| 2 | Condition of fire Door |
| 3 | Tag mentioning entry of prohibition for un-authorized persons |
| 4 | Display of safe operating procedure |
| 5 | Emergency control procedure is displayed |
| 6 | Earthing of xantator and motor |
| 7 | Display of caution boards "No Smoking" , "No Mobile Usage”,” No other ignition source” in the xanthator room |
| 8 | Painting |
| 9 | Lagging of $CS_2$ lines and xantator |
| 10 | Support for line |
| 11 | Provision of jumper or flange on $CS_2$ lines |
| 12 | Color code of pipelines and measuring vessels |
| 13 | Condition of ladders |
| 14 | Condition of platforms |
| 15 | Hydrant system and sparger system |
| 16 | Fire extinguishers |
| 17 | Availability of breathing apparatus and canister gas mask |
| 18 | Condition of flame proof lighting |
| 19 | Level of illumination |
| 20 | Ventilation of xanthator room |
| 21 | Condition of $CS_2$ supply tripping switch |
| 22 | Condition of fire alarm |
| 23 | Condition of emergency trip switch |
| 24 | Condition of overflow alarm |
| 25 | Condition of measuring vessel and tube |
| 26 | Condition of rupture disc |
| 27 | Condition of castle lock provided between $CS_2$ addition & vacuum valve |
| 28 | Condition of main $CS_2$ isolating valve/$CS_2$ strainers |

**Table G.1.2: Check-List for $CS_2$ furnaces**

| S.No | Check Points |
|---|---|
| 1 | Physical condition of $CS_2$ furnace |
| 2 | Condition of furnace lining |
| 3 | Condition of furnace temperature measuring device |
| 4 | Condition of electrodes |
| 5 | Ensure all instruments are in good working condition |
| 6 | Condition of safety valves, asbestos discs and safety pipes |
| 7 | Condition of steam valves |
| 8 | Condition of decanter coil |
| 9 | Condition of decanter filling valve |
| 10 | Condition of traps |
| 11 | Condition of sulphur transfer pump |
| 12 | Movement of float valve |
| 13 | Condition of steam line |
| 14 | Lagging of steam line |
| 15 | Ensure poking plug is clear |
| 16 | Condition of charging vessel |
| 17 | Condition of lifting device |
| 18 | Condition of charging lid and cone of charging box |
| 19 | Availability of water on each floor |
| 20 | Availability of canister gas mask and breathing apparatus set |
| 21 | Condition of escape route |
| 22 | Condition of sight glass of measuring vessel |
| 23 | Condition of drain valve of measuring vessel |
| 24 | Condition of overflow valve of measuring vessel |
| 25 | $CS_2$ line gradient |
| 26 | Condition of return pot strainer |

**Table G.1.3: Check-list for $CS_2$ condensers**

| S.No | Check Points |
|---|---|
| 1 | Physical condition of $CS_2$ recovery trough |
| 2 | Water level in $CS_2$ recovery trough |
| 3 | Water sealing at man-hole of $CS_2$ recovery trough |
| 4 | Low pressure curtain for vapor before outer baffle in recovery Trough |
| 5 | Steam pressure/Flow in $CS_2$ recovery Trough |
| 6 | Condition of flexible steam pipe |
| 7 | Mat formation |
| 8 | Condition of OFF-TAKE pipe |
| 9 | Condition of reflux pipe |
| 10 | Condition of scrubber plate |
| 11 | Flow of water in scrubber |
| 12 | Scrubber outlet temperature |
| 13 | Soft water inlet pressure |
| 14 | 1st Condenser outlet temperature |
| 15 | Bend temperature |
| 16 | Brine/Chilled water inlet pressure |
| 17 | Brine/Chilled water inlet temperature |
| 18 | Brine/Chilled water outlet temperature |
| 19 | Vent temperature |
| 20 | Separator water overflow |
| 21 | Condition of $CS_2$ line |
| 22 | Condition of ladder |
| 23 | Condition of failing |
| 24 | Availability of fire extinguishers |
| 25 | Availability of water and hose reel |
| 26 | Display of caution board regarding "No Smoking" And "No Source of Ignition |
| 27 | Lagging of Brine/Chilled water line |
| 28 | Condition of Control valve |
| 29 | Flame proof lighting provided |

**Table G.1.4: Check-list for measuring vessels**

| S.No | Check Points |
|---|---|
| 1 | Condition of $CS_2$ lines |
| 2 | Lagging of $CS_2$ lines |
| 3 | Provision of jumper on flange |
| 4 | Color code |
| 5 | Line gradient |
| 6 | Tripping switch condition |
| 7 | Condition of main $CS_2$ valve |
| 8 | Physical condition of measuring vessel |
| 9 | Painting |
| 10 | Identification of number painted |
| 11 | Support of measuring vessel |
| 12 | Firefighting arrangement |
| 13 | Level tube is clearly visible |
| 14 | Condition of measuring vessel's inlet valve |
| 15 | Ensure that the level does not increase after closing Inlet valve |
| 16 | Condition of measuring Vessel's outlet valve |
| 17 | Condition of $CS_2$ addition Valve |
| 18 | Ensure that no addition after closing outlet and addition Valve |
| 19 | Condition of locking system |
| 20 | Condition of platform |
| 21 | Display of safe operating procedure |
| 22 | Display of instructions to control emergency |
| 23 | Display of caution board regarding "No Smoking" and "No Other source of Ignition" |
| 24 | Availability of breathing apparatus set and canister gas mask |

**Table G.1.5: Check-list approach for $CS_2$ refinery**

| S.No | Check Points |
|---|---|
| 1 | Physical Condition of $CS_2$ refinery |
| 2 | Condition of $CS_2$ lines |
| 3 | Lagging of $CS_2$ lines |
| 4 | Provision of jumper or flange on $CS_2$ lines |
| 5 | Color code |
| 6 | Painting |
| 7 | $CS_2$ line gradient |
| 8 | Condition of $CS_2$ valves |
| 9 | Condition of sight glass |
| 10 | External condition of distillation column |
| 11 | Lagging of steam lines |
| 12 | Condition of steam traps |
| 13 | Chilled water inlet temperature |
| 14 | Chilled water outlet temperature |
| 15 | Chilled water inlet pressure |
| 16 | Chilled water outlet pressure |
| 17 | Condition of platform |
| 18 | Condition of railing |
| 19 | Display of safe operating procedure |
| 20 | Display of instructions to control emergency |
| 21 | Display of caution board regarding"No Smoking" And "No source |
| | of ignition" |
| 22 | Availability of breathing apparatus set and canister gas mask |

## Table G.2.1: HAZOP of jacket water circulation in xanthator

**Department: Viscose**

**Section: Xanthator** **Sub section: Jacket water circulation**

| S.No. | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| **1** | **None** | No flow of circulation water | a. Circulation pump tripped<br>b. Controller fail<br>c. Major leakage of line | Reaction temperature rises | Explosion may occur | a. Hooter to be provided for low pressure of pump<br>b. Watch flow of circulating water<br>c. Change weak old lines/ jackets timely |
| | | | | | | |
| **2** | **More** | Excess flow of circulation water | a. Controller fail | Reaction time will increase | None | a. Controller to be calibrated timely |
| | | | | | | |
| **3** | **Less** | Less flow of circulation water | a. Circulation pump tripped<br>b. Controller fail<br>c. Major Leakage of line | Reaction temperature rises | Explosion may occur | a. Hooter to be provided for low pressure of pump<br>b. Watch flow of circulating water<br>c. Change weak old lines/ jackets timely<br>d. Jacket and line cleaning as per schedule |
| | | | | | | |
| **4** | **As well as** | $NH_3$ may mix with circulating water | a. By chilled water supply | a. Irritation of Eyes of operator<br>b. $NH_3$ smell can cause giddiness | Contact may cause little burn | a. At initial stage it can be be controlled by purging the inerts |
| **5** | **Part of** | Chilled water supply stopped | a. Problem from refrigeration section | Reaction Temperature rises | Explosion may occur | a. Temperature rise therefore, hooter to be provided<br>b. Monitor temperature during reaction<br>c. Temperature controller to be provided |

## Table G.2.2: HAZOP of Hopper room

**Department: Viscose**

**Section: Hopper room** **Sub Section: $CS_2$ air vent header**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| 1 | **None** | No flow of $CS_2$ | Not applicable | None | None | Not applicable |
| | | | | | | |
| 2 | **More** | More flow of $CS_2$ | a. Measuring vessel (MV) inlet open for more time<br>b. $CS_2$ inlet valve leakage<br>c. MV level tube chocked<br>d. $CS_2$ may come from other MV through air vent<br>e. Diameter of sensor overflow line is 1" but diameter of main line is 2” | a. $CS_2$ may go to other MV connected to header with air vent<br>b. May come out from header air vent and exposed at terrace in case of header outlet valve choking<br>c. May go to storage tank at spinning section department through overflow tank<br>d. May go to other vessel if $CS_2$ | Fire/Explosion in case of ignition | a. Auto tripping of $CS_2$ valve when level rises beyond limit in the MV<br>b. $CS_2$ intake into MV through metered inlet valve<br>c. Regular checking of $CS_2$ MV inlet valve<br>d. Level tube quality/maintenance<br>e. Head of air vent line to be increased to avoid overflow<br>f. Increase diameter of $CS_2$ overflow line from 2 inch to 3inch<br>g. Parallel line to be provided in the mainline to overflow sensor so during overflow$CS_2$ will flow through sensor |
| | | | | | | |
| 3 | **Other than** | Failure of $CS_2$ line | a. Gasket failure | Spillage on floor | Fire/Explosion in case of ignition | a. Temperature rise up hooter to be provided<br>b. Monitor Temp during reaction<br>c. Temp controller to be provided |

## Table G.2.3: HAZOP of $CS_2$ measuring vessels

**Department: Viscose** **Section: Xanthation** **Sub Section: $CS_2$ Measuring Vessels**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| **1** | **None** | No flow of $CS_2$ | a. Inlet valve/main valve closed<br>b. No $CS_2$ supply from plant<br>c. $CS_2$ line ruptured or leaked | None | None | Not applicable |
| | | | | | | |
| **2** | **More** | More flow of $CS_2$ | a. Inlet valve open for more time<br>b. Internal leakage through valve<br>c. Level tube chocked<br>d. More deposition of carbon<br>e. Clamp failure | a. $CS_2$ may go to other MV connected to header with air vent<br>b. May come out from header air vent and exposed at terrace<br>c. $CS_2$ strainer may get clogged | Fire/Explosion in case of ignition | a. Auto tripping of $CS_2$ valve when level rises beyond limit in the MV<br>b. Leakage valve to be replaced<br>c. Maintenance of level tube<br>d. $CS_2$ intake into MV through metered valve<br>e. Periodical checking of $CS_2$ strainer |
| | | | | | | |
| **3** | **Less** | Less flow of $CS_2$ | a. Inlet valve throttled<br>b. Less Pressure in Line | a. None<br>b. Xanthation reaction will be slowed | None | Not applicable |
| | | | | | | |
| **4** | **As well as** | Water with $CS_2$ | a. Leakage in $CS_2$ outlet line above<br>b. $CS_2$ level in storage tank | Concentration of $CS_2$ will decrease thereby retarding the rate of reaction | None | Liquid chromatography should be used to check concentration |
| | | | | | | |
| **5** | **Part of** | Less $CS_2$ flow | Not applicable | None | None | Not applicable |
| | | | | | | |
| **6** | **Reverse** | Reverse flow | Not applicable | None | None | Not applicable |
| | | | | | | |
| **7** | **Other than** | Failure of $CS_2$ line/valve | Gasket failure | Spillage on floor | Fire/explosion in case of ignition | a. Periodical checking of all joint valves<br>b. Less no of joints in the line |

## Table G.2.4: HAZOP of $CS_2$ storage tank in spinning area

**Department: Spinning**
**Section: $CS_2$ Storage** **Sub Section: $CS_2$ Storage tank**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| **1** | **None** | No flow of $CS_2$ | Inlet valve may be closed | Inlet line will get filled up and may result in back pressure in separator | None | Valves checking must form part of routine job |
| | | | | | | |
| **2** | **More** | More flow of $CS_2$ | a. MV inlet open for more time<br>b. $CS_2$ inlet valve leakage<br>c. MV level tube chocked<br>d. $CS_2$ may come from other MV through air vent<br>e. More $CS_2$ recovered from recovery trough | If tank cannot accommodate it will overflow | Direct exposure of $CS_2$ may cause unconsciousness | a. Care to be taken to see that the level do not go more than 180 cm<br>b. Check the sump below the tanks for any $CS_2$ collection periodically<br>c. Dyke should be filled with water, so that if any spillage is collected under water |
| | | | | | | |
| **3** | **Less** | Less flow of $CS_2$ | Not Applicable | None | None | Not Applicable |
| | | | | | | |
| **4** | **As well as** | Water with $CS_2$ | Flushing water of line | None | None | Not Applicable |
| | | | | | | |
| **5** | **Reverse** | Reverse flow | Misoperation | Creates back pressure | None | NRV should be provided |
| | | | | | | |
| **6** | **Other than** | Leakage from separator bottom joints | Gasket Failure<br>Welding joint operation | Spillage on Dyke | Fire/Explosion in case of ignition | Periodical checking of all joint valves |

## Table G.2.5 HAZOP for $CS_2$ overflow tank

**Department: Spinning**
**Section: $CS_2$ Storage** **Sub Section: $CS_2$ Separator**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| 1 | **None** | No flow of $CS_2$ | Not Applicable | None | None | Not Applicable |
| | | | | | | |
| 2 | **More** | More flow of $CS_2$ | a. MV inlet open for more time<br>b. Internal leakage through valve<br>c. MV level tube chocked<br>d. $CS_2$ may come from other MV through air vent | a. $CS_2$ may go to storage tank<br>b. $CS_2$ may come out from overflow from top | Fire/Explosion in case of ignition | Increase diameter of $CS_2$ overflow line from 2" to 3" |
| | | | | | | |
| 3 | **Less** | Less flow of $CS_2$ | Not applicable | None | None | Not applicable |
| | | | | | | |
| 4 | **As well as** | Water with $CS_2$ | Leakage in $CS_2$ outlet line above $CS_2$level | None | None | Not applicable |
| | | | | | | |
| 5 | **Part of** | Less $CS_2$ flow | Not applicable | None | None | Not applicable |
| | | | | | | |
| 6 | **Reverse** | Reverse flow | Misoperation | Creates back pressure | None | NRV should be provided |
| | | | | | | |
| 7 | **Other than** | Leakage from separator bottom line | Gasket failure<br>Welding joint operation | Spillage on dyke | Fire/Explosion in case of ignition | Periodical checking of all joint valves |

## Table G.2.6: HAZOP for $CS_2$ furnace

**Department: $CS_2$**
**Section: $CS_2$furnace** **Sub Section: Measuring vessel**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| 1 | **None** | No flow of $CS_2$ | a. Strainer Chocking<br>b. Major leakage of line | Chocking will create back pressure | Fire/explosion in case of ignition | a. check the lines and $CS_2$ flow regularly<br>b. clean strainer<br>c. change weak and old lines time to time |
| | | | | | | |
| 2 | **More** | More flow of $CS_2$ | Not applicable | None | None | Not applicable |
| | | | | | | |
| 3 | **Less** | Less flow of $CS_2$ | Not applicable | None | None | Not applicable |
| | | | | | | |
| 4 | **As well as** | Water with $CS_2$ | Flushing of condenser with water | corrosion | None | Proper monitoring of water ingress |
| | | | | | | |
| 5 | **Reverse** | Crude $CS_2$ pressed to furnace | Misoperation | Backpressure to furnaces and may result in safety flap burst | Fire in dryer | a. Sieve should be fabricated on the condensates<br>b. Procedure for startup to be followed and temperature to be controlled |

## Table G: 2.7: HAZOP for $CS_2$ refinery

**Department: $CS_2$**

**Section: $CS_2$ Refinery** **Sub Section: $H_2S$ loop**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| **1** | **None** | No flow of $H_2s$ | a. chocking in the system or in system ahead refinery.<br>b. No flow of $CS_2$<br>c. No vaporization due to no flow of steam.<br>d. chocking of condenser | a. Pressurization of the blocked segment.<br>b. Crude $CS_2$ may enter into condenser which may go to refined storage that may lead to overflow in case of human error.<br>c. The temperature of still increases that may lead to leakage.<br>d. Refining losses | Leakage | a. Flow control valves level indicators to be provided.<br>b. High level of $CS_2$ in still alarm to be provided. |
| | | | | | | |
| **2** | **More** | More flow of $CS_2$ | a. Poor quality of $CS_2$<br>b. Refining above set point | System pressurization may lead to lifting of gasholder | None | Gas holder high alarm tobe provided |
| | | | | | | |
| **3** | **Less** | Less flow of $CS_2$ | a. Less quantity of $H_2S$<br>b. Less refining.<br>c. Partial chocking | Same as in case of none | Leakage | Same as in case of none |

## Table G.2.8: HAZOP for $CS_2$ refinery

**Department: $CS_2$**
**Section: $CS_2$ Refinery** **Sub Section: $CS_2$Loop**
**Flow Parameter**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| **1** | **None** | No flow of $CS_2$ | a. Any of the line valve / strainers or equipments chock.<br>b. Block of return line of $CS_2$ after reflux condenser. | a. Refining affected<br>b. May lead to introduction of $CS_2$ in $H_2S$ loop | Leakage | Visual monitoring |
| | | | | | | |
| **2** | **More** | More flow of $CS_2$ | The failure of automation of level control alarms. | May lead to overflow in the refined tank or $CS_2$ may enter into gasholders | None | Additional high level alarm is provided in the still. |
| | | | | | | |
| **3** | **Less** | Less flow of $CS_2$ | a. Partial chocking.<br>b. Pressure raise or blockage in $H_2S$ loop | Possibility of pressurization | Leakage/Fire hazard | Flow meters<br>visual monitoring |
| | | | | | | |

## Table G.2.9: HAZOP for $CS_2$ storage area

**Department: $CS_2$**
**Section: $CS_2$ Furnace** **Sub Section: Measuring vessel**

| S.No | Guide Words | Deviation | Possible Causes | Consequences | Hazards | Recommendation |
|---|---|---|---|---|---|---|
| 1 | **None** | No flow of $CS_2$ | Inlet valve may not be opened | Back pressure to the furnace | Not applicable | Check valve regularly for proper running positioning |
| | | | | | | |
| 2 | **More** | More flow of $CS_2$ | All furnaces measuring vessels drained at one time | Tank will overflow if it is filled overcapacity | Exposure of $CS_2$ | a. Care to be taken to see that tank level do not go more than 210 cm<br>b. Checking dyke for any $CS_2$ trace<br>c. Provisioning of dyke with water to contain $CS_2$ in case of leakage |
| | | | | | | |
| 3 | **Less** | Less flow of $CS_2$ | Not Applicable | None | None | Not applicable |
| | | | | | | |
| 4 | **Other than** | a. $CS_2$ transfer of one tank to another<br>b. Sudden leakage of tank | a. Misoperation<br>b. Corrosion<br>c. Pressing water pressure increase | a. One of the tanks gets overflowed<br>b. $CS_2$ will go to dyke under the tank | Leakage | a. Dyke provision below storage tank.<br>b. Pressure test of $CS_2$ tank<br>c. Pressure relief valve in water pressure line |

## TABLE G.3.1: FMEA for xanthator

**Department : Viscose**
**Equipment :Simplex**
**Section : Hopper room and xanthator**
**Function: Xanthation of alkali cellulose**

| S.No | Component | Failure | | | Rating on 10 point scale | | | Risk Factor | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 1 | Bottom valve | Piston plate rustlings | Damages piston plates | Moisture in air | 6 | 5 | 6 | 180 | SS piston plates to be adopted in place of MS plate. Moisture separator to be installed | Maintenance | C.E. |
| | | Wearing and pitting of inner surface of cylinder | a. Damages piston seal<br>b. Air Bypassing<br>c. Poor operation of bottom valve | Moisture in air | 6 | 4 | 6 | 144 | SS 316 cylinder to be adopted in place of MS cylinder Moisture separator to be installed | Maintenance | |
| | | Pitting and rusting of shaft | a. Air seal damage.<br>b. malfunction-on of bottom valve | corrosion | 6 | 4 | 4 | 96 | SS 304 shaft to be adopted in place of MS plate | Maintenance | C.E. |
| | | Pitting and scratches on disc seat of bottom valve | a. Vacuum leakage<br>b. Stoppage of simplex | corrosion and foreign particle | 5 | 8 | 4 | 160 | Teflon seat to be fitted | Maintenance | C.E. |

## TABLE G.3.1: FMEA for xanthator (contd)

**Department: Viscose**
**Equipment: Simplex**
**Section: Hopper room and xanthator**
**Function: Xanthation of alkali cellulose**

| S.No. | Component | Failure | | | Rating on 10 point scale | | | Risk priority number | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 1 | Bottom Valve (contd) | Pitting and rusting of shaft | a. Air seal damage.<br>b. malfunction-on of bottom valve | corrosion | 6 | 4 | 4 | 96 | SS 304 shaft to be adopted in place of MS plate | Maintenance | C.E. |
| | | Pitting and scratches on disc seat of bottom valve | a. Vacuum leakage<br>b. Stoppage of simplex | corrosion and foreign particle | 5 | 8 | 4 | 160 | Teflon seat to be fitted | Maintenance | C.E. |

**C.E: Continuous exercise**

## TABLE G.3.1: FMEA for xanthator (contd)

**Department: Viscose**
**Equipment: Simplex**
**Section: Hopper room and xanthator**
**Function: Xanthation of alkali cellulose**

| S.No. | Component | Failure | | | Rating on 10 point scale | | | Risk priority number | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 2 | Two speed gear box | Oil seal damaged | a. Wastage of oi<br>b. Stoppage of simplex for 8 hrs | a. Misalignment<br>b. life of seal<br>c. low oil level | 6 | 8 | 3 | 144 | To be replaced as per life | Maintenance | C.E. |
| | | Bearings damages | Stoppages o simplex | i. Low oil level Improper replacement of oil | 2 | 9 | 6 | 108 | Roller bearing in place of ball bearing to be adopted | Maintenance | C.E. |
| | | Gears damaged | Stoppage o simplex | i. Low oil level<br>ii. Improper replacement of gears<br>ii. Life of gears | 1 | 9 | 7 | 63 | To be replaced as per life | Maintenance | C.E. |

**C.E: Continuous exercise**

## TABLE G.3.1: FMEA for xanthator (contd)

**Department: Viscose**
**Equipment: Simplex**
**Section: Hopper room and xanthator**
**Function: Xanthation of alkali cellulose**

| S.No. | Component | Failure | | | Rating on 10 point scale | | | Risk priority number | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 3 | Impeller | a. Shaft damage<br>b. Ribbon damage<br>c. Spoke damage<br>d. knife edge damage | Stoppage simplex | a. life acheived<br>b. foreign material<br>c. manufacturing defect<br>d. poor batch | 1 | 9 | 6 | 54 | a. To be replaced as per life<br>b. Regular checking of magnet<br>c. DP testing to be conducted half yearly<br>d. Modified impeller with extra reinforcement to be adopted | Maintenance | C.E. |
| | | Bearings damaged | | a. Low oil level<br>b. Improper replacement of oil | 2 | 9 | 6 | 108 | Roller bearing in place of ball bearing to be adopted | Maintenance | C.E. |
| | | Gears damaged | Stoppage o simplex | a. Low oil level<br>b. Improper replacement of gears<br>c. Life of gears | 1 | 9 | 7 | 63 | To be replaced as per life | Maintenance | C.E. |

**C.E: Continuous exercise**

## TABLE G.3.1: FMEA for xanthator (contd)

**Department: Viscose**
**Equipment: Simplex**
**Section: Hopper room and xanthator**
**Function: Xanthation of alkali cellulose**

| S.No. | Component | Failure | | | Rating on 10 point scale | | | Risk priority number | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 4 | Vacuum valve | Seat damage | a. Vacuum leakage<br>b. Stoppage of simplex | Life of seat achieved | 1 | 5 | 4 | 20 | To be replaced as per life | Maintenance | C.E. |
| 5 | Exhaust Valve | Seat damage | a. Vacuum leakage<br>b. Stoppage of simplex | Life of seat achieved | 1 | 5 | 4 | 20 | To be replaced as per life | Maintenance | C.E. |
| 6 | Rupture Disc | Crack in disc | a. Vacuum leakage<br>b. Stoppage of simplex | Life of seat achieved | 2 | 5 | 5 | 50 | To be replaced as per life | Maintenance | C.E. |
| 7 | Doors | Door packing damage | a. Vacuum leakage<br>b. Stoppage of simplex | Life of packing achieved | 4 | 5 | 5 | 100 | Periodic monitoring to be done | Maintenance | C.E. |
| 8 | Body | Gland packing damage | a. Vacuum leakage<br>b. Stoppage of simplex | Life of packing achieved | 3 | 5 | 5 | 75 | Periodic monitoring to be done | Maintenance | C.E. |

**C.E: Continuous exercise**

## TABLE G.3.2: FMEA for $CS_2$ FURNACE

**Department: $CS_2$**
**Equipment : $CS_2$ Furnace**
**Section: Furnace**
**Function: Reaction of Charcoal with molten Sulphur**

| S.No | Component | Failure | | | Rating on 10 point scale | | | Risk Factor | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mode | Effect | Cause | Frequency A | Severity B | Detection C | A*B*C | | | |
| 1 | Top Electrode | Break | High pressure release | Flow rate of charcoal | 2 | 10 | 10 | 200 | Install valves that check flowrates | Maintenance | C.E. |
| 2 | Refractory lining | Fusion | Shall become hot | wear or tear | 2 | 4 | 10 | 80 | Scheduled checking | Process Engineer | Monthly twice |
| 3 | Bottom Electrode | Break | None | None | 1 | 5 | 5 | 25 | Scheduled checking | Process Engineer | Monthly twice |
| 4 | Mild steel shell plates | Leakage | Sulphur will come and release | corrosion and thickness | 3 | 4 | 3 | 24 | None | None | None |

**C.E: Continuous exercise**

## TABLE G 3.3: FMEA for $CS_2$ REFINERY

**Department: $CS_2$**
**Equipment: $CS_2$ Storage tanks**
**Section: $CS_2$ Refinery**
**Function: to store $CS_2$ in liquid form and return to $CS_2$**

| S.No | Component | Failure | | | Rating on 10 point scale | | | Risk Factor | Corrective Action | Responsibility | Target Date |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cause | Mode | Effect | Frequency A | Severity B | Detection C | A*B*C | | | |
| 1 | Reflux line | Leakage | Spillage | a. Seal failure<br>b. High flow rate<br>c. Vacuum | 3 | 10 | 8 | 240 | Schedule checking | Process Engineer | C.E. |
| 2 | Crude $CS_2$ inlet valves | Leakage | Spillage and open to atmosphere | a. Erosion and corrosion<br>b. Joint failure<br>c. High pressure and cladding | 2 | 10 | 10 | 200 | Insert metallic blank using breathing apparatus in case of leakage | Maintenance | C.E. |
| 3 | Condensate line | Leakage | Spillage and open to atmosphere | Scaling | 2 | 10 | 5 | 100 | Schedule checking | Process Engineer | C.E. |
| 4 | Steam coils not operating | Scaling | Desired temperature is not obtained | a. Salts present in water<br>b. Deposition of solid particles | 1 | 5 | 5 | 25 | Preventive maintenance once a year Check water hardness | Chemical lab | C.E |

## Table G.4.1: DOW INDEX calculation for xanthator

| | | | |
|---|---|---|---|
| | **Material factor (from Dow manual)** | | **21** |
| | 1. General process hazards | Penalty factors range | Penalty factor for use |
| | Base factor | 1.00 | 1 |
| **A** | Exothermic chemical reaction | 0.30-1.25 | 0.5 |
| **B** | Endothermic process | 0.20-0.40 | |
| **C** | Material handling and transfer | 0.25-1.05 | 0.5 |
| **D** | Enclosed or indoor process units | 0.25-0.90 | |
| **1** | Access | 0.20 -0.35 | 0.3 |
| **F** | Drainage and spill control | 0.25-0.50 | 0.3 |
| | **General process hazards $F_1$** | | **2.6** |
| | **Special process hazards** | | |
| | **Base factor** | 1.00 | 1 |
| **A** | Toxic materials | 0.20 -0.80 | 0.5 |
| **B** | Sub-atmospheric pressure < 500 mm Hg | 0.5 | |
| **C** | Operation in or near flammable range inerted not inerted | | |
| **(i)** | Tanks farms storage flammable liquids | 0.5 | 0.2 |
| **(ii)** | Process upset or purge failure | 0.3 | 0.1 |
| **(iii)** | Always in flammable range | 0.8 | 0.3 |
| **D** | Dust explosion | 0.25-2.00 | 1.2 |
| **E** | Pressure operating pressure psig or kPa gauge | | |
| **F** | Low Temperature | 0.20-0.30 | |
| **G** | Quantity of Flammable/Unstable material quantity lb or kg | | |
| | Hc = Btu/lb or Kcal/kg | | |
| **(i)** | Liquids or gases in process | | 1.5 |
| **(ii)** | Liquids or gases in storage | | |
| **(iii)** | Combustible solids in storage , dust in process | | |
| **H** | Corrosion and erosion | 0.10-0.75 | 0.2 |
| **I** | Leakage -joints and packing | 0.10-1.50 | 0.1 |
| **J** | Use of fired equipment | | |
| **K** | Hot oil heat exchange system | 0.15 -1.15 | |
| **L** | Rotating equipment | 0.5 | 0 |
| | **Special process hazards $F_2$** | | **5.2** |
| | **Process unit hazard factor$F_3$= $F_1$*$F_2$** | | **13.52** |
| | **Fire and explosion Index F&EI=$F_3$*MF** | | **283.92** |
| The degree of Hazard is severe from Dow table so use of corrective actions is suggested to mitigate the risks. It includes preventive maintenance by monitoring corrosion and also using keeping all the process parameters within range | | | |

## Table G.4.2: DOW INDEX Calculation for $CS_2$ storage tank

| | | | |
|---|---|---|---|
| | **Material factor (from Dow manual)** | | **21** |
| | 1. General process hazards | Penalty Factors Range | Penalty factor for use |
| | Base factor | 1.00 | **1** |
| **A** | Exothermic chemical reaction | 0.30-1.25 | |
| **B** | Endothermic process | 0.20-0.40 | |
| **C** | Material handling and transfer | 0.25-1.05 | 0.3 |
| **D** | Enclosed or indoor process units | 0.25-0.90 | 0.25 |
| **1** | Access | 0.20 -0.35 | |
| **F** | Drainage and spill control | 0.25-0.50 | 0.2 |
| | **General process hazards $F_1$** | | **2.05** |
| | **Special process hazards** | | |
| | **Base factor** | 1.00 | 1 |
| **A** | Toxic materials | 0.20 -0.80 | 0.5 |
| **B** | Sub-atmospheric pressure < 500 mm Hg | 0.5 | |
| **C** | Operation in or near flammable range inerted not inerted | | |
| **(i)** | Tanks farms storage flammable liquids | 0.5 | 0.3 |
| **(ii)** | Process upset or purge failure | 0.3 | |
| **(iii)** | Always in flammable range | 0.8 | 0.3 |
| **D** | Dust explosion | 0.25-2.00 | 1 |
| **E** | Pressure operating pressure psig or kPa gauge | | |
| **F** | Low Temperature | 0.20-0.30 | |
| **G** | Quantity of Flammable/Unstable material quantity lb or kg | | |
| | Hc = Btu/lb or Kcal/kg | | |
| **(i)** | Liquids or gases in process | | |
| **(ii)** | Liquids or gases in storage | | 0.3 |
| **(iii)** | Combustible solids in storage , dust in process | | |
| **H** | Corrosion and erosion | 0.10-0.75 | 0.15 |
| **I** | Leakage -joints and packing | 0.10-1.50 | 0.1 |
| **J** | Use of fired equipment | | |
| **K** | Hot oil heat exchange system | 0.15 -1.15 | |
| **L** | Rotating equipment | 0.5 | |
| | **Special process hazards factor $F_2$** | | **3.65** |
| | **Process unit hazard factor $F_3 = F_1 * F_2$** | | **7.4825** |
| | **Fire and explosion Index F&EI=$F_3$*MF** | | **157.1325** |

The Degree of Hazard is intermediate from Dow table so use of corrective actions is suggested to mitigate the risk. This includes preventive maintenance and good housekeeping.

# Table G.4.3: L DOW INDEX Calculation for $CS_2$ refinery

| | | | |
|---|---|---|---|
| | **Material factor (from Dow manual)** | | **21** |
| | 1. General process hazards | Penalty factors Range | Penalty factor for use |
| | Base factor | 1.00 | 1 |
| **A** | Exothermic chemical reaction | 0.30-1.25 | |
| **B** | Endothermic process | 0.20-0.40 | |
| **C** | Material handling and transfer | 0.25-1.05 | 1 |
| **D** | Enclosed or indoor process Units | 0.25-0.90 | |
| **(i)** | Access | 0.20 -0.35 | |
| **F** | Drainage and spill control | 0.25-0.50 | 0.45 |
| | **General process hazards $F_1$** | | **2.45** |
| | **Special process hazards** | | |
| | **Base factor** | | |
| **A** | Toxic materials | 1.00 | 1 |
| **B** | Sub-atmospheric pressure < 500 mm Hg | 0.20 -0.80 | 0.5 |
| **C** | Operation in or near flammable range inerted not inerted | 0.5 | |
| **(i)** | Tanks farms storage flammable liquids | | |
| **(ii)** | Process upset or purge failure | 0.5 | 0.5 |
| **(iii)** | Always in flammable range | 0.3 | |
| **D** | Dust explosion | 0.8 | 0.6 |
| **E** | Pressure operating pressure psig or kPa gauge | 0.25-2.00 | 1 |
| **F** | Low Temperature | | |
| **G** | Quantity of Flammable/Unstable material quantity lb or kg | 0.20-0.30 | |
| | Hc =Btu/lb or Kcal/kg | | |
| **(i)** | Liquids or gases in process | | |
| **(ii)** | Liquids or gases in storage | | 1.6 |
| **(iii)** | Combustible solids in storage , dust in process | | 1 |
| **H** | Corrosion and erosion | 0.10-0.75 | 0.2 |
| **I** | Leakage -joints and packing | 0.10-1.50 | 0.5 |
| **J** | Use of fired equipment | | |
| **K** | Hot oil heat exchange system | 0.15 -1.15 | |
| **L** | Rotating equipment | 0.5 | |
| | **Special process hazards factor $F_2$** | | **6.9** |
| | **Process unit hazard factor $F_3$= $F_1$*$F_2$** | | **16.905** |
| | **Fire and explosion Index F&EI=$F_3$*MF** | | **355.005** |
| The Degree of hazard is severe from Dow table so use emergency handling tools, be alert to small changes and implement high safety standards. | | | |

**Table G.4.4: DOW INDEX calculation for $CS_2$ furnace**

| | | | |
|---|---|---|---|
| | **Material factor (from Dow manual)** | | **21** |
| | 1. General process hazards | Penalty Factors Range | Penalty factor for use |
| | Base factor | 1.00 | 1 |
| **A** | Exothermic chemical reaction | 0.30-1.25 | |
| **B** | Endothermic process | 0.20-0.40 | 0.2 |
| **C** | Material handling and transfer | 0.25-1.05 | |
| **D** | Enclosed or indoor process units | 0.25-0.90 | 0.45 |
| **1** | Access | 0.20 -0.35 | 0.2 |
| **F** | Drainage and spill control | 0.25-0.50 | 0.35 |
| | **General process hazards $F_1$** | | **2.2** |
| | **Special process hazards** | | |
| | **Base factor** | 1.00 | **1** |
| **A** | Toxic materials | 0.20 -0.80 | **0.5** |
| **B** | Sub-atmospheric pressure < 500 mm Hg | 0.5 | |
| **C** | Operation in or near flammable range inerted _not inerted | | |
| **(i)** | Tanks farms storage flammable liquids | 0.5 | |
| **(ii)** | Process upset or purge failure | 0.3 | |
| **(iii)** | Always in flammable range | 0.8 | **0.5** |
| **D** | Dust explosion | 0.25-2.00 | **0.25** |
| **E** | Pressure operating pressure psig or kPa gauge | | |
| **F** | Low Temperature | 0.20-0.30 | |
| **G** | Quantity of Flammable/Unstable material quantity lb or kg | | |
| | Hc = Btu/lb or Kcal/kg | | |
| **(i)** | Liquids or gases in process | | |
| **(ii)** | Liquids or gases in storage | | |
| **(iii)** | Combustible solids in storage , dust in process | | |
| **H** | Corrosion and erosion | 0.10-0.75 | **0.1** |
| **I** | Leakage -joints and packing | 0.10-1.50 | **0.3** |
| **J** | Use of fired equipment | | |
| **K** | Hot oil heat exchange system | 0.15 -1.15 | |
| **L** | Rotating equipment | 0.5 | |
| | **Special process hazards factor $F_2$** | | **2.65** |
| | **Process unit hazard factor $F_3= F_1*F_2$** | | **5.83** |
| | **Fire and explosion Index F&EI=$F_3$*MF** | | **122.43** |
| The Degree of hazard is intermediate from Dow table so use corrective actions to mitigate it. | | | |

## Parameters for consequence analysis

**Table H.1: Physical impact of heat radiation (World Bank, 1985)**

| **Radiation Level ($kW/m^2$)** | **Observed effect** |
|---|---|
| 37.5 | Sufficient to cause damage to process equipment |
| 25 | Minimum energy required to ignite wood at indefinitely long exposures (non-piloted) |
| 12.5 | Minimum energy required for piloted ignition of wood, melting of plastic tubing |
| 9.5 | Pain threshold reached after 8s; second degree burns after 20s |
| 4 | Sufficient to cause pain to personnel if unable to reach cover within 20s; however blistering of the skin (second degree burns) is likely; 0: lethality |
| 1.6 | Will cause no discomfort for long exposure |

**Table H.2: Exposure** time **necessary to reach the pain threshold (API, 521)**

| **Radiation level ($kW/m^2$)** | **Time to pain threshold (s)** |
|---|---|
| 1.74 | 60 |
| 2.33 | 40 |
| 4.73 | 16 |
| 6.94 | 9 |
| 11.67 | 4 |
| 19.87 | 2 |

**Table H.3: Physical impact of explosion overpressures (Clancey, 1972)**

| Pressure (bar(g)) | Damage produced by Blast |
|---|---|
| 0.02 | "Safe distance" (probability 0.95 no serious damage beyond this value); projectile limit; some damage to house ceilings; 10% window glass broken |
| 0.05 | Minor damage to house structures |
| 0.1 | Repairable building damage |
| 0.2 | Heavy machines (3000 lb) in industrial building suffered little damage; steel frame building distorted and pulled away from foundations |
| 0.35 | Wooden utility poles snapped; tall hydraulic press (40,000 lb) in building slightly damaged |
| 0.70 | Probable total destruction of buildings; heavy machines tools (7000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survived |
| 21 | Limit of crater lip |

**Table H.4: Physical Impact of toxic concentration (Lees, 2000)**

| Concentration Level | Observed Effect |
|---|---|
| Threshold Limit Value (TLV) | Average concentration of the substance in ambient air for a normal 8 hour workday or 40 hour workweek, to which nearly all workers may be repeatedly exposed, day after day, without adverse effects. |
| Short -Term Exposure Limit (STEL) | Maximum concentration of the substance to which workers can be exposed for a period upto 15 minutes continuously without suffering from irritation, chronic tissue change, provided that no more than four executions per day are permitted, with at least 60 minutes between exposure and that the daily TLV is not exceeded. |
| Immediately Danger to Life and Health (IDLH) | It represents the maximum airborne concentration to which a healthy male worker can be exposed for as long as 30 minutes and still be able to escape without loss of life or irreversible organ system damage. |
| Lethal Concentration at 50% mortality ($LC_{50}$) | Lethal concentration levels that kill 50 % of exposed laboratory animals under controlled experiments. |

**Table H.5: Atmospheric stability classes**

| Surface wind speed (at 10 m) m/s | Day | | | Night | |
|---|---|---|---|---|---|
| | Incoming solar radiation | | | Amount of overcast | |
| | Strong | Moderate | Slight | > 4/8 low cloud | < 3/8 low cloud |
| <2 | A | A – B | B | | |
| 2 – 3 | A – B | B | C | E | F |
| 3 – 5 | B | B – C | C | D | E |
| 5 – 6 | C | C – D | D | D | D |
| >6 | C | D | D | D | D |

## Discussion of other pillars

### I.1 Health monitoring systems

Another pillar is the health monitoring systems. Even though the elements of workplace environment can be visually inspected, but quantification of these parameters is also required for impact of these parameters on Health. Occupational health and monitoring should be carried out using various monitoring instruments such as gas and fumes detector, dust analyzer and chromatography.

Workers are mainly exposed to physical and chemical hazards as discussed earlier. Chemical hazards are shown in Table 6.10. Noise, light, vibration and heat stresses are the predominant physical hazards.

**Table I.1: Chemical Hazards in the process**

| Chemical | Toxic | Corrosive | Flammable | Explosive |
|---|---|---|---|---|
| $CS_2$ | Yes | | Yes | Yes |
| $H_2SO_4$ | | Yes | | |
| HCl | | Yes | | |
| NaOH | | Yes | | |
| $NH_3$ | Yes | | Yes | Yes |
| $Cl_2$ | Yes | Yes | | |
| $H_2S$ | Yes | | Yes | |
| $SO_2$ | Yes | Yes | | |
| $SO_3$ | Yes | Yes | | |

Apart from that there are mechanical hazards in the staple fiber process which are often leads to injuries. The following is the list of jobs that pose potential Mechanical Hazards:

a. Work on slurry injection pump
b. Work on shaft
c. Work on replacing jets to gear pumps
d. Work on the spinning machine
e. Work on the cutter
f. Work on the baling press

For all the above activities the risk involved is the cuts, bruises, the spillage of the material processed, caught between the godets of the spinning machine etc. All these hazards can be reduced in the process through adoption of total productive maintenance (TPM), adherence to work-permit system, and systematic audit with process and material changes. The procedure for periodic health checks is different from that of pre-placement examinations. A special form needs to be designed, with emphasis on the aspects of the history and physical examination most relevant to the exposure in question. The scope and periodicity. of the health examination should depend on the nature and extent of the risk involved. The examination should focus on the body organs and systems most likely to be affected by the harmful agents in the workplace.

The best way to comprehend Occupational Health problems is to carry out clinical and laboratory tests for early detection of work -related illnesses in the main organs and systems. The following table shows the laboratory tests suggested for Staple Fibre Division, Grasim Industries Ltd. The exposure is based on the all likely contaminants present in the workplace of various departments. Use of personal protective equipment and ergonomically safe working methods should be adopted for all the process operations.

**Table No I.2: Recommended laboratory tests for SFD, GIL**

| **Exposure** | **Target Organ/ Tissue** | **Department/ Process Involved** | **Frequency of Examination** | **Laboratory and other tests** | | |
|---|---|---|---|---|---|---|
| | | | | Urine | Blood | Additional Tests |
| $CH_3COOH$ | Respiratory system, skin, eyes, teeth | Spinning and After Treatment | Annual | - | - | PFT- X-Ray test |
| $NH_3$ | Skin, eyes, mucous membrane, respiratory system | Viscose Refrigeration | Annual | - | - | PFT- X-Ray test |
| $Cl_2$ | Eyes, mucous membrane, respiratory system | Water Treatment Process | Annual | - | - | PFT- X-Ray test |
| $CS_2$ | Eyes, mucous membrane, respiratory system | Viscose, Spinning & After Treatment, $CS_2$ | Annual | - | Hematology | PFT- X-Ray test |
| $H_2S$ | Eyes, mucous membrane, respiratory system | Spinning & After Treatment, $CS_2$ | Annual | - | Hematology | PFT- X-Ray test |
| NaOH | Respiratory system, skin, eyes | Viscose | Annual | - | - | PFT- X-Ray test |
| S | Respiratory system, skin, eye | $CS_2/H_2SO_4$ | Bi Annual | - | - | PFT- X-Ray test |
| $SO_2$ | Eyes, mucous membrane | $CS_2/H_2SO_4$ | Bi Annual | - | - | PFT- X-Ray test |
| $H_2SO_4$ | Eyes, mucous membrane | $CS_2/H_2SO_4$ | Bi Annual | - | - | PFT- X-Ray test |
| Hot Environment | Skin Body | Spinning, $CS_2/H_2SO_4$ | Annual | - | Hematology | ECG |
| Light | Eyes | Viscose | Annual | - | - | Eyes Check up |

## I.2 : OHSIM

An OHSIM (Occupational health and safety information management) system should be treated as the essential framework for supporting safety management. The information systems that are applied at Staple Fiber Division should include:

a. Reporting of accidents, mishaps and even near miss accidents. The latter are important to learn and prevent accidents.
b. Investigation reports that give information about accidents in detail, analyze them, recommend actions for prevention and inform about action taken.
c. Record keeping and analysis of trends
d. Inter-industry and region comparisons
e. Collection of published information and making it known to employees along with the actions taken by the company
f. Display of company's safety performance to employees on a regular basis.

The allocated key OSH management roles and responsibilities should be well defined. Reports should be generated at all three levels:

Level 1 : Executive Reports for Top Level Management
Level 2: Analysis Report for Middle Level Management
Level 3: Information Report for Lower Level Management

**Table I.3 suggests the categorization of the elements for OHSMS level-wise at GIL**

**Table I.3: Requirement of OHS Information Systems**

| S.No | OHSIM Requirements | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| 1 | OHS Policy | | | |
| 2 | Statutory Requirements | | | |
| 3 | Accident Statistics | | | |
| 4 | Chemical Safety Information | | | |
| 5 | Hazard Communication | | | |
| 6 | Risk Communication | | | |
| 7 | Occupational Health Information | | | |
| 8 | Fire Incidents | | | |
| 9 | Management of Change (Modification) | | | |
| 10 | Emergency Plans | | | |
| 11 | Sub-Committee performance | | | |
| 12 | Safety Audit Observation | | | |

Required Quarterly

Requirement for Particular Level

Required Monthly

As and when Required

| | | | | | | |
|---|---|---|---|---|---|---|
| **Level 1** | **GM** | **A.VP** | **Sr.V.P** | **Sr. E.P** | | |
| **Level 2** | **ENGG** | **AM** | **DM** | **M** | **AGM** | **DGM** |
| **Level 3** | **Workers (Badli+Contractor+Permanent)** | | | | | |

The pillar of Audit is the structured process of collecting independent information on the efficiency, effectiveness and reliability of the safety management system and drawing up plans for corrective action. The Plant visit/observation is a significant aspect of safety audits. The auditor collects evidence through what can be seen, heard, touched or smelt. The following points should be kept in mind during plant visit The example of such observation for GIL is shown in TableI.4

**Table I.4: Non-Compliances observed during audit at GIL**

| **Department** | **Non-Compliance** |
|---|---|
| HRD | Currently training need on OHSMS have not been identified for the workmen, therefore the training calendar does not reflect planning on the subject to meet standards requirements. |
| $CS_2$ & $H_2SO_4$ | Workplace monitoring is not being carried out for sulphur dust at the location of charging pits and Sox in the work place area to demonstrate compliance to norms. |
| Auxiliary | Risk analysis is not meaningful such that all hazards are categorized low, even though they are sufficiently high. |
| Viscose – 1 | Caustic storage tanks 15 &16 do not have Bund walls. Also the Bund walls of other caustic storage tanks in the tank form area has holes at the bottom. |
| Electrical | 1. Electrical area classification for all the plant areas to be established and schedule of checking integrity of classification made and followed-up.<br>2. In the daily log mentioned under Serial no. 16 is an incident where in MTB flash took place during starting of the motor. No root cause analysis for the incident had been carried out in order to prevent reoccurrence.<br>3. Objective and targets for the electrical dept. were not made in line with OHSMS requirement. |
| Mech. Workshop | While inspection certificates for lifting equipment were available, identification numbers could not be found on equipment viz, one Jib Crane. |
| Ind. Transport | 1. Noise level measurement for all heavy vehicles is not being carried out. Effect on driver's hearing capacity needs also to be established.<br>2. Records of vehicles accidents, mal-operation or other mis-happening are not being kept to enable taking corrective and preventive action. |

Once the non-compliances are observed and written by the auditor, the management should take the review of such non-compliances and generate an action plan. This corrective action includes identifying the root cause and eliminating it. Also, then the management changes the OHSMS system requirements as per the observations.

Thus, this pillars provides the guidelines for OHSMS system to be successful, it can measured through the audit these pillars. If not successful, it has to be started again and check the noncompliance's of each pillar of OHSMS and build it again. Therefore, it can be termed as a continuous cycle which has to be followed to ensure an accident free workplace

# List of publications

## International journals

Kale, S.R, Gujrathi, A., Kale, L (2013), **"Review Of Occupational Health And Safety Management System (OHSMS) Of Process Industries With A Case Based Study of A Fiber Industry",** International journal of Engineering Research and Technology, Vol.2, Issue 6, 1250-1259

Kale, S.R, (2004), **"Symbiosis of Maintenance and Safety in Process Industry",** published in M-News: Edition 50, www.plantmaintenance.com/articles/ maintenance_safety_process_industry.shtml

## National journal articles

Kale, S.R (2003), **"A Framework for Implementation of Occupational Health and Safety Management Systems in Process Industry"**, UDYOG PRAGATI (The Journal of Practising Managers), Vol 27, 28-35

## Conference Proceedings

Kale, S.R, Maity, A., **"Reliability and Safety Aspects of Fibre Drum Dryer"**, published & presented at the proceedings of International Conference of Reliability and Safety Engineering (INCRESE 2005) Organized by Reliability Centre, IIT Kharagpur at Bhuvaneshwar on 21-23$^{rd}$ Dec, 2005, 85-94

Kale, S.R, **"Challenges for Occupational Health and Safety Management System (OHSMS) for Year 2020"** paper presented on the eve of XXI Convention of Chemical Engineers held at Udaipur and published in the proceedings held on 04.09.2005,302-308

Kale, S.R, **"Ergonomic and Workplace Assessment of an Integrated Fibre Industry using Quantitative Techniques"**, paper presented at the National Conference on Chemical Engineering and Environment (NCCEECTI): Current Issues and Trends held at IPS Academy and published in the proceedings held on 3-4 November 2006 at INDORE, 9-15

Kale, S.R, Maity A, Joshi A, **"Impact of Workplace Environment on Occupational Health and Safety of a Process Industry"**, paper presented at the National Conference of Environmental Conservation (NCEC) held on 1-3 September 2006 at BITS, Pilani, 90-99

Kale, S., Lamba, D., **"Workplace Culture: A Key to Enhance Safety, Health and Environment of a Process Industry".** Special Issue on Safety, Health and Environment, Published in Grasim Sandesh, Sep-Dec 2006 issue

## Communicated

Paper entitled **"OHSMS Framework for chemical Process industries"** is in review for publication at International Journal of Loss Prevention

# Brief biography of the candidate

**Samir R. Kale**, completed his B.Tech (Chemical Technology) from Amravati University in the year 1999 and M.E (Chemical Engineering) from BITS, Pilani in the year 2000. He thereafter joined as a Lecturer (2001 - Aug. 2014) at BITS, Pilani for the off campus location at Grasim, Industries Limited, Nagda.

Primarily the profile was to teach the employees of Grasim, courses related to Chemical Engineering for the B.S (Process Engineering) program. Apart from that facilitate and guide the Practice school students (Internship of six months) for the various projects in the various departments of Grasim Industries Limited. He has supervised more than 100 projects of Practice school, work integrated learning program.

He is presently working as Assistant Professor (Off-Campus since Aug. 2014) at Hyderabad center. He is looking after the collaborations of Dr. Reddy’s Labs [B.S. (Process Engineering) program] and LVPEI (LV Prasad Eye Institute) and has been involved in teaching courses such as Process Plant Safety, Chemical Process Calculations and Thermodynamics.

He has published articles and publications in the safety field. Presently he is enrolled for the Doctoral program of BITS, Pilani under the supervision of Prof. (Dr.) Arun Maity, Associate Professor, BITS, Pilani.

# Brief biography of the supervisor

Prof. (Dr.) Arun Maity is Associate Professor of BITS, Pilani since 2005 . His skill sets include Project Management, Quality Management, and Management Systems.

He is presently the Group Leader of Work Integrated Learning Programs (WILP) for Civil, Chemical and Mechanical group. His task is to improve the existing WILP programs, build the skill set of the faculties in pedagogy and content development. He was the coordinator for the Off campus programs at Grasim Industries Limited, Nagda (1995-2005) and Chambal fertilizers Limited (2005-2009). Thereafter, till date he is at BITS Kolkota Off Campus center and looked after the collaboration of Texmaco limited, DCPL (Development Consultancy Private Limited).

He did his B.E. (Mechanical Engineering) from Government College, Raipur in 1987 and ME (Mechanical Engineering) from MSU (Maharaja Sayaji University, Baroda) in year 1991 and PhD (BITS, Pilani) in year 2001 and joined as a Lecturer of BITS, Pilani at its Off Campus Center at Grasim Industries limited in year 1991. He was promoted as Assistant Professor in the year 2000 and Associate Professor since 2005. He has 24 years of teaching/ research experience He has published many papers in various national and international journals in WCM (World Class manufacturing). He has supervised more than 200 BE and ME students for their Internship program. He teaches project management course online for the WILP students and professionals.