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A NEW RISK AND SAFETY ANALYSIS MODEL FOR PETROL FILLING STATIONS WITH SPECIAL REFERENCE OF PAKISTAN FUEL STATIONS

MIRZA MUNIR AHMED

MAY 2013

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DOCTOR OF PHILOSOPHY
CIVIL ENGINEERING

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by

MIRZA MUNIR AHMED

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By

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A Thesis

Submitted to the Postgraduate Studies Programme

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Dedicated to my father

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Who was very keen to enhance the educational activities in the family. I hope he would be very pleased to see me contributing my part.

ABSTRACT

A petrol filling station (PFS) is a common facility that is available in urban and rural areas. It stores and sells a highly flammable liquid. A PFS has potential hazards to the people, asset, and environment. Variety of hazards such as fire hazards, static electricity, fuel tank explosions, transportation hazards and air pollution evoked by aromatic organic compounds are found to be the major causes of accident/incident occurrences at PFS. Many companies are using different risk assessment methods to priorities hazards related to their work activities. In this study, a new risk and safety analysis model for PFS is to be developed.

In this study, 3.5 years data of non-compliances was collected from 2500 PFS located in various cities in Pakistan. The significant numbers of health safety and environment (HSE) non-compliances recorded were due to various factors during operation and maintenance of PFS. The HSE non-compliances were classified into two categories i.e. hazards contributing factors (HCFs) and incident occurrences [fatality (F), accident (A), incident (I) and near miss (NM) cases]. The hazards contributing factors were then further classified into 8 categories. These were Housekeeping (HK), Transportation Hazard (TH), Slips, Trips and Falls (STF), Carelessness (C), Fire Risk (FR), Electrical Faults (EF), Miscellaneous Cases (MC) and Medical Treatment Cases (MTC). A monthly, quarterly and seasonal categorization of HSE non-compliances was carried out to evaluate the hazard occurrences flow pattern for the two categories. The risk assessment of the hazards was carried out and prioritized by using three different widely used risk assessment methods. These were, risk ranking criterion, risk matrix criterion and As Low As Reasonably Practicable (ALARP). The hazard prioritization results by using each risk assessment model were found to be different. Gaps were identified and finally data was analyzed by using a new risk and safety analysis model for PFS. With the use of irrelevant risk assessment model the hazard merely shifts within the system but not eliminated. Therefore, availability of database for development of risk assessment model is needed.

A new statistical safety and risk analysis model was then developed with reference to statistical association among the hazard contributing factors. The proposed safety and risk analysis model was based upon seasonal occurrences of hazard contributing factors. The model was then validated and finally, hazards were prioritized and mitigation strategies were proposed to control the occurrences of these hazards. The proposed model was based upon the actual data collected and found successful. It introduced a systematic approach to analyze the hazards that exists within a system. It is hoped that by analyzing activities with a new risk and safety analysis model the occurrences of hazards can be controlled during operation and maintenance of PFS. The proposed model was developed by using HSE non-compliances recorded during PFS operation with the use of same approach the risk and safety analysis model for other industrial sectors can be developed for hazards prioritization. It helps to take remedial and preventive measures to protect the facility with upcoming hazards and ultimately leads to a safe and accident free work environment.

ABSTRAK

Stesen minyak (PFS) adalah satu kemudahan yang biasa boleh didapati di kawasan-kawasan bandar dan luar bandar. Ia adalah satu-satunya sumber untuk membekalkan bahan api untuk kenderaan khususnya kereta. Stesen minyak menyimpan dan menjual cecair yang sangat mudah terbakar. Sebuah PFS mempunyai potensi bahaya kepada manusia, aset dan persekitaran. Pelbagai bahaya seperti kebakaran, elektrik statik, letupan tangki bahan api, bahaya pengangkutan dan pencemaran udara yang di timbulkan oleh sebatian aromatik organik didapati menjadi punca utama kepada kejadian kemalangan/kejadian di PFS. Risiko yang berkemungkinan terjadi ini berbeza dari satu PFS kepada PFS yang lain. Banyak syarikat menggunakan kaedah penilaian risiko yang berbeza mengenai keutamaan bahaya yang berkaitan dengan aktiviti kerja mereka. Kajian yang berkaitan untuk mengutamakan kepentingan langkah-langkah keselamatan di PFS tidak mencukupi, ternyata di negara-negara membangun. Dalam kajian ini, risiko baru dan analisis model keselamatan untuk PFS akan dijalankan.

Dalam kajian ini, data ketidakpatuhan sepanjang 3 setengah tahun telah dikumpulkan dari 2500 PFS yang terletak di pelbagai bandar di Pakistan. Bilangan ketidakpatuhan kesihatan, keselamatan dan alam sekitar (HSE) yang dicatatkan adalah disebabkan oleh pelbagai faktor semasa operasi dan penyelenggaraan PFS. Ketidakpatuhan HSE telah dikelaskan kepada dua kategori iaitu penyumbang faktor bahaya dan berlakunya insiden [kematian (F), kemalangan (A), insiden (I) dan hampir berlaku (NM) kes]. Faktor penyumbang bahaya kemudian diklasifikasikan kepada lapan (8) kategori. Ini adalah Kepenjagaan (HK), Pengangkutan Bahaya (TH), Tergelincir, Renjatan dan Jatuh (STF), Kecuaian (C), Risiko Kebakaran (FR), Kegagalan Elektrik (EF), Pelbagai Kes (MC) dan Rawatan Perubatan Kes (MTC). Setiap bulan, pengkategorian suku penggal dan bermusim ketidakpatuhan HSE telah dijalankan untuk menilai aliran corak bahaya kejadian untuk dua kategori. Penilaian risiko bahaya telah dijalankan dan diutamakan dengan menggunakan tiga jenis

penilaian kaedah risiko yang digunakan secara meluas. Ia adalah kriteria kedudukan risiko, kriteria matrik risiko dan serendah praktikal yang munasabah (ALARP). Jurang diantaranya telah dikenal pasti dan akhirnya data telah dianalisa dengan menggunakan risiko baru dan analisis model keselamatan untuk PFS. Keputusan keutamaan bahaya dengan menggunakan setiap model penilaian risiko didapati berbeza. Penggunaan model penilaian risiko yang sesuai untuk mengutamakan bahaya adalah sangat penting. Dengan menggunakan model penilaian risiko bahaya tidak berkaitan mengalami perubahan dalam sistem tetapi tidak dihapuskan. Oleh itu, keperluan pangkalan data bagi pembangunan model penilaian risiko adalah diperlukan.

Statistik keselamatan yang baru dan model penilaian risiko kemudiannya dibangunkan dengan merujuk kepada statistik di kalangan faktor penyumbang bahaya. Model penilaian risiko keselamatan yang dicadangkan adalah berdasarkan kejadian bermusim faktor yang menyumbang bahaya. Model itu kemudian disahkan dan akhirnya, bahaya telah diberi keutamaan dan strategi mitigasi telah dicadangkan untuk mengawal kejadian bahaya ini. Model yang dicadangkan adalah berdasarkan kepada data sebenar yang dipungut dan didapati berjaya. Ia memperkenalkan satu pendekatan yang sistematik untuk menganalisis bahaya yang wujud di dalam sistem. Adalah diharapkan bahawa dengan menganalisis aktiviti dengan risiko baru dan model analisis keselamatan kejadian, bahaya boleh dikawal semasa operasi dan penyelenggaraan PFS. Model yang dicadangkan telah dibangunkan dengan menggunakan ketidakpatuhan HSE yang dicatatkan semasa operasi PFS melalui pendekatan risiko yang sama dan analisis keselamatan bagi sektor perindustrian yang lain boleh dibangunkan untuk keutamaan bahaya. Ia membantu untuk mengambil langkah-langkah pemulihan dan pencegahan untuk melindungi kemudahan daripada bahaya yang akan datang dan akhirnya membawa kepada persekitaran kerja yang selamat dan bebas daripada kemalangan.

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AHP	Analytical Hierarchy Process
BTEX	Benzene, Ethyl Benzene, Toluene and Xylene
CCTV	Closed Circuit Television
CNG	Compressed Natural Gas
EIA	Environmental Impact Assessment
HCF	Hazard Contributing Factors
HSD	High Speed Diesel
HSE	Health Safety and Environment
IEE	Initial Environmental Examination
ILO	International Labor Organization
MRA	Multiple Regression Analysis
NEQS	National Environmental Quality Standards
O & M	Operation and Maintenance
OHSAS	Occupational Health and Safety Assessment Series
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PFS	Petrol Filling Station
PPE	Personal Protective Equipments
RAC	Risk Assessment Criteria
RAM	Risk Assessment Method
SMS	Safety Management System
SPSS	Statistical Package of Social Sciences
T/L	Tanker Lorries
TTIFR	Total Treated Injury Frequency Rate

UAUC	Unsafe Acts and Unsafe Conditions
UGST	Underground Storage Tanks
UPS	Un-interrupted Power Supply

LIST OF SYMBOLS

A	Accidents
C	Carelessness
EF	Electrical Faults
F	Fatalities
FR	Fire Risks
HK	Housekeeping
I	Incident
MC	Miscellaneous Cases
MTC	Medical Treatment Cases
NM	Near Miss
R_A	Risk of Accident Occurrence
R_F	Risk of Fatality Occurrence
R_I	Risk of Incident Occurrence
R_{NM}	Risk of Near Miss Occurrence
S_A	Severity of Accident
Sc	Severity level of Carelessness
S_{EF}	Severity level of Electrical Faults
S_F	Severity of Fatality
S_{FR}	Severity level of Fire Risk
S_{HK}	Severity level of Housekeeping
S_I	Severity of Incident
S_{MC}	Severity level of Miscellaneous Cases
S_{MTC}	Severity level of Medical Treatment Cases
S_{NM}	Severity level of Near Miss

S_{S1}	Severity level of Season 1 (Cold Season)
S_{S2}	Severity level of Season 2 (Hot Season)
S_{S3}	Severity level of Season 3 (Warm Season)
S_{S4}	Severity level of Season 4 (Monsoon Season)
S_{STF}	Severity level of Slips, Trips and Falls
STF	Slips, Trips and Falls
S_{TH}	Severity level of Transportation Hazard
TH	Transportation Hazard
β_A	Standardized co-efficient for Accident
β_C	Standardized co-efficient for Carelessness
β_{EF}	Standardized co-efficient for Electrical Faults
β_F	Standardized co-efficient for Fatality
β_{FR}	Standardized co-efficient for Fire Risk
β_{HK}	Standardized coefficient for Housekeeping
β_I	Standardized co-efficient for Incident
β_{MC}	Standardized co-efficient for Miscellaneous Cases
β_{MTC}	Standardized co-efficient for Medical Treatment Cases
β_{NM}	Standardized co-efficient for Near Miss
β_{S1}	Standardized coefficient for Season 1 (Cold Season)
β_{S2}	Standardized coefficient for Season 2 (Hot Season)
β_{S3}	Standardized coefficient for Season 3 (Warm Season)
β_{S4}	Standardized coefficient for Season 4 (Monsoon Season)
β_{STF}	Standardized co-efficient for Slips, Trips and Falls
β_{TH}	Standardized co-efficient for Transportation Hazard

CHAPTER 1

INTRODUCTION

1.1. Introduction

This chapter presents brief description and discussion of various areas that covered in this study. The problem statement, objectives and scope of study will be discussed in subsequent sections. The structure of complete thesis is presented in the last section of this chapter.

1.2. Background

A petrol filling station (PFS) is a facility most commonly available in urban and rural areas which sells fuel and lubricants for automobiles. Different countries know them with different names such as retail outlets, filling stations, gas stations, fuelling stations or service stations. PFS's are also important for airports, refineries, sea ports and other places where the movement of vehicles and other fuel operating machines such as generators and engines are common. The availability of fuel depends upon the requirements at a particular location. At PFS, the most common fuels sold are petrol, compressed natural gas (CNG), diesel and kerosene oil. PFS's may contain only one fuel among these three or a combination of them. Fuel storage capacity, associated hazards, layout, area, location, number of staff working, climatic conditions and safety considerations at the PFS's vary from place to place. The number of PFS's is increasing continuously as the number of vehicles and the use of fuel for other uses are increasing. The numbers of refueling stations to satisfy market demands has been investigated in a number of studies [1-4]. The number of vehicles to determine the required number of petrol filling stations was also highlighted by [5-7]. The studies conducted didn't highlight the hazardous impacts of PFS's on the nearby residential areas, environment, soil and water bodies.

A study conducted by [8] was related to the suitability of a filling station at a particular place. The Geographical Information System (GIS) and Analytical Hierarchy Process (AHP) were used in integration. A spatial analysis was performed for identification of a suitable site by computing the environmental considerations. It included water system protection from underground storage tank leakages, vicinity area protection from PFS fires, explosion hazards, proper land use selection and access road selection to access–egress activities.

The contamination of ground water aquifers with fuel spillage and leakages from underground storage tanks was reported by [9, 10]. Ground water contamination has major effects on people's health living in the surroundings of a PFS. Many localities rely on the use of ground water for their daily life due to the scarcity of a fresh water supply, especially in rural areas. A United States Geological Survey study conducted in the year 2003 detected the petrol additive MtBE (Methyl-tertiary-butyl ether) in 40 percent of the wells out of 225 in Rockingham County. A correlation was found between the Methyl-tertiary-butyl ether concentration and the proximity to the underground storage tanks as was also mentioned by [11]. Studies conducted by [12, 13] discussed the harmful impacts of petrol vapours on fuel station attendants. They found that petrol vapours that were emitted during vehicle filling are hazardous to the health. The studies have also proved that exposure to benzene via gasoline vapours and exhaust put workers at significant health risk. Both studies highlighted two significant aspects to health, safety and environment (HSE); the first is the great number of workers employed in petroleum distribution trades and the second is the relevant contribution of such sources to the pollution burden in urban environments.

In a recent study conducted by [14], it was proposed that many urban rivers, lakes and ponds are rendered unfit for use as drinking water sources due to pollution from petrol filling stations.

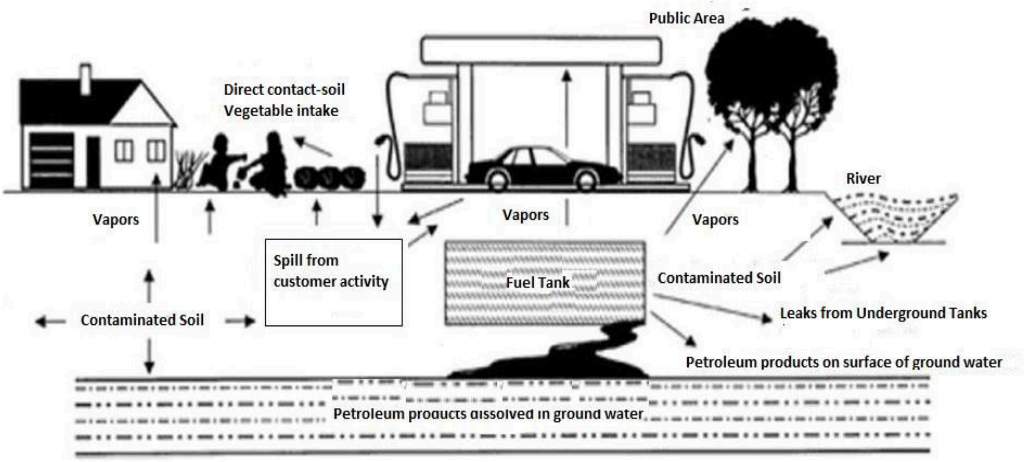

Figure 1.1: Typical Flow Diagram of Fuel Leakage and Spill during Petrol Filling Station Operation

Many PFS's discharge effluent from their septic tanks into storm drains without any treatment. Figure 1.1 shows the impact of fuel leakages from underground storage tanks on the surroundings. The sources of pollution released from petrol filling stations contaminate the air, soil, and water [15].

The main sources of contamination at PFS's are tank leakages, spills on driveways and uncontrolled petrol waste disposal as mentioned by [16] in an environmental impact assessment of petrol usage. Different processes related to soil and groundwater contamination are highlighted in Figure 1.2.

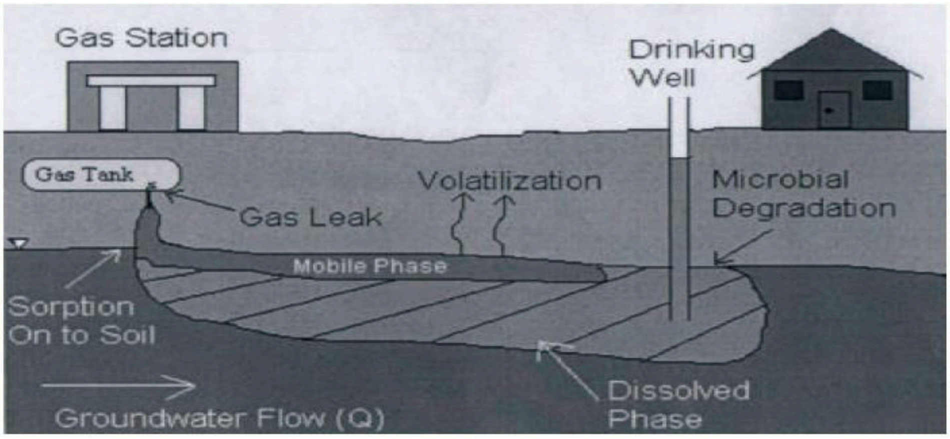

Figure 1.2: Various Aspects Related to Soil and Groundwater Contamination due to PFS

The hazardous effects posed by the availability of petrol filling stations in surrounding areas are also highlighted by [17]. He mentioned that the petrol filling stations can have potential hazards to the health and well being of persons living in the vicinity.

1.3. Health Safety and Environment (HSE) Non-Compliances during Operation and Maintenance of Petrol Filling Stations

Hazards posed by activities are different from one operating sector to another. The hazards that can pose a significant risk to the construction industry are not the same as for the petroleum industry. Therefore, to prevent unwanted scenarios, each sector's hazards require a different strategy. The HSE non-compliances recorded during operation and maintenance of PFS produce variety of hazards that may cause fatalities, accidents, incidents and near miss cases. A PFS is a unique facility that stores and sells a flammable and hazardous material in close vicinity to houses within rural and urban areas. Normally PFS contains large quantities of hazardous materials. A PFS poses potential hazards to the people, assets, environment and reputation of an operating company. Hazards related to PFS operations can be mainly divided into two categories, i.e., onsite hazards and off site hazards. Fire hazards, static electricity, and air pollution evoked by aromatic organic compounds are major causes of accident/incident occurrences at PFS. There are other potential hazards in PFS operations which make them unsafe. Activities such as carelessness, maintenance, housekeeping, slips, trips and falls, transportation hazard, major and minor injuries, robberies and snakebites have a potential to create unsafe conditions. The level of risk of these hazards varies from PFS to PFS as it depends upon many factors as highlighted in section 1.1. To control occurrences of these hazards noticed difficult due to some of the components at PFS were in direct use of customers. At some PFS concise information to use these components was found clearly written but most of the places it was missing. Another important aspect is that whether the customers that are coming to take the fuel at PFS are giving consideration to these instructions or not. Two important sources for the occurrences of fire and explosion remains exist at PFS throughout the operations hours i.e. continuous arrival and departure of customers vehicles and the presence of public [18].

Caltex is a PFS retail outlet organization operating in many countries around the world. The total treated injury frequency rate (TTIFR) for employees recorded were 21 per million hours worked in 2002 and 16 in 2003, and for contractors were 30 in

2002 to 12 in 2003 as shown in Figure 1.3. Figure 1.4 depicts that 3 fire cases occurred in the year 2002 and each caused damages exceeding $2,000 [19].

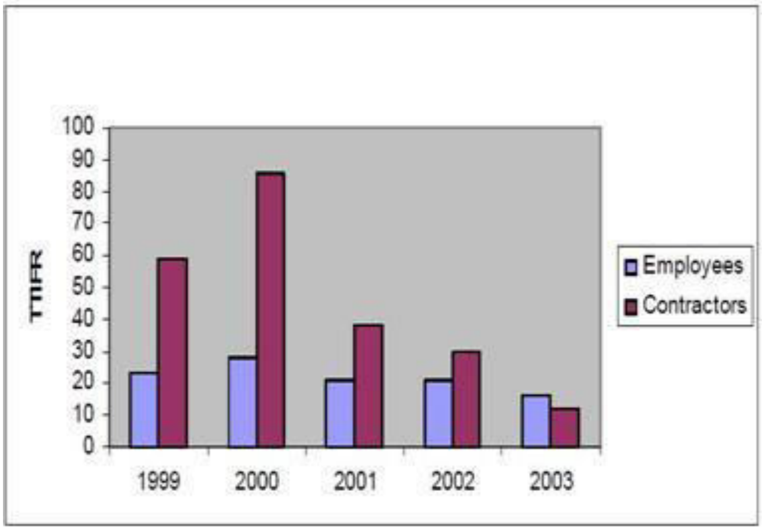

Figure 1.3: Caltex's Total Treated Injury Frequency (TTIFR) Rate for the Year 2002 & 2003 [19]

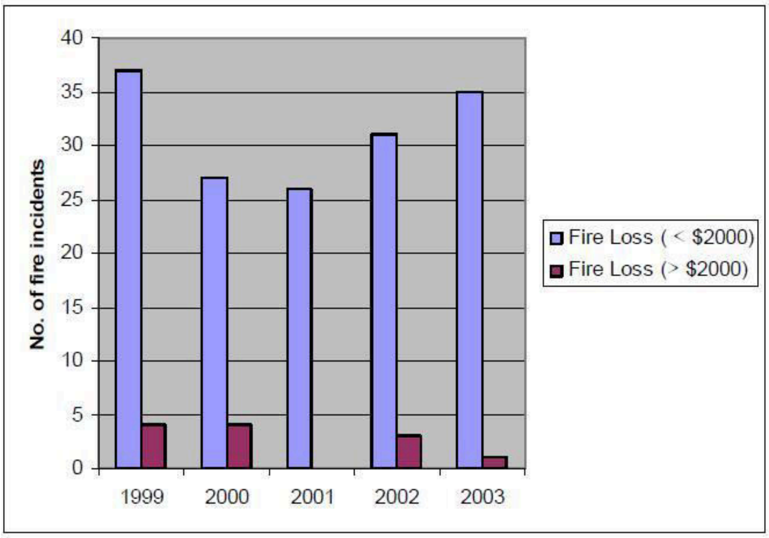

Figure 1.4: Fire Incidents at Caltex [19]

A study conducted in France with reference to hazardous conditions that can caused by PFS [18]. The report consisted of petrol filling stations accidents in France from 1958 to 2007. The sample of 270 large scale accidents studied in details. The study highlighted the effects of PFS on people, environment and company assets. The accidents reported caused degradation of environment due to spillages of fuel, explosion due to fire and carelessness, inappropriate maintenance practices and violation of standard operating work practices. The summary of few accidents is depicted in Table 1.1.

Table 1.1: Causes of Accidents at Petrol Filling Stations [18]

No	Description	Root Cause
1-	17 people killed in an explosion that occurred in a garage equipped with fuel distribution pumps. The explosion happened when the garage owner activated the electrical switch. The switch ignites due to fuel vapours emitted via a leak caused by severing an obsolete pipe that had been left in place after undeclared expansion work.	Vapours Leakage
2-	During degassing and cleaning process of underground storage tank an explosion occurred. Two people died and one person was severely injured. The tank was completely destroyed.	Cleaning (Maintenance work)
3-	An explosion occurred in a truck contains di-isocyanate (a product use to manufacture plastics) drum. The truck was parked at filling station.	Carelessness
4-	Leakage in fuel distribution line at PFS caused spillage of 24,650 litres of petrol into the ditch. No containment dike was constructed at PFS. Pollution was detected in ground water.	Leakages
5-	In super market at PFS, a premium unleaded petrol line was torn out during construction work. 4 m^3 fuel was spilled into the ground.	Carelessness (Inappropriate supervision)
6-	During a welding process of tank lorry an explosion occurred. A worker died on spot. No hot work permit was issued and job hazard analysis was performed before performing the task.	Carelessness
7-	In adequate distancing of vents in the compartment of fuel tank caused explosion and death of one person. The all 4 vents were interconnected. The welding job was carrying out in the 4^{th} compartment. Due to interconnection the accumulated vapors in the 4^{th} compartment was exploded.	Carelessness
8-	3 catastrophic explosions were occurred due to leakage in defective LPG delivery line. A tank truck was also exploded followed by a raging fire. Three fatality cases were reported and 189 people were injured.	Leakage

Different causes for occurrences of 270 accidents were identified. Table 1.2 shows the number of cases reported due to type of product involved and the category of accident.

Table 1.2: Type of Product s Involved Contribute to Accident

Typologies	Products involved (some incidents involve more than one)					
	Liquid Fuels	PPG	Gas Cartridges	Other (Oils Wastes)	Unknown	Total No of Accidents
Releases of hazardous materials	199	12	5	21	3	237
Fires	20	3	5	6	27	60
Explosions	18	1	4	2	6	30
Others (near accidents)	2	1	0	0	4	7
Total number of accidents	202	13	5	21	32	270

Various hazards associated with petrol filling stations have occurred reported in various studies; such as fires and explosions due to open flames reported by [20], static electricity by [21], air pollution induced by aromatic organic compound concentrations by [22], and the traffic jams due to vehicle queues to access the petrol filling station [23]. It was found that these HCFs were not independent of each other and have a strong correlation.

1.4. Risk and Safety Analysis Models

Risk is a combination of the likelihood of an occurrence of a hazardous event with a specified period or in specified circumstances and the severity of injuries or damage to the health of people, property, environments or any combination of these caused by the event. A documented and well established process for performing detailed risk assessments is required for compliance to the standard code of practices, and also to satisfy the concerns of the buyers [24]. There are various risk assessment methods available that are implemented in industries. The application of an inappropriate risk assessment method is the main cause of hazard occurrences. A risk assessment method that can be applied to calculate the risk for the construction industry is unsuitable to calculate the risk in refineries and vise versa. With the use of an incompatible risk assessment method, the risk shifts from one zone to another zone but the actual risk within the system remains same.

Three widely used risk assessment models .i.e. as low as reasonably practicable (ALARP), risk matrix criterion and risk ranking criterion were used in this study. Same data was analyzed but different results were obtained. It was due to the unavailability of guidance and instructions for the application of risk assessment models. The brief description of three risk assessment models is described below;

1.4.1. As Low as Reasonably Practicable (ALARP)

According to ALARP, all risks in a company must be managed at a level which is as low as reasonably practicable (ALARP) for that company. ALARP is implemented in oil and gas companies in Malaysia [25]. To each activity a particular consequence and probability number was assigned and it was based on the severity level. Table 1.3 shows the ALARP risk assessment matrix. The consequence levels have a rating from 0 to 5. The rating can affect people, assets, the environment and the reputation of an operating company.

Table 1.3: ALARP Risk Assessment Matrix

CONSEQUENCE					PROBABILITY				
Rating	People	Assets (RM)	Environment	Reputation	A Never Heard of in industry	B Heard of Incident in Industry	C Incident Has occurred in Our Company	D Happens Several Times Per Year in Company	E Happens Several Times Per Year
0	No injury	No Damage	No impact	No impact					
1	Slight injury	Slight Damage	Slight impact	Slight impact					
2	Minor injury	Minor Damage	Minor impact	Limited impact				Demonstrate ALARP	
3	Major injury	Local Damage	Localized impact	Considerable impact					
4	Single fatality	Major Damage	Major impact	Major national		Incorporate Risk Reduction Measures			
5	Multiple fatalities	Extensive Damage	Massive impact	Major international				Control or Alternatives	

1.4.2. Risk Matrix Criterion

The risk matrix evaluation method is widely used in upstream oil and gas sectors in Pakistan to determine risks [26]. Risk associated with any activity depends upon 2 parameters, i.e., severity and likelihood. Risk is the multiplicative product of severity times likelihood.

Table 1.4 shows the risk matrix criterion to calculate the risk score associated with hazardous activities. During risk analysis, a severity and likelihood value is assigned to the hazardous event.

Table 1.4: Risk Matrix Criterion to Calculate Risk Associated with Hazardous Activities

	LIKELIHOOD			
SEVERITY	Extremely likely Could happen at any time (E) 10	Often likely Could happen at sometime (F) 08	Unlikely Could happen but very rarely (G) 06	Very unlikely Could happen but probably never will (H) 04
Death or permanent disability or extreme damage to equipment or property **(A) 10**	**100**	**80**	**60**	**40**
Long term illness or serious injury or major damage to property or equipment **(B) 08**	**80**	**64**	**48**	**32**
Medical treatment several days off work or minor damage to equipment or property **(C) 06**	**60**	**48**	**36**	**24**
First Aid needed or negligible property damaged **(D) 04**	**40**	**32**	**24**	**16**

The risk value can be calculated by using equation 1.1.

$$\text{Risk Score} = \text{Likelihood (L)} \times \text{Severity (S)} \quad (1.1)$$

A risk score value is calculated and put up respectively in Table 1.5. Based upon the risk score value, the hazard is categorized into one among the four main groups. The action required depends upon the category of hazard.

Table 1.5: Risk Evaluation Scale

Evaluation Scale		
Score	Category	Action Required
80 – 100	Critical	Isolate the hazard immediately. Take Corrective measures on high priority and eliminate the hazard as soon as possible.
50 – 79	Major	Isolate the hazard as soon as practicable. Engineering control and administrative controls need to be taken. Regularly monitor the cause(s) until rectification.
30 – 49	Moderate	Must fix the cause(s) when time and resources permit. Administrative control is to be taken.
≤ 29	Minor	Need to monitor and consider. Administrative control is to be taken & use appropriate PPEs.

1.4.3. Risk Ranking Criterion

The risk ranking criterion is normally used to rank the hazards [27]. According to the risk ranking criterion, there are many processes in progress at any work place. It is not possible to tackle the entire hazard process effectively because it may be time consuming and this may cause delay to the work. Thus, a ranking system based on priority for the list of hazards to be controlled is performed to arrest the problem. All components should be assessed and the probability of the risk of hazard to occur is formulated. Table 1.6, Table 1.7 and Table 1.8 describe further steps to determine the risk score by using the risk ranking criterion.

Table 1.6: Probability of Hazard

Rating	Likelihood	Frequency	Description
1	Highly unlikely	About 1 in 1000 activity times	Unlikely to happen
2	Unlikely	About 1 in 100 activity times	Probably will happen but rarely
3	Likely	About 1 in 10 activity times	Could happen occasionally
4	Very likely	Frequent	Could happen frequently

Table 1.7: Consequences from the Hazard

Rating	Severity	Description
5	Not harmful (Negligible)	Hazard will not result in serious injury or illness, remote possibility of damage beyond minor first aid case.
10	Slightly harmful (Marginal)	Hazard can cause illness, injury or equipment damage but result would not be expected to be serious.
15	Harmful (Critical)	Hazard can result in serious illness, severe injury, property and equipment damage.
20	Extremely harmful (Catastrophic)	Imminent danger exists, hazard capable of causing death and illness on a wide scale.

The ranking of risk can be calculated using the equation 1.2,

$$\text{Risk Ranking} = \text{Probability of hazard} \times \text{Consequences} \qquad (1.2)$$

Table 1.8: Priority of Action from the Risk of Ranking

Risk Ranking	Action	Timescale and Urgency
Low (5,10)	Relevant action and control measures are required and records need to be kept. Consideration need to be given for an effective solution or improvement. Monitoring is required to ensure that controls are maintained.	Within 1 week
Medium (15,20,30)	Efforts should be made to minimize the risk. Control measures should be implemented. Where moderate risk is associated with extremely harmful consequences, further assessment may be necessary to establish more precisely the likelihood of harm as a basic for determining the need for improved control measures.	Within 1 day
High (40,45,60,80)	Work should not commence until the control measures have been taken to minimize risk. For work in progress, take action within the same day. Work should be stopped immediately until proposed control measures has been taken satisfactorily to eliminate or minimize risk.	Immediately

The gaps were identified during data analysis in the three risk analysis approaches. A statistical approach was used and a new risk and safety analysis model was developed. The study proposes a detailed methodology for the development of a new risk and safety analysis model during the operation and maintenance of petrol filling stations.

Risk analysis models are work system design methods and are helpful to address the associated risks in a project. During the study it was felt that many resources are available within an organization to minimize accidents/injuries but due to under utilization of the resources accidents/incidents occurs. After calculating the risks, the application of available resources can be done more appropriately. In case of unavailability, requirements can be highlighted and applied strategically to get better results. The application of an inappropriate risk analysis model to calculate risk will not give suitable results because of the difference in the base data used to establish these criteria. Therefore, there is a need for a new risk and safety analysis model that can be applied to determine risks on PFS related activities. An intrinsically safe working environment is equally needed at petrol filling station.

During the study no guidelines were found with reference to the use of a particular risk analysis model for specific industrial use. It was also noticed that companies were using risk analysis methods without any consultation with the experts. It may be the root cause of occurrences of non-compliances that can lead to any catastrophic event. This can be considered as the main cause for occurrences of fatalities, accident and incidents in industries. Therefore, there is a need for the development of industry specific risk analysis models.

1.5. Checking and Review Process Based upon HSE Non-Compliances

Checking and corrective action is an essential component to measure the workability of any proposed system of practices. In this study to measure the checking and creativeness of a study a corrective and measurement framework was developed, proposed, implemented and tested. The methodology for corrective and checking framework is illustrated in Figure 1.5.

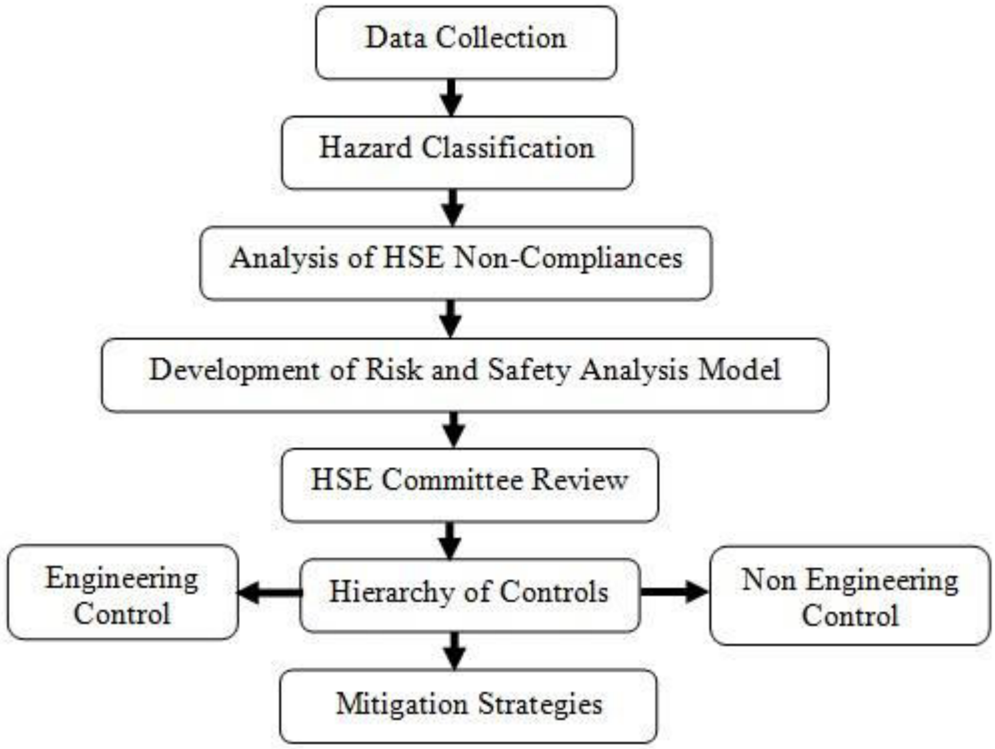

Figure 1.5: Flow Diagram of Checking and Review Process Based upon HSE Non-Compliances

The framework consists of seven steps. The detailed description of each process is presented in chapter 4.

1.6. Problem Statement

Occurrences of accidents, incidents and near miss cases are quite common at PFSs. The principal factors for occurrences of unsafe acts and unsafe conditions are due to variations in hazard contributing factors and the use of inappropriate risk assessment criteria. Various risk assessment criteria are currently in practice in many organizations. Continuous occurrences of hazard contributing factors during operations and maintenance of PFS's indicate weaknesses in these approaches. These hazard contributing factors have the potential to create unwanted scenarios at PFS's. Therefore, there is a need to develop a risk assessment method that prioritizes hazards and calculates the risk value to assist health safety and environment professionals in their decision making. This study will focus on the identification of the hazard contributing factors and the development of the safety and risk assessment criteria model in depth.

1.7. Objectives

This research endeavors to address the following objectives:

i. Identification and Classification of Hazard Contributing Factors (HCFs) during the Operation and Maintenance of PFS's.
ii. Develop a Safety and Risk Assessment Model for PFS's.
iii. Forecast Hazardous Events that can be occur in future.
iv. Develop Safety Triangle for PFS's.

1.8. Scope of Study

The study is comprised of 3.5 years of data that was collected from 2500 petrol filling stations located in various cities of Pakistan. The duration of the data collection was from July 2007 to December 2010.

1.9. Structure of Thesis

This thesis is structured in five chapters. The first chapter gives an introduction to the whole research in addition to brief background on all the concepts involved in this work, the problem statement was discussed, objectives and finally scope of research. Chapter two provides related works and mentions reviews of literature. Methodology of this research was illustrated in chapter three. Chapter four discusses the results of monthly, quarterly and seasonal classification of HSE Non-Compliances, risk and safety analysis models, analytical hierarchy process, development of safety triangle for PFS and exponential smoothing approach. The last chapter is the conclusion and recommendations. It concludes the major conclusions of this research work, recommendations for future research and research contribution to the body of knowledge.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

This chapter intends to review literature related to petrol filling stations (PFS) and also link it with the present situation. This research concentrates on enhancing the safety measures at PFSs. PFS is a common facility that is equally important in urban and rural areas. It is important being the only source of fuel supply to automobiles. PFS stores variety of fuels such as petrol, diesel, gas and compressed natural gas (CNG), a little negligence has potential to cause catastrophic loss to the human, company assets and environment. The proposed study is considered as an effective work as it produced a methodology for the development of risk and safety assessment models after incorporating gaps and drawbacks noticed in present risk assessment methods. The literature review covers various terminologies that are essential for better understanding of the study work. In subsequent sections literature related to objectives of the study will be presented.

2.2. Terminologies

The following terminologies were used for the study conducted. These terminologies will help to clearly understand the concept and framework proposed in this study.

2.2.1. HSE Non-Compliances

HSE Non-Compliances can be defined as “The unsafe acts and unsafe conditions (UAUCs) recorded during the operation and maintenance of PFS’s within the 3.5 year data collection period. These UAUC’s have the potential to create unwanted scenarios and harmful effects on people, the environment and company assets”.

2.2.2. Unsafe Act

The unsafe act is a violation of an accepted safe procedure which could permit the occurrence of an accident.

Examples of unsafe acts are as follows:

- Operating without authority
- Failure to wear or secure
- Operating at improper speed
- Making safety devices inoperable
- Using defective equipment
- Using equipment improperly
- Failure to use personal protective equipment
- Improper loading or placement
- Improper lifting
- Taking improper position
- Servicing equipment in motion

2.2.3. Unsafe Condition

The unsafe condition is a hazardous physical condition or circumstance which could directly permit the occurrence of an accident. This could be the result of an unsafe act by someone.

Examples of unsafe conditions are as follows;

- Inadequate guards or protection
- Defective tools, equipment, substances
- Congestion
- Inadequate warning system
- Fire and explosion hazards
- Substandard housekeeping
- Hazardous atmospheric conditions due to gases, dust, fumes, vapours etc
- Excessive noise
- Radiation exposure
- Inadequate illumination or ventilation

2.2.4. Risk

Risk is the product of the occurrences of a hazardous event or exposure and the severity of the injury or ill health that can be caused by event or exposure [26].

2.2.5. Severity

Severity is defined as the degree of injury or illness which is reasonably predictable [26].

2.2.6. Likelihood

Likelihood is defined as the chance that a given event will occur [26].

2.2.7. Risk Control

Risk control is the process of deciding how and to what extent risk factors can be reduced or eliminated by considering the risk assessment, engineering factors, and social, economic and political concerns [27].

2.2.8. Risk Assessment

Risk assessment is a process of evaluating the risk arising from a hazard taking into account the adequacy of any existing controls, and deciding whether the risk is acceptable or not [27].

2.2.9. Hazard

A hazard can be a situation, condition or environment which has a potential to cause harm, damage, human injury or ill health, or combination of these [26].

2.2.10. Accident

Accidents are unexpected happenings that may cause loss or injuries to people who are not at fault for causing the injuries. Accidents have a potential to cause a fatal occupational injury or non fatal occupational injury [26].

2.2.11. Incident

An incident is an undesired event which under slightly different circumstances could have resulted in harm to people or failure of a process [26].

2.2.12. Near Miss

Near misses are events that occur without causing injuries to the people involved [26]. Most accidents occur as a result of an unsafe condition or unsafe action coming together with a person. The end result is the person gets injured. Often unsafe acts or unsafe conditions have several misfires and the result is a near miss accident or incident. The only difference between a near miss and an accident is luck.

2.3. Accidents and Causes

Safety matters play a vital role on the reputation, well being and marketability of companies associated with retail outlet businesses. These firms have direct customer dealings during the everyday operation of their business. The petrol filling station (PFS) is one of those kinds of businesses in which the relationship between the firm and the customer is of vital importance. A growth in the population yields an increase in the number of vehicles; therefore, the rise in the demands for PFS's is obvious. At PFS's, the significance of safety aspect considerations vary from company to company. Matters pertaining to safety issues also vary from country to country. It was noticed that attention towards safety principals were more important in developed countries as compared to developing countries. Developing countries prefer to give less focus on reporting occupational health & safety deficiencies; thus, they were found to possess no records. Therefore, very little room exists to do improvement. On the other hand, developed countries possess data bases, records and histories of their occupational health & safety statistics. By manipulating this data, they can figure out the problems in a better manner to resolve the issues. Therefore, safety records in developed countries are improving continuously. Occupational accident estimates were elaborated by [28] using World Bank divisions. Table 2.1 shows the occupational accidents by continent in 1994, 1998 and 2001.

Table 2.1: Occupational Accidents by Continent in 1994, 1998 and 2001

Continent	Fatal Accident			Accident causing greater than 3 days absence (average)	
	1994	1998	2001	1998	2001
Africa	62604	61237	59332	46733548	45279851
America	33910	37313	47047	28475899	35904311
Asia	212774	222776	223407	170013413	170494538
Europe	23328	23110	20377	17636367	15550859
Australia and Oceania	944	979	1040	747422	793712
World	333560	347414	353204	263606649	268023272

A petrol filling station operating company in Pakistan [29] achieved 27.21 million safe operational man hours without any lost work days from July 2002 to June 2007. The incident rate remained at 0.669% for the (FY 06–07). The potential causes of unsafe acts and unsafe conditions reported were poor housekeeping, snakebites, carelessness, poor maintenance, electrical faults, mechanical faults and miscellaneous cases. The Pakistan State Oil (PSO) incident cause analysis as depicted in Figure 2.1 highlights the percentage distribution of incident causes during operation and maintenance of a PFS.

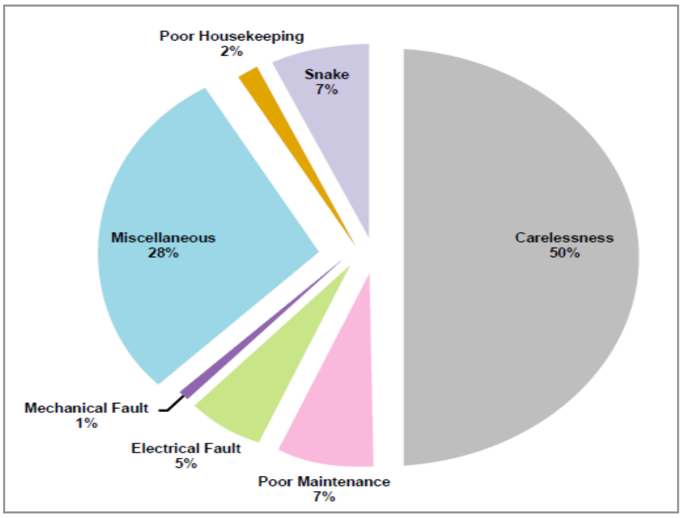

Figure 2.1: PSO Incident Cause Analysis

PFS's are normally operated in 3 main ways. These are fuel station company operated retail outlets, contractor operated retail outlets and company & contractor operated retail outlets. More violations related to standard operating procedures were observed at petrol filling stations operated by contractors operated and company-contractor operated. The PSO report 2007 highlighted that unsafe acts and unsafe conditions were caused by contractor's workers during the period 2008. Figure 2.2 shows the incident cause analysis results observed by contractors.

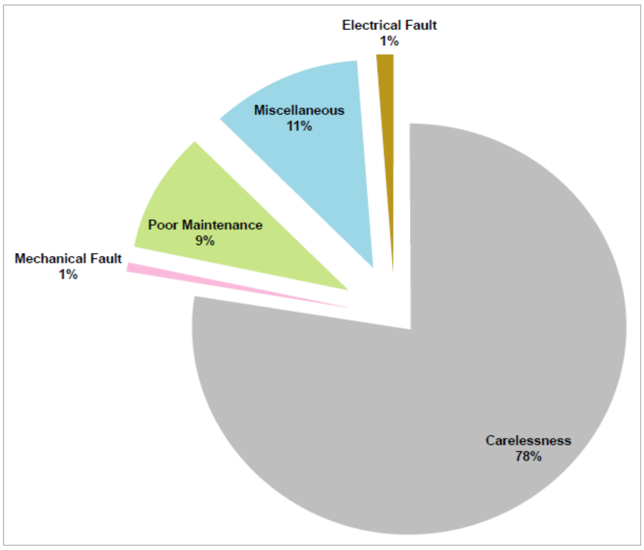

Figure 2.2: Contractor Incident Cause Analysis

The incidents reported by contractors and the PSO were 172 and 130, respectively. The PSO and the contractors identified carelessness as the main root cause for the occurrences of incidents [29]. Table 2.2 shows the monthly distribution of incident occurrences by the PSO and the contractors from July 2006 to June 2007.

Table 2.2**:** Summary of Incident (FY 06-07) for PSO Employees and Contractors

Months	July	Aug	Sep	Oct	Nov	Dec	
Year	2006	2006	2006	2006	2006	2006	
PSO	12	5	20	6	8	4	
Contractor	13	16	21	5	17	8	
Total	25	21	41	11	25	12	
Months	Jan	Feb	Mar	Apr	May	June	
Year	2007	2007	2007	2007	2007	2007	Total
PSO	12	6	12	9	14	22	130
Contractor	2	9	17	15	16	33	172
Total	14	15	29	24	30	55	302

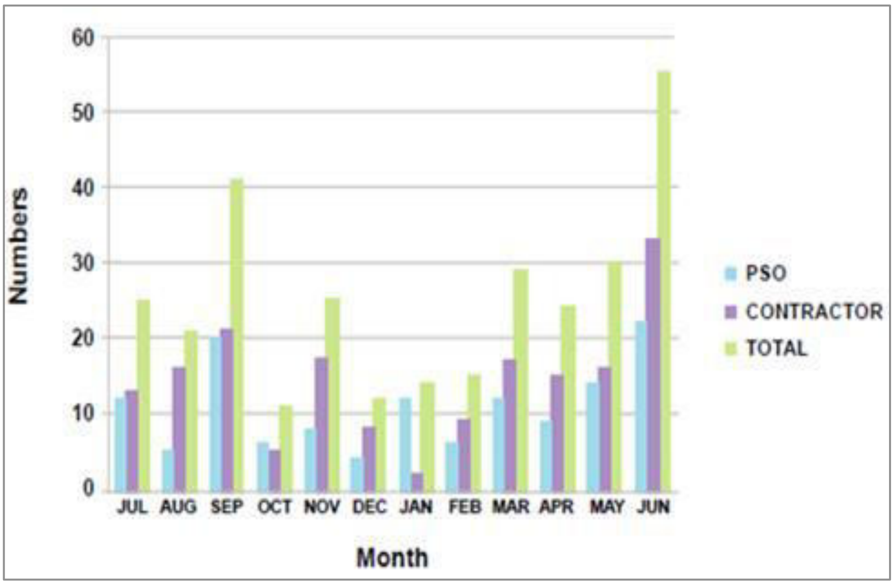

Figure 2.3: Monthly Occurrences of Unsafe Acts and Unsafe Conditions at PFS

Figure 2.3 shows the graphical representation of the monthly occurrences of incident cases by the contractors and the PSO. It can be observed that the highest number of incident cases was reported in the months of September 2006 and June 2007.

Many safety studies have been conducted to highlight the importance of safety climate and safety culture. Safety culture development at fuel stations could reduce the occurrences of hazardous conditions. Safety culture comes from the people's behaviour and their way of working. To produce a safety climate at sites, more effort is needed from the management. The application of a safety climate has been addressed in many studies. The safety climate plays a vital role to reduce accidents and injuries during work operation and was investigated by [30-33]. A safety culture introduced in an organization to minimize incidents has been identified as more helpful to improve health safety and environment statistics in an organization and was studied by [29, 34-36]. Safety practices in developing countries were studied by [37] and reported as unsatisfactory. Continuously, the accident, incident and fatality rates were found increased due to negligence towards safety matters. In many organizations, the safety rules and regulations exist but implementation is found to be weak. Implementation of the safety rules and regulations can be improved by incorporating them into government legislations. The enforcement can be carried out through government authorities. It was mentioned by [38] that one of the main reasons to give a significance value to safety aspects is the weak structure of occupational health and safety guidelines in a country's byelaws and regulations.

2.4. Components of Petrol Filling Stations

A petrol filling station (PFS) is a facility where petrol or other fuels such as kerosene oil, diesel and compressed natural gas are sold. Apart from the selling of fuel, other amenities to facilitate customers are available. It includes minor automobile repair services, mini shopping market, automated teller machine (ATM) card machines, public toilets and water dispenser units [39]. The availability of the desired facilities depends upon a customer's needs and requirements. The main components of PFS's can be categorized into 10 elements; these 10 elements are further divided into sub groups. Table 2.3 highlights the main components of PFS's.

Table 2.3: Components of Petrol Filling Stations

1-Fuel System	2-Forecourts	3-Non Fuel	4-Equipments
• Underground Storage Tanks • Fuel supply pumps Fuel supply piping system and • Tank Lorries (T/Ls)	• Surfacing • Islands • Oil separator	• By the way • Car wash • Tyre shop • Oil Suction • Machine • Service Bays	• Generator • Compressor
5-CNG	**6-Allied Facilities**	**7-Signages**	
• CNG island • Compressor shed • Fire rated wall • Control room • Pipe Channel	• Restaurant • Prayer Area • Credit Card Reader • Security post • Public Toilets • Water cooler • Truck parking Shed	• Car wash • Restaurant • Lube trolleys • Decantation sign • Fire extinguishers and buckets • Canopy column • Safety signs	• Canopy Fascia • Monolith/ Flag/Pole • In/Out/CNG • Site Name • Service block • Shop fascia • Tyre shop • Waiting room • Oil change
8- Canopy			

9- Forecourt: Forecourts are normally designed as tollgate, echelon or four square arrangements. The provision of forecourt depends upon the availability of space. Figure 2.4 shows the three main design shapes of forecourt.

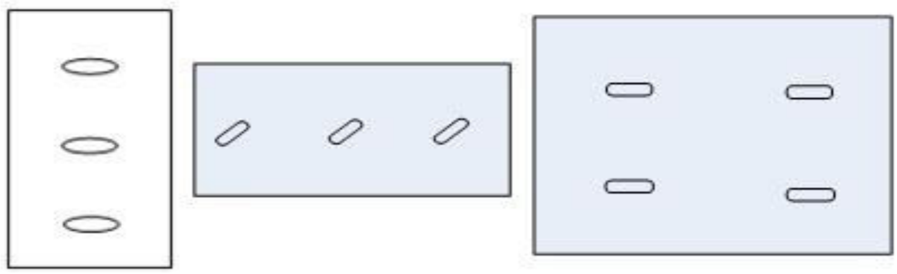

Figure 2.4 Tollgate, Echelon and Square Configuration of Forecourts

10-Fuel Tanks: Fuel tanks are normally bitumen coated single skinned mild steel tanks. The fuel tanks are located depending upon the safe decantation position of the Tank Lorries and to minimize pipe-work costs. The number of tanks required is determined by selecting the closest configuration of the three nominal sizes which best meet the sales volumes for a five (5) day fuel supply. The nominal tank sizes are 18000, 27000 and 45000 liters. Tanks maybe single or double compartment for the 45000 liters tank. Reinforced concrete pits were provided around the tanks.

Numbers of accidents cases reported at PFS associated with these components. It was reported in a study conducted in France [18] that during operation and maintenance of a PFS the activities such as general operation or unspecified specific circumstances, fuel procurement operations and maintenance work shall be given due considerations. Table 2.4 illustrates an origin and circumstances of accidents cases related to these trades.

Table 2.4: Origin and Circumstances of the Accidents [18]

Origin	Circumstances						
	Maintenance / Renovation/ Test	Petrol Station Procurement	Fuel Distribution of Customers	Stopped Petrol Station	General Operations / Unspecified Circumstances	Total Number of Accidents	%age Among Accidents of Known Origins
Tanks and connected equipment	10	10	0	0	47	**67**	**30.5%**
Tank fill units	0	15	0	0	0	**15**	**7%**
Pipes	2	2	0	0	32	**36**	**16.6%**
Fuel pumps and connected equipment	0	1	14	0	17	**32**	**15%**
Stores / Annexes	1	4	0	0	27	**32**	**15%**
Water treatment equipment	2	0	0	0	4	**6**	**3%**
Petrol station delivery vehicles	0	5	0	0	0	**5**	**2%**
Customers vehicles	0	0	7	0	11	**18**	**8%**
Petrol station is general	1	0	0	0	5	**6**	**3%**
Unknown	0	10	1	1	41	**53**	
Total	16	47	22	1	184	**270**	
%age	**6%**	**17.5%**	**8%**	**0.5%**	**68%**		

2.5. Hazardous Effects of Petrol Filling Stations

Hazard contributing factors for every industry are different. Petrol filling station have potential hazards to the people, assets, environment and reputation of an operating company. Fire hazards, static electricity, and air pollution induced by aliphatic and aromatic organic compounds are major causes of accident/incident occurrence at PFS's. A Table 2.5 shows the human and environmental consequences due to petrol filling stations. Total 27 fatalities cases were reported in 8 accidents.

Table 2.5: Consequences of Incidents [18]

Description	Number of Accidents	
Human Consequences	Fatal	8
	Causing serious injury	16
Environmental Consequences		157
Material Damage	Internal	74
	External	19

There are other hazards available in fuel station operations which make them unsafe. Activities such as carelessness, maintenance, housekeeping, slips, trips and falls, transportation hazard, major and minor injuries, robbery and snakebites have a potential to create unsafe conditions. The level of risk of these hazards varies according to location and country. Moreover, the emphasis on safety considerations by the government is variable all around the world. Developed countries' safety records are much better as compared to developing countries. Developed countries found to practice significant safety improvement techniques that are useful to reduce the occurrences of unsafe acts and unsafe conditions. Filling stations are the most commonly available facilities that contain flammable and hazardous materials in urban, rural and most importantly in a close vicinity of human beings. Due to the continuous operation of petrol filling stations, they pose various hazards to people, the environment and the assets of an organization. The PFS operation is unique as compared to other businesses. For a smooth operation, it demands the involvement of the operating company, contractor and operator groups.

The enterprise business covers the distribution of fuel to retail outlets in urban and rural areas, airport refueling and filling in refineries as well. The workplace safety condition indicates the health of a company as well as the competence and commitment of the management. Caltex is a petrol filling station retail outlet organization operating in many countries around the world. According to [19], the total personnel on board recorded was 3,022. The recorded total treated injury frequency rate (TTIFR) for employees was 21 in the year 2002 and 16 in the year 2003; whereas, for contractors, the TTIFR was 30 in the year 2002 and 12 in the year 2003. Table 2.5 illustrates the TTIFR of Caltex for the years 2002 and 2003.

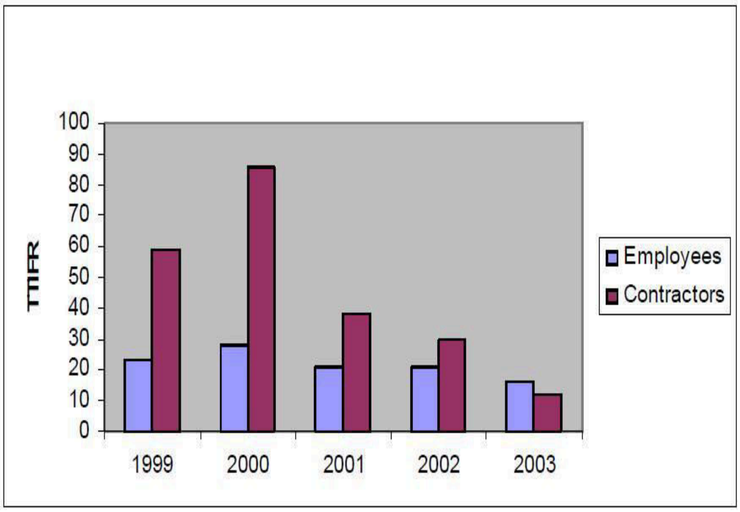

Figure 2.5:

Caltex's Total Treated Injury Frequency Rate for the Year 2002 & 2003

Local and global issues also have a significant impact on the operation and maintenance of PFS's. Local issues are normally covered in a country's byelaws, rules and regulations, whereas global issues are mainly addressed through international laws. Global issues have an impact on occupational accident trends in developed and developing countries. The process of globalization depends upon many factors. They include changes in the market, production, finance and communication [40]. Occupational health & safety (OHS) practice is growing very rapidly in all industrial areas. PFS operating companies are also giving more attention to adhering to OHS rules at their outlets. Human behaviour intervention to reduce occurrences of unsafe acts and unsafe conditions was studied by [41] and it was concluded that people associated with the workplace and from inside and outside of the organization can contribute to accident prevention.

No approach was found during this study that can combine unsafe acts and unsafe conditions to improve safety performances at the workplace. It was mentioned by [42] that more accidents were recorded due to the negligence of human. It was also reported that the severity of accidents caused by human negligence was high. The weak technical structure of an organization was studied by [38, 43, 44] and reported to be a main attribute of accident occurrences.

Integration of people with the outlet facilities creates a homogeneous safety culture for a short time period in a regular sequence. However, it varies from place to place as PFS's are located in urban and rural areas. Road configuration, people's visits for re-fuelling, variety of vehicles, local area surroundings, natural conditions, environmental configuration, infrastructure facilities, urban development etc are totally different from one retail outlet to another. The factors that can create unsafe and disastrous situations are also the results of that safety culture. The importance of addressing cultural aspects has been highlighted by recent well publicized major loss events such as [35, 36, 45] and the inquiry into the Ladbroke Grove rail accident [32]. The studies conducted by [31, 33, 46, 47] demonstrated a relationship between organizational culture and safety performance. The studies highlighted that organizational culture has spawned an increased interest in the identification of methods that allow the measurement of organizational culture.

2.5.1. Effects of PFS's on Human Health

Automobile refuelling is one of the main causes of benzene vapour production. It has severe health effects on workers and staff. It was published in Environmental Protection in February 2011, that in Spain, it is relatively common to come across petrol filling stations closer to houses, schools, shopping centers and hospitals especially in urban areas. Effects of the contamination at the petrol stations that was potentially harmful to health can be noted in buildings less than 100 meters from the service stations. "Some airborne organic compounds – such as benzene, which increases the risk of cancer – have been recorded at petrol stations at levels above the average levels for urban areas where traffic was the primary source of emission". The immediate surroundings of a PFS contain emissions from evaporated vehicle fuels. A minimum of 50 meters distance should be maintained between PFS's and housing, and 100 meters for hospitals, health centers, schools and old people's homes [17]. Figure 2.6 shows a PFS that was located in the close vicinity of residential buildings.

Figure 2.6: Operation of PFS in Immediate Vicinity of Houses and Commercial Building [17]

The cases reported during operation and maintenance of petrol filling stations related to damaging and tilting of petrol filling station roof due to high winds pressure. A Figure 2.7 illustrating a damaged rooftop at a gasoline station along the main highway of Cauayan town after Typhoon Megi hit Isabela province in Philppines.

Figure 2.7: The Roof of a Petrol Station gets Damaged by Typhoon Megi in Isabela Province, Northern Philippines. (19^{th} October, 2010)

Petrol filling stations have hazardous effects on workers as well as occupants residing closer to them. High volatile organic carbon (VOC) levels were recorded among the occupant workers exposed to gasoline vapour emissions and motor vehicle exhausts for a long duration. A study conducted by [48] demonstrated that PFS workers were exposed to higher VOC levels than workers who were not in direct contact with the VOCs. The health risk assessment conducted showed that PFS's have a lifetime cancer risk due to the high level of benzene and 1-3 butadiene. The VOCs associated with gasoline vapor emissions and motor vehicle exhaust, were pollutants of concern because of their toxicity that was reported in studies conducted by [49, 50]. Other studies conducted on occupational exposure to the VOCs from gasoline vapour emissions were [51, 52]. These studies reported that the workers were exposed to highly elevated VOC levels as compared with ambient levels by inhalation, ingestion, and dermal contact. VOCs remain as gases when emitted into the air. The VOCs were not subject to appreciable deposition to soil, surface waters, or plants. Therefore, human exposure does not occur to any appreciable extent via ingestion or dermal exposure. Significant exposure to these volatile organic toxicants emitted into the air only occurs through the inhalation pathway [53], and has therefore gained the attention of researchers. Currently, [54] has classified benzene as a human carcinogen and 1-3-butadiene, chloroform, richloroethylene and 1-4 dioxane have been classified as possible human carcinogens. Benzene has significant risks to the health of workers and occupants. The impact of benzene on the working staff can be minimized with the use of a vapor recovery system. It was reported by [48] that gas service stations should consider the use of vapor recovery systems, which are mandatory in many other countries, and strict measures to control the gasoline emission during the gasoline transmission to storage and transport trucks.

2.5.2. Effects of PFS's on the Environment

Petrol filling stations have harmful effects on the environment, i.e., land, air and water. Guidelines provided by [55, 56] are related to water system protection from underground storage tank leakage, vicinity area protection from PFS fires, explosion hazards, the proper land use selection and minimizing disturbances to access road selection due to in-out activity. Table 2.6 highlights the distance criteria for different objectives related to PFS's.

Table 2.6: Distance Criteria Related to Different Objectives

Objective	Criteria	Indicator
Water system protection from underground storage tanks leaking.	Safe the groundwater	At least 300 ft from groundwater
	Safe the seawater	At least 3.250 ft from saline water
	Safe the river and lake	At least 500 ft from river and lake
	Safe the private well	At least 250 ft from artesis well
Vicinity area protection from petrol filling station's fire and explosion hazard	Minimizing impact for the residential properties	At least 500 ft from residential properties
	Minimizing impact for the nearest hospital and school	At least 100 ft from hospital and school
	Avoiding electro static environment	At least 150 ft from High Voltage Area
Proper land use selection	Land availability	At least 12.000 ft^2 on vacant land
	Safety UST's construction	Less than 35% steep
	Land use	Located in commercial/industrial zone
Minimizing disturbance to access road selection due to in-out activity	Distance to intersection	At least 250 ft from intersection
	Distance to road	At least 40 ft from road property boundaries
	Distance to grade crossing	At least 820 ft from grade crossing

Source: [55, 56]

Petrol can give rise to health problems. It can be dangerous with excessive skin contact, aspiration, ingestion or vapor inhalation [57]. The sources of pollution released from petrol filling stations contaminate air, soil, and water [8]. Figure 2.8 shows the impact of fuel leakage from underground storage tanks and its impact on the surroundings.

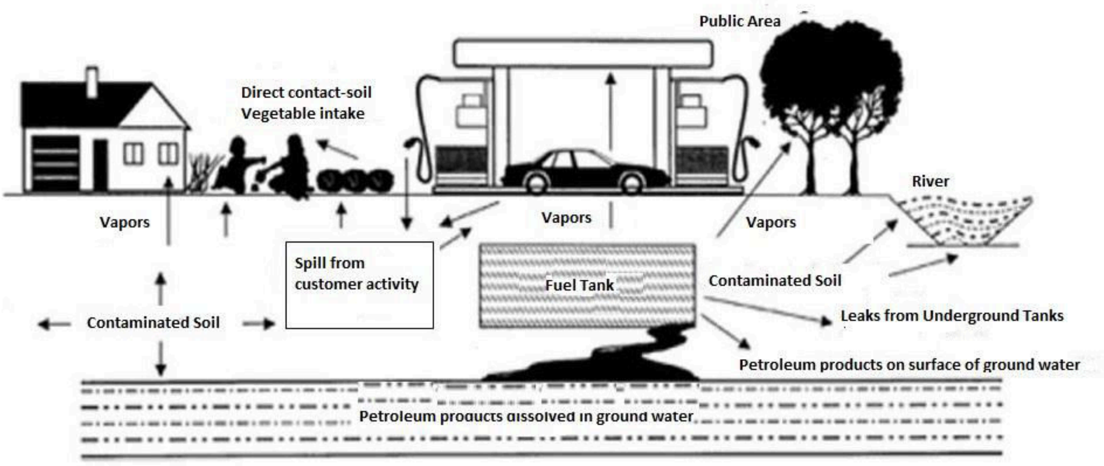

Figure 2.8: Typical Flow Diagram of Fuel Leakage and Spill during PFS Operation

2.5.3. Soil Contamination

Leakages from underground storage tanks and directly from PFS's are the two main sources of seepage of fuel into the soil. In cases of spillage, part of the fuel evaporates but most of it sinks into the soil. The degree of contamination depends upon the soil characteristics. If the soil is fine, fuel can be retained in the soil. That sites are termed as contaminated sites but it can be removed. The soil can be treated by using a bioremediation process and other practices as well. When the soil texture is medium or coarse, it would be more hazardous as among the spaces in the soil, the pollutants migrate down towards the water table and mix with the ground water aquifer. The significant sources of soil contamination were tank leakages at PFS's, spills on motorways and uncontrolled petrol waste disposal [16]. Different processes related to soil and groundwater contamination are depicted in Figure 2.9.

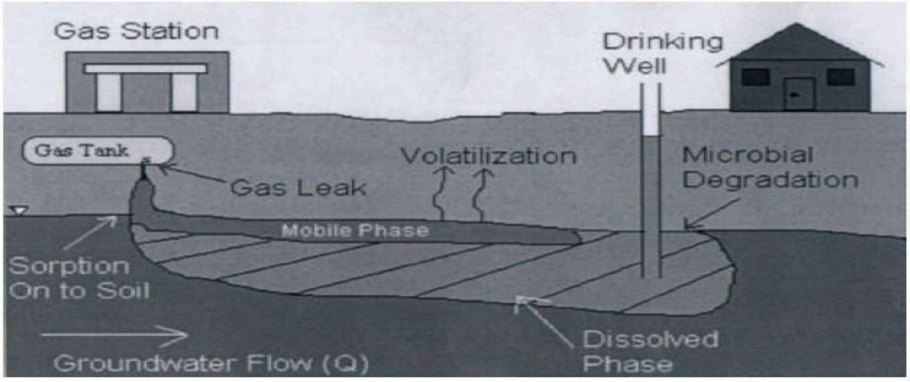

Figure 2.9: Effects of Petrol Retail Outlet on Soil, Ground Water Aquifer and Surroundings [16]

2.5.4. Water Contamination

Petrol, diesel and kerosene oil are aromatic hydrocarbons. These compounds are termed as BTEX (benzene, ethyl benzene, toluene and xylene) [30]. Aromatic hydrocarbons are hazardous to health. Their mixing with water is harmful to human beings, flora and fauna. Normally, the potential source of these aromatic hydrocarbons into water bodies is from leakages of underground storage tanks, spills from fuel transportation lorries, leakages from fuel supply pipelines, chemical industries, petrochemical industries, oil and gas fields, evaporation ponds, and petrol filling stations. At PFS's there are three potential sources that contribute to the release of aromatic hydrocarbons into the environment. Leakages of petrol and other hydrocarbons from vehicles during filling operations, minor and major leakages during filling of underground storage tanks by tank lorries and leakages from underground tanks are the potential sources of aromatic hydrocarbons into the environment. During washing and cleaning of PFS's, the drainage water disposed of directly into the municipal drainage system without any treatment. During a 3.5 year data collection period from more than 2500 retail outlets, no septic tank was found at any fuel station. As the municipal wastewater normally discharges to the rivers or ponds after only minor treatment, these aromatic compounds reach water bodies and affect aquatic life. In addition, these compounds pollute the natural environment by penetrating into the atmosphere from where they are distributed via snow and rain into the soil, surface and ground water as well [58]. The degree of the contamination is represented in Figure 2.10 below. The pollutant concentration is measured in ppb (parts per billion).

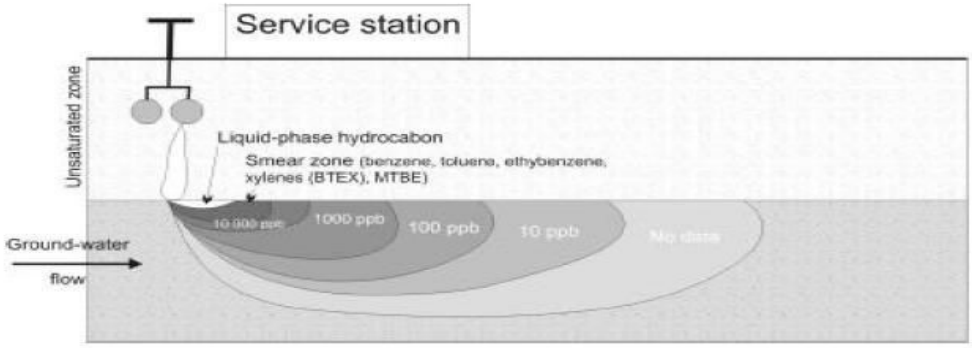

Figure 2.10: Concentration of the Pollutant in Groundwater Depending on Distance from Source of the Pollution [58]

2.6. Theories of Accident Causation

Unsafe acts and unsafe conditions cause dangerous cases at workplaces and are the potential cause of occurrences of fatalities, accidents, incidents and near miss cases. A study conducted by [59] in 1959, he proposed his findings through Figure 2.11 and illustrated that approximately 88% of all accidents are happened because of unsafe acts of people, 10% by surrounding unsafe conditions, and 2% by the act of God.

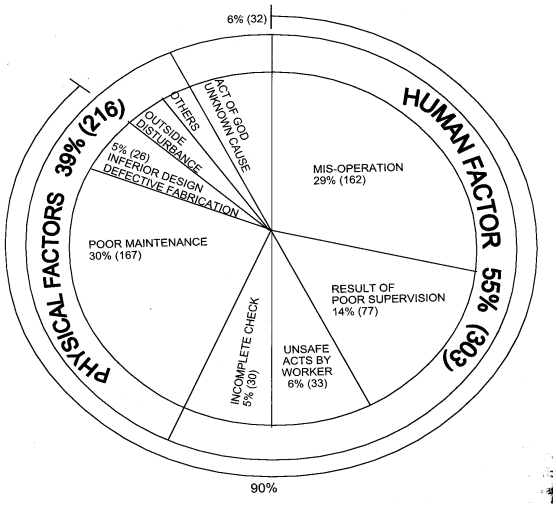

Figure 2.11: Accident-Cause Classification (Total Number of Accidents = 531) Figure in Brackets Denotes Number of Accidents (Henrich. 1959)

A strong relationship exists among the root causes of dangerous cases. Dangerous cases posse's tendency to cause one fatality case to multiple fatalities. But on the other side dangerous cases may cause accident, incident and near miss cases. An occurrence of fatalities, accidents, incidents and near miss cases is depends upon the severity of dangerous cases. A study conducted by [60] in 1950 to determine the relationship among major or lost time injury, minor injuries and no injury accidents. He indicated that 300 no injury cases (near miss) will give rise to 29 minor injuries and 1 lost time or major injury case. He proposed an accident causation triangle as shown in Figure 2.12.

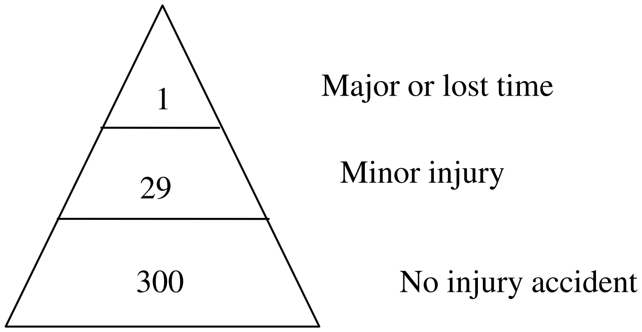

Figure 2.12: Heinrich Accident Causation Triangle

Another study was conducted by Bird in 1969 to further explore the causes of dangerous cases. Bird's research work added one more step in the accident causation triangle with some modifications [27]. He splits the triangle into four components. According to Bird, 1 serious or disabling injury case is followed by 10 minor injuries, 30 property damage accidents and 600 incidents with no visible injuries or damages. Figure 2.13 shows the Bird's approach to address accident causation.

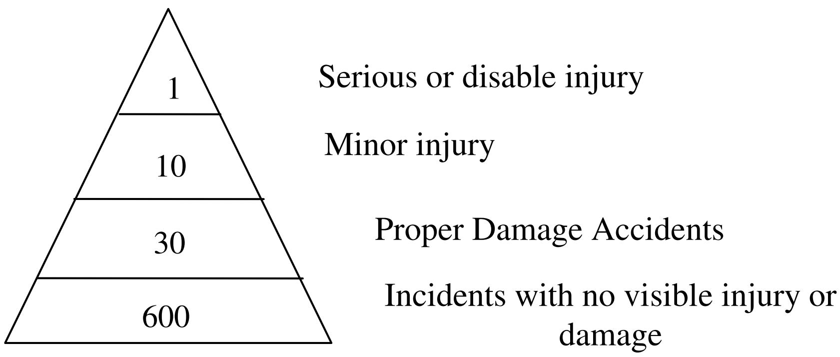

Figure 2.13: Bird's Approach to Address Accident Causation

Further research was conducted by Tye & Pearson in 1974 to explore the relationship among dangerous cases. They split the accident causation triangle into 5 main components [27]. The description of the Tye & Pearson triangle is shown in Figure 2.14.

Figure 2.14: Tye & Pearson Study (1974) Variations on Accident Ratio Approach

The accident causation triangles proposed by Heinrich in 1950, Bird in 1969 and Tye & Pearson in 1974 vary from study to study but the basic principle remains the same. It was often a matter of chance whether dangerous events caused ill health, injury or damage. The "no-injury" incidents and "near misses" in each case has the potential to become an event with more serious consequences. However, not all near misses involve risks which might have caused fatal or serious injury. What all the cases do indicate is a failure of control. The "near misses" at the base of the accident triangles offer preventative opportunities. If action can be taken at this level, the chances of more serious injuries occurring will be greatly reduced.

2.7. Hazard Contributing Factors for Petrol Filling Stations

Petrol filling stations (PFS's) are normally located within a close vicinity of an urban environment. The significance of the PFS is also important along the highway/roadside to facilitate customer vehicles for fuelling. Various hazards are present during the operation and maintenance of the PFS. These hazards cause fatalities, accidents, incidents and near miss cases within urban and rural environments. The situation becomes more problematic if public places such as shopping centers, hospitals, schools, commercial areas and water bodies are available. There are many factors that contribute to create hazardous situations during the operation and maintenance of the PFS. During the data collection period it was found that the identified root causes of occurrences of these hazards were housekeeping

(HK), transportation hazard (TH), slips, trips and falls (STF), carelessness (C), fire risks (FR), electrical fault (EF), miscellaneous cases (MC) and medical treatment cases (MTC). These hazards are caused due to unsafe acts and unsafe conditions (UAUC). Reduction in occurrences of UAUC cases can be improved with modifications of human behaviour. Researchers proposed safety instruments that incorporate human behavioural change for reduction in accident/incident causation. The noticeable improvements can observed with the change from of human unsafe behaviour to safe behaviour. Studies conducted by [61-63] found that the higher the safe performance the lower the accident rate.

Hazard contributing factors (HCFs) were found to be different at different operating facilities. HCFs were primarily classified into 8 main categorizes, i.e., housekeeping (HK), transportation hazard (TH), slips, trips and falls (STF), carelessness (C), fire risks (FR), electrical faults (EF), miscellaneous cases (MC) and medical treatment cases (MTC). These HCFs have a significant impact on humans, the environment and company assets. During the study, it was found that data collected from PFS's varies from one PFS to another PFS. It was due to the differences in safety conditions, size and location, safety advisor observation approach, management commitment, fuel storage capacities, composition and the number of vehicles visiting the PFS. The distribution of hazard contributing factors can be carried out in different ways to identify the potential hazards. As normally, the health and safety professionals have so much data and it is difficult to find which hazard is more prominent in a particular period, the different ways of hazard classification are useful to target particular hazards in a specific period.

The hazards can be classified on:

- Monthly Distribution of Hazard Contributing Factors
- Quarterly Distribution of Hazard Contributing Factors
- Seasonal Distribution of Hazard Contributing Factors

2.7.1. Monthly Distribution of Hazard Contributing Factors

Monthly distribution of Hazard Contributing Factors (HCF) is an important tool to see the flow pattern of HCF. It helps to understand the variation in nature and variety of hazards on monthly interval. Health, Safety and Environment (HSE) committee meetings in companies normally organized either on monthly or quarterly basis. The results of monthly and quarterly distribution of HCFs are useful to present the HSE statistics in these meetings and discuss solutions for prevention of occurrences in future. Annual HSE plans also discussed and reviewed on monthly basis in organizations. It was reported in [64] that teams meetings held on monthly basis and all officers participates, internal and external reports prepared on the health and safety service progress and measured against action plan and targets. In a study conducted by [65] the risk classification results ranging from low, medium to high risk were also collected on monthly duration and reported to safety professionals to review status and progress of health and environment matters. The monthly classification was also reported beneficial by [66, 67] as normally newsletters, HSE articles and review literature published on monthly duration; it contains HSE comparative studies and records. Therefore, by analyzing activities on monthly duration also helpful to compare actual results with past studies.

2.7.2. Quarterly Distribution of Hazard Contributing Factors

The distribution of Hazard Contributing Factors (HCFs) on quarterly basis is equally important as monthly distribution. The monthly and quarterly distribution of activities has various similarities such as risk assessment analysis, HSE committee meeting scheduling, and to measure progress of annual HSE targets and plans. The analysis and review of data in various legislations also required quarterly review [68]. A quarterly distribution of activities is very viable to show flow patter on large amount of data. The HSE statistics between the year 1997 and 2010 was presented on quarterly basis in [69]. It was reported by [65] that risk analysis on quarterly basis was found successful to improve unsafe acts and unsafe condition occurrences.

2.7.3. Seasonal Distribution of Hazard Contributing Factors

The seasonal classification of Hazard Contributing Factors introduced with reference to this study found very successful to analyze the data. A study conducted by [70] to measure lost time injuries among professional and youth players on seasonal basis. The data for the study was collected over the period 1994 and 1997. The injury frequency in youth players found to increase in second half of the season and it decreased for professional players. The seasonal distribution of data is normally used for large epidemiological studies. The variation in numbers of workers at construction site was studied by [71]. In his study work he identified seasonal variation of workers as the potential cause for occurrences of HSE non-compliances. Natural events such as hurricane and high wind during operation and maintenance of PFS were found one significant parameter. It also includes the fogs, mists and dusty environment that especially very important during fuel transportation operation. This aspects is mainly important for tank lorries. The significance of seasonal variations in climatically conditions was studied by [72] and noticeable fluctuations were reported. During the study a noticeable similarities in hazard contributing factors was recorded each year on seasonal basis.

2.8. Hazard Categorization

Hazard classification can be defined as "the process of distribution of data with reference to certain bench mark". Researchers termed them different names such as hazard categorization, hazard identification etc. For PFS, the terminology introduced here is named as "hazard contributing factors". Many activities and processes are in progress within close vicinity of a PFS. They include the arrival and departure of various kinds of vehicles at the PFS to buy fuel, filling of underground storage tanks, processing of various electrical components, shift operation and customer dealings at the retail stores. Due to the availability of flammable and hazardous materials every process generates a variety of hazards. In addition, fuel station components are unique as compared to other facilities. Every component creates different hazards for the smooth operation of the PFS. The proposed contributing factors was developed by using 3.5 years of data collection and introduced a new approach for the hazard distribution pattern for a PFS.

2.8.1. Housekeeping (HK)

Good housekeeping practices are the key to a safe workplace. To keep the workplace well organized is everyone's responsibility. Housekeeping encompasses cleanliness of facility, materials, tools & equipment, vehicles and the elimination of non essential materials and hazardous conditions. There are many advantages of good housekeeping, such as good housekeeping practices minimize the environmental impact of the activities, reduce the costs incurred due to slips, trips and falls, and other incident; moreover, it prevents fire incidents, maintains a pleasant and good work place etc. PFS's are located in rural and urban areas. In rural areas they have normally wide spaces as compared to urban areas. A growth of trees was found close to the boundary wall around a PFS. The growth of trees creates major hurdles during storm and thunderstorm seasons. The standard of housekeeping was found to be unsatisfactory to control this risk at PFS's. Good housekeeping practices help to prevent fires, tripping and contact hazards. Incidents reported during operation and maintenance of petrol filling station related to housekeeping include slips, trips and falls, articles dropping from above, slipping on greasy, wet or dirty surfaces, knocking into poorly stacked or misplaced materials and fire hazards.

Due to bad housekeeping practices, a scrap material was found unattended outside the scrap yard; moreover, an un-orderly pile of scrap material was placed in an open area adjacent to the PFS which is shown in Figure 2.15. The blowing of heavy winds was found to be quite common and a dominant hazardous factor for PFS's that were located in open areas. Cases have been reported in which due to high wind pressure, trees have fallen on the ground and created hindrances in movement of vehicles and have blocked the passage. It was also noticed that due to heavy winds blowing, the trees swing and touch the high voltage electricity cables. It may cause disastrous circumstances due to the generation of electromagnetic waves. Moreover, it was found that earthing cables were randomly placed on the ground. Figure 2.16 shows the laying of the earthing cables at the PFS. Emergency exits in offices and store areas were found to be blocked with unnecessary materials. Figure 2.17 shows that staff members were sitting close to emergency exit points. Unsatisfactory water drainage systems were also observed at the PFS. Figure 2.18 shows the electrical trenches full of water that could cause electrical sparks and short circuiting.

Figure 2.15: Retail Scrap and Inventory in Large Quantity at PFS.

Figure 2.16: Spillage Marks in Power Generation Room.

Figure 2.17: Access to Manual Call Point found Blocked.

Figure 2.18: Cable Trench was found Filled with Water.

Fire hazard exists where housekeeping is poor. It can be caused by oil-soaked rags and clothing, igniting from spontaneous combustion, piles of paper and other packaging materials being allowed to accumulate. A good housekeeping can be maintained at facility by considering;

- Good floor surface
- Kept clean and free of loose material
- Free of oil, grease, etc
- Floors are free of scrap & unnecessary articles
- Free of obstructions
- Safe and free passage to fire-fighting equipment and fire exits
- Safe and free access to staff
- Clearly defined
- Equipments are free from unnecessary dripping of oil or grease
- Area around machines cleaned and free of rags, paper, etc

- First-aid facilities and equipment fully stocked and in clean condition
- Properly piled and arranged
- Kept at designated areas
- Inspected and maintained at regular intervals
- Tool rooms and racks must be cleaned

2.8.2. Transportation Hazard (TH)

TH can be classified into two main categories, i.e., onsite and offsite. Onsite TH consists of hazards that are associated with the movement of T/Ls, other company vehicles and private/public modes of transportation within the PFS facility. While the offsite TH is comprised of hazards related to the mode of transportation outside the PFS facility. Onsite hazards that were recorded which involved T/Ls include collision with dispenser units, private vehicles, filling gantries, piping systems and with other T/Ls during the PFS operation. Offsite hazards that involved T/Ls were mostly collision with private vehicles. Offsite hazards include many factors such as a driver's perception, condition of T/Ls, road configuration and conditions, traffic congestion on road and the transportation route. Another important feature of fuel transportation via tankers is that they possess higher VOC loss into the atmosphere [73, 74]. Pedestrian injury pattern in Ghana was studied in a study [75] the cause of occurrence of pedestrian fatality was reported being hit by heavy vehicles, speeding, and roadside activities. The study also illustrated that by reducing vehicles speeds in settlements, providing medians on road, installing street lighting in settlement and minimizing roadside activities are helpful to reduce pedestrian fatalities.

Most of the accident cases related to these heavy vehicle collisions are published in newspapers. However, very few records have been found in company documents. Most fuel companies don't even maintain the records. If they maintain their records, they only keep them in their files. They don't extract the information from this data for further improvements.

Table 2.7: Work Related Fatality Cases Record in Few Countries [29]

Regions	Economically active population	Fatal accidents reported to the ILO (2003)	Best estimate: Fatal accidents 2003	Accidents causing at least 4 days' absence Average 2003	Work-related diseases	Work-related mortality	Deaths caused by dangerous substances
EME	427681309	11210	15159	14252505	269989	285148	90400
FSE	193354716	2111	14519	13650601	170166	184685	56976
CHN	740792400	180	97542	91706292	334138	431680	111879
IND	473300000	179	46928	44120055	355863	402791	119153
OAI	457166678	1247	80567	75746706	269541	350107	90250
SSA	273414298	15	57771	54314626	364554	422322	122062
LAC	222632385	2196	31165	29300625	107180	138345	35887
MEC	128010251	929	14296	13441062	73687	87984	24673
Total	2916352037	18067	357948	336532471	1945115	2303063	651279
EU-27	205431242	4422	7460	7013545	159485	166945	73989

Legend: world bank regions EME=established market economies FSE=Former socialist economies in Europe	IND = India CHN = China OAI = Other Asia and Islands	SSA = Sub-Saharan Africa LAC = Latin America and the Caribbean MEC = Middle Eastern Crescent

The safety record in developing and developed countries has considerable variations. More than 85% fatalities and 90% of disability-adjusted life years lost from traffic accidents occur in developing countries [76-78]. Table 2.7 shows the safety statistical records in different countries [28].

PFS operating companies have a vital role in the transportation network to provide the smooth operation of their business activities. Tank Lorries (T/Ls) during their operation and their maintenance at PFS's possess various kinds of hazards on allied facilities and staff. It was found that road accidents have the highest occupational risk in the retail outlet operations followed by fires, cleaning, electrical hazards, storms, filling operations, loading and unloading, slips, trips and falls and minor injuries. Occurrences of road accidents involving T/Ls are quite common. PFS operating companies have a vital role in the transportation network to provide a smooth operation of their business activities. PFS's are commonly located in the vicinity of populated areas to facilitate vehicle fuelling operations. They pose significant risks to people, property and the environment [30]. There are three modes of fuel transportation, i.e., railways, pipelines and road networks. Occurrences of accidents via railways are quite controlled, safe and functional but relatively slow as compared to transportation of fuel via road links and pipe networks. Transportation of fuel via T/Ls is mostly used during fuel transportation everywhere in the world. Occurrences of accidents related to this mode are also quite common. Although all three modes of fuel transportation have their own failure modes, transportation of fuel via road networks consists of many dependent variables. It involves many factors such as conditions of vehicles, driver's attitude & education level, company safety culture, road conditions, time of journey, allowable speed limits, climatic conditions, traffic congestion on the road etc. Every factor needs careful attention to reduce the risk down to an acceptable level.

During this study period, many accidents were reported during fuel transportation. In one accident, two T/Ls during overtaking on highways rolled over along the road. Both TLs drivers died on the spot, fuel spilled on the ground and the T/Ls were ruined completely. Figure 2.19 shows the T/Ls conditions at the scene.

Figure 2.19: During Overtaking on Highways T/Ls Rolled Down from Road. Driver Died on Scene

In another accident, two T/Ls rolled over off the road and went down the embankment. The T/Ls were damaged completely and all the fuel was lost as it spilled out and seeped into the ground. Figure 2.20 shows the picture of the T/Ls at the accident spot.

Figure 2.20: T/Ls Rolled Over Off the Road. Fuel Spilled and T/Ls Fully Damaged

In July 2009, another case was reported in which a 48 year old man, his wife and 2 sons were killed when a truck towing a container-counted trailer overturned and crushed their stationary car. In the month of September 2009, in the daily "Dawn" newspaper, two accident cases were reported due to T/Ls. In the first accident, 3 persons were killed when a fast moving trailer truck rammed into their car. In the second accident, four people died when a fast moving oil tanker carrying diesel overturned and crushed a car on the national highway near Gulshan-e-Hadeed. The truck driver pressed on the brakes but due to the momentum and the weight of the heavy vehicle, it overturned and fell on the car. There were serious damages caused to the oil tanker. The tank punctured and hundreds of liters of diesel drained from it. The investigation report highlighted that the tie-rod of the oil tanker had snapped. The detached tie rod of the heavy vehicle exposed the weak or ill-maintained structure of these vehicles carrying flammable materials. Fatalities and oil spills on roads were the major losses.

Use of compressed natural gas (CNG) as a fuel for vehicles is common. In many countries such as Argentina, Italy, Pakistan, Brazil, USA, India, New Zealand, and Malaysia it has been used as a fuel for last several years. CNG is compressed into a cylinder normally at a very high pressure of usually 3000-3600 psi. It is equally used for cars and buses. CNG cylinder burst cases have been reported due to improper maintenance and servicing. The normal life period of a CNG cylinder is 5 years. After 5 year duration, the gas cylinder requires testing and inspection. Due to the ignorance and carelessness, people normally don't carry out an inspection of their cylinders. An accident happened due to a cylinder bursting causing 4 fatalities. Figure 2.21 shows the damages resulting from a CNG cylinder burst at a retail outlet.

Figure 2.21: Car CNG Cylinder Bursts

Accidents reported while transferring fuel through pipelines are fewer in number as compared to during the transportation of fuel via T/Ls but whenever they do happen, they cause huge infrastructure loss, fire, fatalities, and major and minor injuries. It was reported in another newspaper, "Star", from Malaysia, that on the 21st of December 2010,27 people were killed in a pipeline blast. The explosion took place in San Martin Texelucan, Mexico. The accident was caused by thieves trying to siphon off fuel from the Petroleos Mexicanos (Premex) pipeline. The fuel spilled out of control because of the high degree of pressure. 52 people were reported injured and 116 homes completely destroy by the blaze. Hundreds of people were evacuated. Administrative authorities were worried that the fuel may have spilled into the nearby Atoyac river. The blast broke windows and burned cars in a 3km radius. Locals reported that thieves operate drilling machinery and sell stolen fuel to truck drivers along the road passing through the region. Petroleos Mexicanos (Premex) highlighted in their report that the blast was caused by "fire on two pipelines"; the fuel supply was immediately cut off to those pipelines. It was also highlighted by authorities that the theft of fuel from Mexican oil pipelines causes an average loss of US $800 mil (RM 2.51 bil) per year.

An incident was reported on December 18, 2008 in "The Nation". A major oil pipeline of Parco (Pak Arab Refinery Ltd) burst and oil started gushing out when workers were busy working on the pipeline. During the work, the pipeline was struck hard and oil started to spill out from the opening with immense pressure. The oil made its way into houses and spread onto the streets. The oil spill caused major damages to the environment. Figure 2.22 illustrates the spot and time of the pipeline burst.

Figure 2.22: Pipeline of Parco Burst in Korangi Karachi.

Marketing and media plays an important role in petrol fuel retail outlet businesses. Accident occurrences pose a significant impact to a company's reputation and causes business losses. The safety of personnel, customers and the public must be achieved during operation and maintenance at petrol fuel outlets as a first priority [79].

According to the Federation of Malaysian Manufacturers (FMM) loss prevention fundamentals "loss control may contribute more to profit than an organization's best". It is required for the salesman of a business to sell an additional $1,667,000 in products to pay the costs of $50,000 in annual losses from injury, illness, damage or theft, assuming an average profit on sales of 3% [27]. Table 2.8 shows the number of dollars in sales required to pay for different amounts of costs for accident losses, i.e., if an organization's profit margin is 5%, it would have o make sales of $500, 000 to pay for $25, 000 worth of losses. With a 1% margin, $10, 000, 000 of sales would be necessary to pay for $100, 000 of the costs involved with accidents.

Table 2.8**:** Sales Profits vs. Incident Costs. Federation of Malaysian Manufacturers (FMM), Loss Prevention Fundamentals

IN TIMES OF KEEN COMPETITION AND LOW PROFIT MARGINS, LOSS CONTROL MAY CONTRIBUTE MORE TO PROFIT THAN AN ORGANIZATION'S BEST SALESMAN					
The amount of sales required to pay for losses will vary with the profit margin.					
YEARLY INCIDENT COSTS	PROFIT MARGIN				
	1%	2%	3%	4%	5%
1,000	100, 000	50, 000	33, 000	25, 000	20, 000
5,000	500, 000	250, 000	167, 000	125, 000	100, 000
10,000	1, 000, 000	500, 000	333, 000	250, 000	200, 000
25, 000	2,500, 000	1,250, 000	833, 000	625, 000	500, 000
50, 000	5,000, 000	2,500, 000	1,667, 000	1,250, 000	1, 000, 000
100, 000	15, 000, 000	5, 000, 000	3,333, 000	2,500, 000	2, 000, 000
150, 000	15, 000, 000	7,500, 000	5, 000, 000	3,750, 000	3, 000, 000
200, 000	20, 000, 000	10, 000, 000	6,666, 000	5, 000, 000	4, 000, 000

Transportation accidents involving releases of liquefied petroleum gases and other petroleum products cause substantial damage to the population, environment and properties adjacent to an accident scene [80].

According to [81], 15 percent of all accidental deaths (≈12,000/year); this is the second leading cause behind motor vehicles.

2.8.3. Slips, Trips and Falls (STF)

Slips, trips and falls (STF) were recorded as major causes of medical treatment cases and lost time injury cases. Due to STFs, injuries were reported on the legs, arms and heads of the workers. Carelessness was identified as the root cause in most of the cases. It was also reported that tools falling down during working at heights caused injuries to the workers and pedestrians passing nearby. Falls of workers during cleaning from heights result in higher severity of injuries than during other kinds of work. Since PFS's are considered to be small facilities, less consideration was observed during working at heights. Wooden ladders were found to be in a dangerous state, using the equipment in this condition could result in a serious injury. The overall condition of ladders was to be found not satisfactory. Slippery conditions in the working area at filling gantries were due to minor leakages of oil. It significantly contributed to the cause of STF cases. Workers' cases of slipping were reported while climbing up to the T/Ls after filling operations; major and minor injuries on legs and arms were reported. Major and minor injuries were also reported by the workers due to falls from the roof. An STF case was reported due the workers' carelessness and faults in the design. Figure 2.23 shows the gap in the design. It indicates that there is a permanent gap in the design and is a repeated cause of occurrences of STFs. According to [81], STFs make up the majority of general industry accidents; over 17% of all disabling work injuries are the results of STF cases.

Figure 2.23: Diesel Dozing Pipe has become a Trip Hazard

2.8.4. Carelessness (C)

Contractors and clients have activities that can create major and minor injuries during operations. The number of minor incidents reported in [29] were 130 excluding the incidents by contractors. The major cause identified was carelessness. Occurrences of these accidents and incidents show that there was less impact from the available theories proposed by various researchers and working groups to reduce occurrences of cases related to carelessness. With an appropriate approach and scrutinizing of the main causes of accidents; incidents, unsafe acts and unsafe conditions can be improved significantly. With the application of a behaviour based safety approach and identification of at risk behaviours, safety conditions can be improved [82, 83]. Carelessness happens because of taking the lazy way out. The supervisor or safety inspector cannot eliminate the chances of carelessness from workers but they can remind them and supervise closely the work that they do. Events related to carelessness cases were recorded due to workers;

1. Not following work instructions
2. Not following the set of disciplinary rules and regulations
3. Not using safe working methods
4. Not paying attention to the job they are carrying out or to the operating equipment
5. Using personnel protective equipment improperly
6. Not possessing the aptitude for the complete scope of the work layout plan

7. Possessing insufficient skills required for the work they are performing
8. Not possessing knowledge of the limits and strength of the material being used
9. Not using tools and equipment properly
10. Eye's not being on the task at hand
11. Not possessing a good safety attitude

Carelessness was found to be one of the main elements contributing to hazards during the operation and maintenance of petrol filling stations. Various cases were observed related to carelessness at PFS's. Such as unsatisfactory use of personnel protective equipment (PPE), improper use of tools and equipment (conditions of tools recorded as deteriorated), inadequate use of signages and instructions, missing signages at desirable locations, use of cell phone in tank zone, not using seat belts while driving, emergency number plates with outdated contact numbers, insufficient medical supplies in first-aid box, sudden application of brakes on transportation lorries and other vehicles. Due to carelessness on the part of the driver, T/L have collided with other allied facilities at PFS's such as fire water monitors, dispenser units, islands and boundary walls.

2.8.5. Fire Risks (FR)

Three main elements are needed to produce fire .i.e. fuel, oxygen and ignition source [84]. The first element to produce fire at PFS is petrol (fuel) which is available 24 hours at petrol filling station. Fuel has the potential to create fires [85]. The fuel hazard fire assessment is an important input for fire management plans. From 1993 to 2004, approximately 243 incidents related to fires breaking out were reported at petrol filling stations around the world [86]. Static electricity is produced by the build-up of electrons on weak electrical conductors or insulating materials [87]. It creates explosion or serious injury to a person. Electrostatic charges were found to be the root cause of fire occurrences at PFS's. Every year in the USA alone, about 150-200 fires occur due to static-electricity-caused ignition of gasoline vapors [88]. Electrostatic charges have interaction with weather, clothing, and car seat material as well as getting in and out of a car [89]. Most of the incidents occur under low-humidity conditions; consequently, they are more prevalent in cold weather. It was reported by [3] that a vapour concentration of suspended fuel volatiles depends upon the weather conditions but near surface fuels always burn in an any fire scenario even in situations of lower intensity. A disproportionate fraction of these incidents (55% of the incidents where the ignition details are known) have involved an individual who re-enters and re-exits the vehicle during the fueling operation [90]. Static-prone seats in vehicles allow a high charge to be built up on a person moving in or out of the seat [91]. Although only 5–8 kV values are typically generated by an individual during a single action of getting out of a car, the individual sometimes can produce over 15 kV. Other studies have shown that the charging of an individual to around 6 kV can suffice to produce an incentive spark [92]. In terms of responsibility of the individual doing the refuelling, the American Petroleum Institute issued a widely-publicized press release on February 3, 2000, "Do not get back into your vehicle during refuelling". The press release also emphasized that if for some reason the person does have to re-enter the vehicle, "Discharge the static electricity built-up when you get out by touching the outside metal portion of your vehicle, away from the filling point, before attempting to remove the nozzle" [93].

The vehicles arrives at PFS were found to be of different kinds. It includes buses, cars, motorcycles, rikshaws, trucks and etc to take fuel. They make a homogeneous work environment for a short time period at PFS. It could be hazardous if the arrived vehicles contain hazardous materials such as chemicals and gas cylinders. No vehicle checking system was noticed at PFS. Another dangerous aspect is that some of the components at PFS were in direct contact with the customers. Therefore, it can be viewed that a homogeneous safety culture due to customers and facility components generated at PFS. A Figure 2.24 below shows that a truck arrived at PFS contains numbers of CNG cylinders. With minor negligence during truck filling operation any unwanted scenario can occur.

Figure 2.24: A Truck Arrived at PFS Contains CNG Gas Cylinders.

Petrol is a major hydrocarbon fuel; it is a mixture consisting mainly of hexane, octane and heptane which is extremely flammable. It is able to give off vapours at temperatures as low as minus 40^{o}C that when mixed with air, can give rise to fire and explosions [94]. Many fire case accidents were reported in many studies such as [20, 95]. According to these studies, the sources of fire at petrol filling stations are open flames, electrical operating components and static electricity. The fire's cause severe injuries, loss of life and damage or destruction of the petrol filling station site as well as major impact on the surrounding infrastructure. These studies also suggested that there is a need to give sufficient distance between petrol filling stations located at residential sites or other sensitive facilities. It is equally important to give distance between the PFS's and high voltage overhead lines.

Fires and explosions cases at PFS resulted in heavy losses to the operating companies. The cases were recorded due to availability of petrol and LPG. The highest numbers of fires and explosion cases were recorded in tanks [18]. Table 2.9 and Table 2.10 below shows the number of fire and explosions cases reported in tanks, pipes, fuel pumps and other PFS associated facilities.

Table 2.9: Accidents Reported Due to Liquid Fuel [18]

Typologies (not mutually exclusive)	Origin								
	Fixed Facilities						Customer vehicles and delivery trucks	Others/unknown	Total number of accidents
	Tanks	Pipes	Fuel pumps	Tank fill units	Effluent treatment	stores			
Release of hazardous materials	62	33	27	14	4	7	8	44	**199**
Fires	1	1	5	2	0	4	4	3	**20**
Explosions	6	3	1	1	0	5	0	2	**18**
0thers (near accidents)	0	0	2	0	0	0	0	0	**2**
Total number of accidents	**62**	**33**	**29**	**14**	**4**	**7**	**9**	**44**	**202**

Table 2.10: Accidents Recorded Due to LPG [18]

Typologies (not mutually exclusive)	Origin				
	Fixed facilities				
	Tanks	Fuel pumps	Pipes	Vehicles running on LPG	Total number of accidents
Release of hazardous materials	1	2	6	4	**12**
Fires	0	1	0	3	**3**
Explosions	0	0	0	1	**1**
Other (near accidents)	0	1	0	0	**1**
Total number of accidents	**1**	**3**	**6**	**4**	**13**

In 2002, there were three fires, each causing damage exceeding $2,000, as compared to only one in 2003 as reported by [19]. The number of minor fires reported has increased since 2001. This increase is attributed to a larger number of small fires reported by the marketing business and not increases in the reported fires at the refineries. Figure 2.25 shows the graphical representation of fire occurrence cases during the years 2002 & 2003.

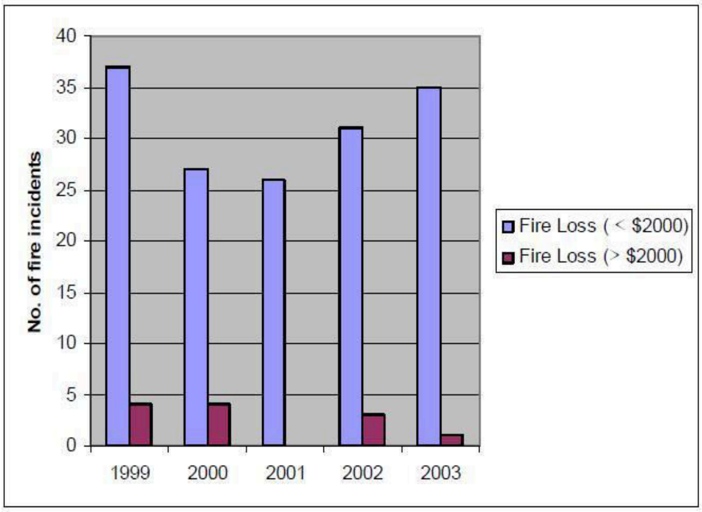

Figure 2.25: Fire Incidents at Caltex

During this study period fire incidents were reported during the operation and maintenance of PFS's. Photographs of the few fire incidents cases are illustrated in Figure 2.26, Figure 2.27 and Figure 2.28.

Figure 2.26: T/Ls Caught Fire on Road During Transportation of Fuel.

Figure 2.27: T/Ls Caught Fire at Parking Yard.

Figure 2.28: T/L Rolled Over from Road and Caught Fire.

2.8.6. Electrical Fault (EF)

Electricity is a source of energy but when it accidently brought into contact with people permits release of energy which may result in serious damage or loss of life. When electricity comes in contact with other components it may produce heat and sparks. The principal hazards associated with electricity are electric shock, electric burns, electrical fires and explosions, arcing, portable electrical equipment [87].

Electrical equipment was found to be one of the major causes of fires and explosions during the operation and maintenance of PFS. A PFS is a hazardous facility and needs special care in the design and installation of its electrical systems which must remain safe and secure throughout the life span of the station so as not to cause explosions or other untoward incidents. Pictorial representation of various weaknesses in electrical components that leads to recorded electrical faults cases are shown in Figure 2.29, Figure 2.30, Figure 2.31, Figure 2.32, Figure 2.33 and Figure 2.34.

Figure 2.29: Cable Trays were not Properly Covered.

Figure 2.30: Unsafe Electrical Connections in Power Generation Room.

Figure 2.31: Electric Cables Trench was found Uncovered. Cables found Irregular.

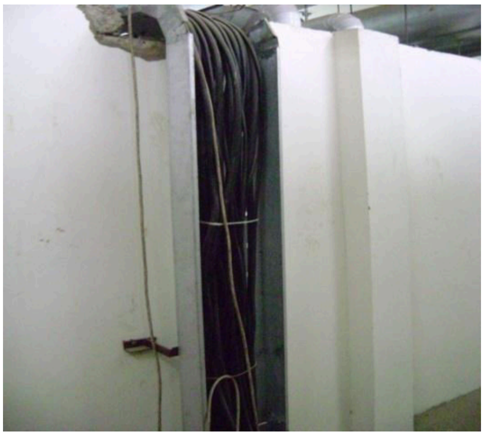

Figure 2.32: Uncovered Electrical Cable Trench in Power Generation Room.

Figure 2.33: Uncovered Electrical Trench.

Figure 2.34: Unsafe Electric Heaters being used at PFSs.

2.8.7. Miscellaneous Cases (MC)

Miscellaneous cases are comprised of hazard contributing factors falling under the following classifications:

- Oil spillages
- Water leakages
- Snakebite cases
- Minor damages
- Maintenance issues
- Robbery
- Theft
- Natural disasters/wind storms
- Law and order situations

Due to the lack of safety awareness by the staff, many unsafe practices were noted, including the failure to clear oil spillages, unsafe manual handling practices and the storage of fuel samples in unmarked mineral water bottles. This indicated poor supervision and lack of training. A safe and environmentally friendly disposal was required to clean out spillage and leakages. The worker was found to be careless when dealing with these leakages and was unaware of the need to take action when small spillages of lubricating oil, liquid hydrocarbons, liquid chemicals or hazardous toxic chemicals (liquid or solid) occurred. The spillage of waste generated must be disposed of in the correct manner. It is the responsibility of the person/department supervising the operation to categorize the component waste product and organize them to be contained and disposed of in line with the guidelines. Where small spillages occur, the affected area should be cordoned off and an absorbent such as sand should be spread liberally over the spillage. Once all the spillage has been absorbed into the absorbent media, it should be collected in suitable containers, labelled and disposed of in accordance with the laid down guidelines. Before attempting to handle the spillage, the nature of the chemical should be checked and the guidelines set out by the supplier followed. Protective clothing as directed in the vendor's guidelines must be provided. Once the chemical has been collected and stored as directed, the disposal guidelines should be adhered to. A thorough washing of the area with clean water should be carried out once the clean-up has been completed. The dispersant should be used with discretion for environmental reasons.

Fuel spillages and explosion cases reported by [96] due to defects, leakages and incompatibility of pipes, coupling and other equipment used at PFS. The use of un-compatible couplings was observed and could be a potential cause of spillages. Figure 2.35 shows the use of sub-standard couplings during a facility operation. Drippings of fuel from the dispenser nozzles were found at various facilities. They contaminated the ground and could be the cause of a fire eruption. Figure 2.36 indicates the dripping of fuel during the facility operation.

Figure 2.35: Use of Non-standardized Couplings at PFS.

Figure 2.36: Spillage at Additive Dosing Point

2.8.8. Medical Treatment Cases (MTC)

Medical Treatment Cases were reported in all eight Hazard Contributing Factors. The MTCs caused injuries or sickness to a person, due to that effect a patient requires treatment more than first aid and he needs to consult from a professional physician or a medical doctor Severe cases were reported during the transportation of fuel from the distribution centre to the PFSs. The gantry used for filling of the T/Ls was observed to be very narrow and 20% of the MTCs were reported at that particular position. Injuries were reported on the head, arms and legs. First aid treatment to the workers was provided at the retail outlet on an immediate basis while in case of any serious injury, the patient was shifted to the nearby hospital. According to [81], STFs were of the most frequent types of reported injuries. MTCs contribute to 25% of insurance claims in each fiscal year.

2.9. Risk and Safety Analysis Models

Risk is the multiplicative product of severity and likelihood of hazardous event. The workers takes risks in their assigned jobs depending upon their risk perception, safety rules & procedures and management [97]. The risk level of different hazardous activities prioritized by using risk assessment methods provides viable knowledge to safety professionals to set company goals and objectives [98]. Issues related to occupational health and safety are quite common in the downstream of oil and gas industries. These include fire, falls, electrocutions, vehicle accidents, robbery and snakebites. The level of risk of these hazards varies according to location and country. PFS's are commonly located in the vicinity of populated areas to facilitate refuelling operations. They pose a significant risk to people, property and the environment [86]. Although PFS's are not costly infrastructures, due to possessing flammable and hazardous materials they acquire attention. The construction cost of PFS that constructed in 1998 and 1999 were ranges between 1.4 million to 4.0 million Pakistani rupees as indicated by [34]. The variation of the cost depends upon the various parameters, such as: is the PFS located in an urban or rural area, is it a covered area, availability of other components, is there a provision for allied facilities and etc. It was noticed that major and minor accident and incident cases were not independent of each other. They were, instead, interrelated with one another. Many risk assessment models were studied during this research but no base data was found. If the risks are calculated by using the risk assessment criteria developed for the construction industry in the petroleum sector and vice versa, it will not give suitable risk values because the working environment in the construction industry is totally different compared to the petroleum sector. The choice of the most relevant risk assessment method is mandatory to calculate the accurate risk.

Risk management is one of the main components of the health and safety (H & S) management system. There are various ways to calculate the risks associated with various work trades. Many researchers have suggested different methods to determine risks based on some specific parameters. The importance of a risk evaluation can be viewed easily by observing that many companies make it a part of its health and safety policy. This is the responsibility of the company to conduct its operational activities in a manner that minimizes HSE risks. Protecting the health and safety of employees, contractors, customers and the community at large in the environment in which the group activities are being conducting is vital. Any company with active involvement of all employees and contractors can manage HSE risks to prevent accident, injuries and occupational illnesses.

Various risk assessment models proposed by different researchers were reviewed during the study period. The detail descriptions of three most widely in practice risk and safety analysis models are discussed in detail below. These were As Low As Reasonably Practicable (ALARP), Risk Matrix Criterion and Risk Ranking Criterion.

2.9.1. As Low as Reasonably Practicable (ALARP)

ALARP is a documented and well established process for performing detailed risk assessment. It is necessary to perform detailed risk assessment in compliance to the standard code of practices, and also to satisfy the concerns of the buyers [24]. ALARP assures the protection of the company's people, assets, reputation and protection of the environment that the company operates in. This risk assessment criterion is used for identification of hazardous activities. During the risk analysis process, the appropriate consequence and probability were assigned to the respective hazards. The risk analysis by ALARP is covered in section 1.4.1. The detail description of some components is described below;

2.9.1.1. Consequence of Hazard (Top Event) - Consequence on People

A consequence of Hazard on people in ALARP can be described as a rating of "0" (zero); this rating severity on people indicates no injury. The rating of "1" reflects a slight injury or health effect. It includes first aid and MTC. Under this rating there is no affect on the work performance or cause of a disability. The rating of "2" indicates a minor injury or health effect. This ranking includes lost time incidents and injury (LTII) cases. It affects work performance, e.g., restriction to certain activities (restricted work cases) or required to take a few days rest to recover like with food poisoning and skin irritation. The "3" rating (major injury) includes permanent disability. Activities under this group cause prolonged leave, e.g., unlimited absence from work, irreversible health loss, chronic back injuries etc. The rating of "4" defines those activities that can cause single fatality or permanent total disability. It can be caused by an accident or occupational illness (cancer). The rating of "5" is considered to be the main cause producing multiple fatalities. It can happen due to an accident or occupational illness.

2.1.2.1 *Consequences on Asset*

According to ALARP consequences on Assets are divided into 6 broad categories .i.e. no damage, slight damage, minor damage, local damage, major damage and extensive damage. This division is based upon the cost assigned to different incidents and accidents by the company. The cost increases from no damage to extensive damage in ranking. This cost to the individual rating normally varies from organization to organization.

2.1.2.2 *Consequences on the "Environment"*

The consequences on the environment are categorized into 6 main groups. Ratings are assigned from "0" to "5" and the effects on the environment are no impact, slight impact, minor impact, localized impact, major and massive impact, respectively. The rating of "0" (zero) indicates no effect on the environment. The rating of "1" shows a slight impact; it can cause local environmental damage. It affects the environment within the boundary/fence or within the system. It causes negligible financial consequences. Minor impact causes contamination, violation of statutory laws and local complaints. There is no permanent /long lasting effect on the environment. The rating of "2" indicates a minor impact on the environment. A localized impact has a rating of "3" and covers limited loss of discharges/fuel, repeated violation of statutory byelaws, and affects the community and neighbourhood. Major affects on the environment have a rating of "4" and defines a severe damage to the environment. Under this category, a company is restricted and must take maximum measures to restore the contaminated environment to its original state. Massive impacts have a rating of "5" and include persistent severe environmental damage over a large area, and commercial, recreational or natural loss. The rating of "5" also indicates a major economic loss to the company, repeated high violations of statutory byelaws or prescribed limits.

2.1.2.3 *Consequences on Reputation*

The consequences on the reputation of a company with reference to ALARP is described as; no impact reflects that there is no harm on the company reputation due to that particular accident or incident. A slight impact rating shows that public awareness may exist, but there is no public concern about the organization with its activity. A limited impact defines that there is some local public concern. A considerable impact indicates that there is regional public concern. An extensive impact results in adverse highlights being given attention in the local media and there is an adverse stance by the local government and/or action groups. A major national impact defines the effects on national public concern, and a major international affect describes the national/international policies with a potentially severe impact on access to new areas, grants of licenses and/or tax legislation.

2.9.2. Risk Matrix Criterion

The risk matrix evaluation method is widely used in upstream oil and gas sectors in Pakistan to determine risks. The description of hazards analysis with reference to risk matrix criterion is described in section 1.4.2. Some literatures present likelihood as a frequency or probability. Table 1.4 shows the risk matrix criterion to calculate the risk score associated with hazardous activities. Table 1.4 is divided into 5 rows and 5 columns. Likelihood is represented on the X-axis and severity is represented on the Y-axis. Likelihood is divided into four categories, i.e., extremely likely (E), often likely (F), unlikely (G) and very unlikely (H). A number value, i.e. (10), (08), (06) or (04) is assigned to each category, respectively. Severity is also divided into four main categories, i.e. death or permanent disability or extreme damage to equipment or property, long term illness or serious injury or major damage to property or equipment, medical treatment with several days off work or minor damage to equipment or property, and first aid needed or negligible property damage. A number is assigned to measure the impact as (A) 10, (B) 08, (C) 06 and (D) 04.

During risk analysis, a severity and likelihood value is assigned to the hazardous event. With multiplication of the severity and likelihood values, a risk score value is calculated and put up, respectively in Table 1.4. Finally, the risk evaluation needs to be carried out according to Table 1.5

2.9.3. Risk Ranking Criterion

The methodology for hazard analysis with reference to risk ranking criterion is described in section 1.4.3.

2.10. Gaps in Safety and Risk Analysis Models

Risk determination is one of the main components of the health & safety management system (HSMS) and checking, review & corrective action process. Development of risk assessment approaches is quite new and rapidly growing field. Various risk assessment approaches are in implementation in different organizations. In this study the three most widely used risk assessment approaches were chosen and studied in detail. With reference to each risk assessment approach the gaps were identified and elaborated below:

1. The choice for selection of appropriate risk assessment model for specific operation is not defined by risk assessment methods.
2. ALARP (as low as reasonably practicable) can involve increased levels of expenditures for more processes [99].
3. No base data is available for the development of risk assessment models.
4. Companies are required to update the models with respect to time due to the value addition/process modification in the plant.
5. Different risk assessment models are in implementation for various operations in a plant. No guidelines are available for the use of combination of risk assessment approaches.
6. Methodology to measure the accuracy of risk assessment is not described in risk assessment approaches.
7. Organizations should get expert opinions in the selection of the appropriate risk assessment model, as many organizations are using risk determination methods of their own choice.
8. These models only focus/prioritize the major accidents and fatality cases. They promote the reduction of major cases while for minor cases they recommend that they be considered at a later time.
9. The criteria of hazard prioritization vary in each criterion.
10. The risk assessment criteria (RAC) do not provide guidance for which risk assessment method (RAM) should be used in certain specific condition.
11. Some RAC show the action required/action needed to be taken while some do not.
12. The RAC show the action required but the control measures are missing.
13. For specific industrial risks, a specific risk assessment method required.

14. With the use of inappropriate RAC, other risks are sometimes increased. The net safety is decreased.
15. The RAC do not provide guidance as to how much of the risk can be reduced in each zone. To eliminate the risk level from certain regions, it requires lots of resources and manpower. There should be an acceptable level/minimum level of risk in each zone. Once this level is achieved, the professionals can move ahead.
16. A criterion for reaching decisions is not clearly provided by RAM.
17. By using unsuitable RAC, they export the hazard from one process to another and make them more dangerous. The hazard is merely exported not removed completely.
18. By using a risk ranking criterion, it shows the timescale urgency. This is difficult to meet in some circumstances. The hazards/risks under a high ranking require immediate attention/action on the same day which is practically impossible.
19. The assigned value of severity depends upon the individual experience and their subjective judgment.
20. To a young and less experienced HSE officer, it is difficult to make a correct judgment, as most of the time assigning values of severity is shifted to the young staff members. This leads to chances of misinterpretations.

2.11. Legislations

At petrol filling stations, the movement of vehicles and people is extensive; therefore, regulations and conditions may vary but the overall goal of all authorities is to make them safer. Before the installation of a fuel station, the owner is required to take approval from the licensing authority. These authorities vary from country to country. Licensing conditions help to control many hazards associated with petrol filling station but to make petrol filling station safe, still a gap exists. Risk to PFS from activities such as vehicle movement, hazardous substances, manual handling, slips, trips and falls, fire risk, electricity, violence to staff and a compressed gas system is not covered in licensing conditions. Following legislations were in implementation at the PFS by the operating company:

- Workmen’s compensation act 1923

- Factories Act 1934
- Electricity Act 1910,1937
- Boiler Act 1923 and Boilers & Pressure Vessel Ordinance 2002
- Petroleum Act 1934, 1985
- Gas Cylinder Rules 1998
- Employment of Children Act 1991
- Hazardous Occupation Rules 1963
- Environmental Protection Act 1997
- IEE and EIA Regulations 2000
- NEQS
- OHSAS 18001
- ILO Standards, Conventions, Recommendations & Codes of Practice
- OSHA Standards
- HSE Executive UK

2.12. Safety Measures Monitoring at Petrol Filling Stations

No audit protocol is available to evaluate the effectiveness of PFS safety. Although companies apply various safety audits and control measures, the improvement in the safety statistics have not been significant. Auditing companies also use environmental management systems to address local safety measures and fulfil the requirements of regulatory byelaws. This is also in line with [37] as the environmental management system focuses on compliance with federal, state and local requirements and is helpful to reduce adverse environmental impacts. Every auditing firm has its own standard protocol, auditing methodology and safety measurement instrument. These systems vary from country to country, organization to organization and place to place. In response to enhanced safety measures at PFS's and to make them safer, there is a need for a particular SMS. SMS's provide an authentic and standard methodology to benchmark the safety audit process. They are equally helpful to the safety professionals to predict the upcoming hazards at their PFS. The development of specific safety management system guidelines for individual industries is also highlighted in [100].

An environmental impact assessment (EIA) is a very essential tool for identifying in place and the after-effects of a project on the environment and people. As per estate byelaws in a study of the country, an EIA was conducted on all the projects such as agricultural, airports, drainage and irrigation, housing and etc. Construction of PFS's were covered under the petroleum area. But, it is alarming to note that when conducting the EIA the PFS had been excluded [101]. The clause under petroleum can be read as follows "Construction of product depots for the storage of petrol, gas or diesel (excluding service stations) which are located within 3 kilometers of any commercial, industrial or recreational areas and which have a combined storage facility of 60,000 barrels or more". Although the storage of fuel at PFS's is not 60,000 barrels individually, as they are located close to one another, if there is a case of any explosion occurring due to mishandling at one station it is equally hazardous / dangerous for another. Moreover, the scenario is much more problematic if any oil refinery, industry or a home operating a small manufacturing company, chemical laboratory or chemical storage yard is located nearby.

The loose SMS and shortcomings in the standard operating protocols create hurdles in safety improvement [102]. During this study, when the contractors were asked about safety conditions of their PFS, they were found to be satisfied whilst the safety auditors thought otherwise. The application of the SMS model to achieve good safety performances at construction sites were found to be very successful. It was mentioned in the studies conducted by [103, 104] that with successful implementation of the SMS models, accidents could be prevail dominantly. Application of SMS's in the construction industry was reported as very viable to reduce occurrences of unsafe acts and unsafe conditions. A study was conducted by [105] illustrating that in construction projects, the best time to influence safety is at the top concept and design phase. He summarized his study work in the form of graphical representation. Figure 2.37 illustrates the time/safety influence curve. It can be viewed in Figure 2.37 that the safety consideration at the construction project reduced as the project moved towards the start up.

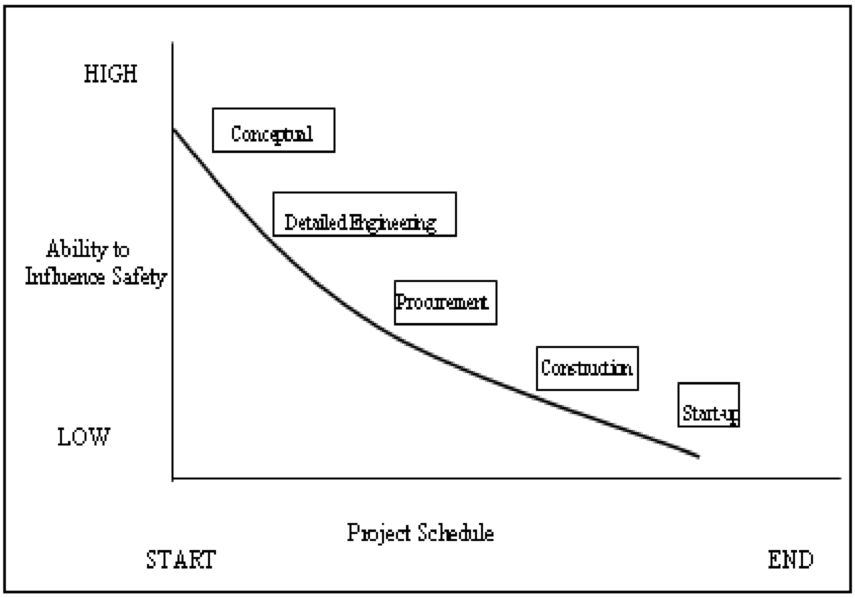

Figure 2.37: Time/Safety Influence Curve

In the same study conducted by [105], the progress of the occupational health and safety matters during the project life cycle is represented. It can be seen from Figure 2.38 that the maximum occupational health and safety (OHS) milestones can be achieved in the project execution phase due to the follow up of plans.

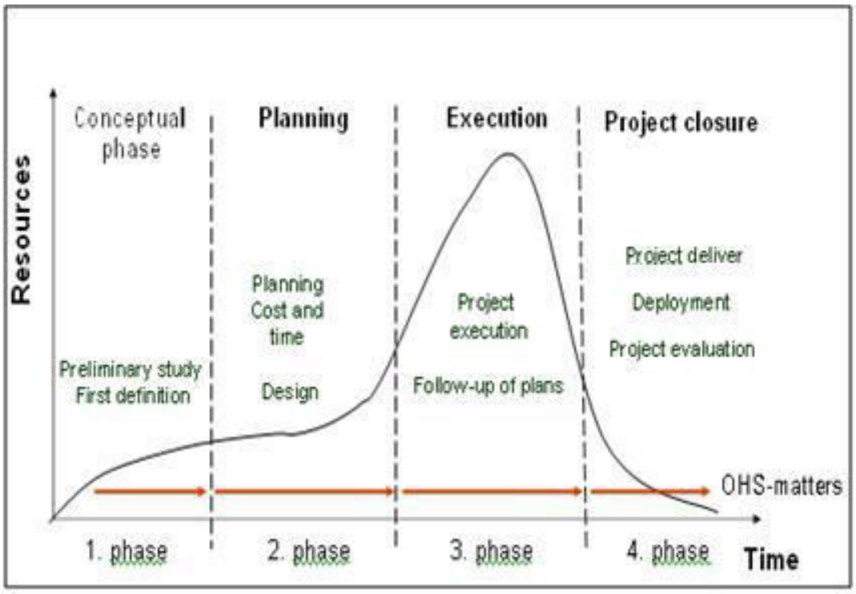

Figure 2.38: Occupational Safety and Health Matters Progress

During the operation phase the PFS stores and sells flammable and hazardous materials. Places used for the storage of flammable liquids are considered as hazardous workplaces; the place becomes more dangerous if the nearby movement of people and vehicles is frequent. At PFS's, the movement of vehicles and people are extensively round the clock; therefore, safety aspects need more attention. Normally, before installation of a PFS, the owner is required to get approval from the licensing authority. The rules, regulations and conditions related to these authorities vary from country to country. License conditions may control the hazards associated with a PFS [106] but at the PFS, the hazard pattern may change during the course of time due to nearby infrastructure development.

TOTAL has more than 200 retail outlet stations all over Pakistan. It was reported in [107] that TOTAL experienced 21 fatalities, especially related to transportation by road. In 2009, TOTAL experienced a succession of unusual and distressing serious accidents in France. Investigations were conducted to understand the specific circumstances of each accident and to learn from them to avoid future occurrences. It was reported that 9 fatalities occurred during site operations, 8 fatalities in the product transportation by road, 2 fatalities in the employees travelling by road and 2 fatalities during a seminar activity. It was also reported that during the years 2007, 2008 and 2009, TOTAL achieved 454,671,000 hours without any lost time injury case. Table 2.11 shows the accident statistics of TOTAL for the years 2007, 2008 and 2009.

Table 2.11: Accident Statistics of TOTAL [107]

Description	Unit	2007	2008	2009
Lost time injury rate (total +contractor employees) - LTR	No	2.4	2.1	1.9
Of which: Exploration & Production		0.8	0.6	0.6
Gas & Power		1.8	2.1	1.00
Refining & Marketing		2.58	2.5	2.4
Chemicals		4.17	3.6	3.1
Total recordable injury rate (total + contractor employee) – TRIR	No	4.2	3.6	3.1
Of which: exploration & Production		2.4	2.2	1.9
Gas & Power		2.7	2.1	1.8
Refining & Marketing		3.2	2.9	2.9
Chemicals		7.7	6.5	5
Fatalities	No	15	8	21
Fatalities per million worked (Total + Contractor employees)		0.034	0.018	0.046

Safety management plans in organizations are monitored with application of safety management system. A safety management system is a process put in place in an organization by the employer to minimize the hazards and risks associated with the operational activities. Accidents are caused either due to unsafe acts by the workers or unsafe working environments/conditions. According to [60], the main cause of occurrences of accidents is the unsafe acts carried out by workers. Workers can be trained by providing job specific trainings, refresher courses and health and safety awareness programs. The safety management system in place within organizations varies in their components. Some organizations include training as a part of a safety management system whereas some don't consider it as an essential element. Safety management systems including the education, training, and employee selection and supervision so that unsafe acts can be eliminated were highlighted by [108] . Safety statistics can be improved significantly by removing hazards from the workplace. In a study conducted by [109] emphasized the importance of a safe work place approach to minimize the occurrences of unsafe acts and unsafe conditions. It was also highlighted that significant safety improvements at the workplace can be achieved by creating an accident free work environment.

Further studies and literature review that have been conducted demonstrated that workers' unsafe acts during the operation stage can create more hazards and put processes at risk. Studies have proposed different safety management systems with various sub components. Identification, assessment and controlling risks to workers in all work related activities are found in the core process of a health and safety management system. According to [110], a safety management system (SMS) comprises a safety policy, planning, implementation, measurement & evaluation, and management review. The result of the management review is an input to the safety policy and as such this provides a continual improvement of the safety performance.

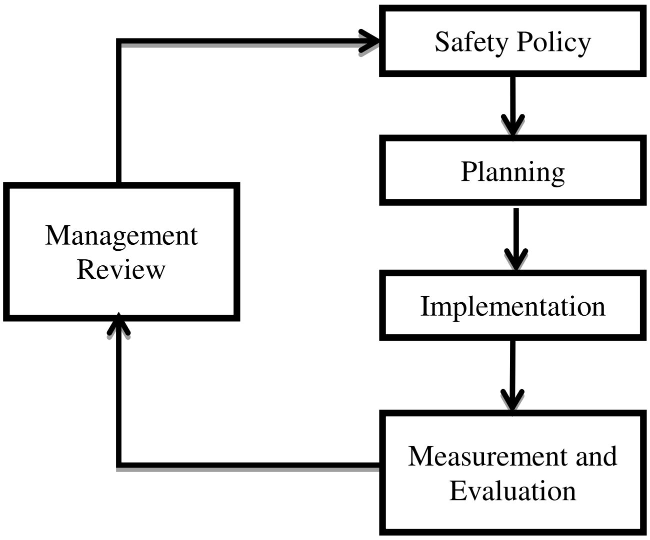

Figure 2.39: Safety Management System Framework

The flow diagram of the SMS proposed by [110] is depicted in Figure 2.39. Each component requirement is fulfilled with further break up into standard operating procedures, guidelines and work instructions.

According to [111], there are six steps in a health and safety management system. Each industrial sector puts emphasis on different components of the safety management system in detail. A SMS framework proposed by Health and Safety Management System (HSG65) is shown in Figure 2.40. Some components need a detail break up and importance to include them while the others only require knowledge at awareness level.

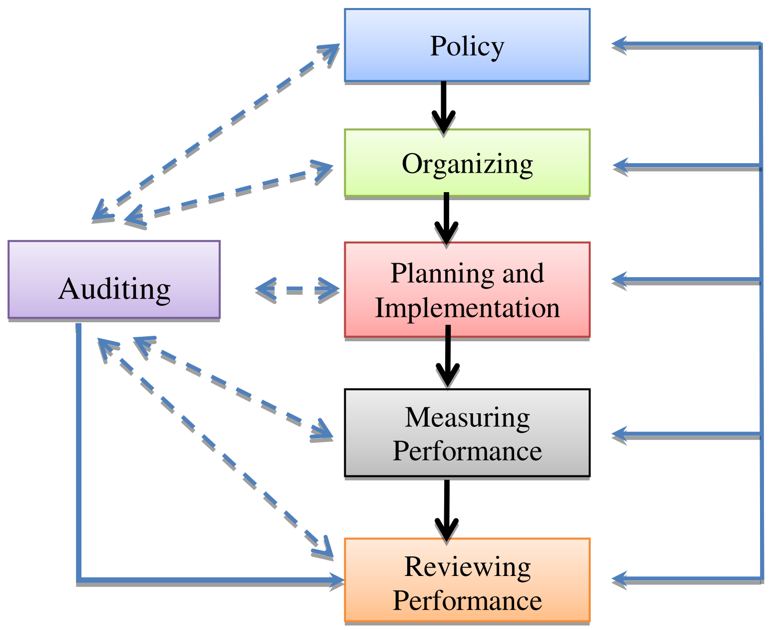

Figure 2.40: Health and Safety Management System (HSG65) Framework

Safety management systems are under implementation in many oil & gas companies in Pakistan for the smooth flow of matters pertaining to occupational health and safety. It supports the four major components of the business: performance, process, plant and people. These four components are further split into eight parameters with desired outcomes. Figure 2.41 shows the required deliverables from each parameter.

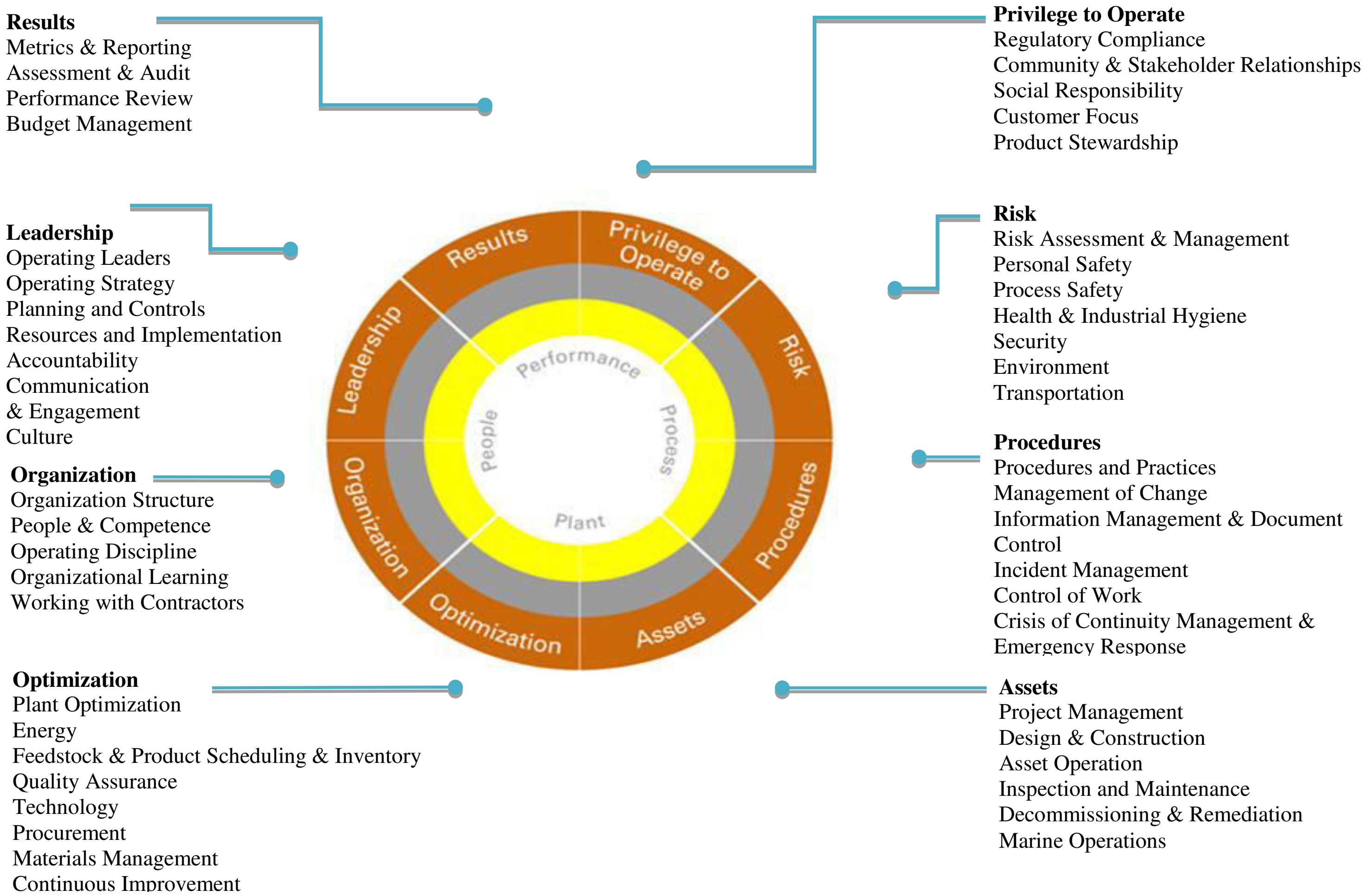

Figure 2.41: Safety Management System Components with Associated Deliverables

Safety aspects require significant attention especially on those facilities that have storage of flammable and hazardous materials. The value of safety aspects is much more viable if handling of hazardous materials by untrained persons is high.

A petrol filling station is a hazardous facility and it needs special care in its design, construction and installations as well as in the maintenance of its components so that they remain safe and secure throughout the life span of the station and do not cause explosions or other untoward incidents. It is necessary to develop such strategies that can help to reduce injury cases. Petrol filling stations are available very common everywhere in the cities and remote areas; however, the associated hazards to these are very unique and specific. It requires proper attention and the utmost vigilance during operations. A variety of vehicles come for fuelling. The operation of the fuel pump stations not only contain onsite hazards but also hazards during transportation of the fuel. Many countries exercise a tremendous road exposure in the transportation of petroleum products. The safety standards implemented not only pertain to the site but are also viable during transportation. Most of the standards pertaining to this industry are extremely outdated and hardly enforced and implemented (standards are simply non-existent).

Past safety studies have investigated various methods to improve safety statistics but accidents are still occurring it shows the failure of control in existing measures. Petrol filling station are considered to be high risk hazardous places within a city environment. Fire, falls, vehicle accidents, electrocutions, robberies and snakebites are the most commonly occurring hazardous conditions at petrol filling station. Very few safety statistics have been found related to PFS accidents. Many accidents that happen in daily routines related to PFS activities are reported in newspapers only. Even many PFS owners don’t develop safety records of the accidents. The major cause of accidents during PFS operations happens during transportation of the fuel. In response to enhancing safety measures at PFS’s and to make them safer, there is a need for a particular SMS. This study introduces an instrument which can be used to measure the effectiveness of safety conditions at petrol filling station. It is equally helpful to the safety professionals to predict the upcoming hazards at their particular PFS. The level of risk of these hazards varies according to location and country. To control these hazards, there is a need for a specific approach for PFS’s.

Safety management system is another form of checking and corrective action of safety measures. Application of the safety measures monitoring to reduce occurrences of unsafe acts and unsafe conditions was found to be very successful. Accidents and explosion cases occurred at PFS's due to the negligence of the workers. In addition, studies conducted related to PFS's to date, have given consideration to the location and the number of PFS requirements within an urban environment. To eliminate problems associated due to the availability of PFS's, there is a need to consider other parameters apart from location only. Moreover, the right site selection approach is workable only for those PFS's that are under the planning stage. But most PFS's that have already been constructed contain no solution except to give safety considerations during the operation and maintenance stage to avoid occurrences of unwanted scenarios.

No study was found during the literature review that focused on the causes of the occurrences of accident and incident cases that make PFS's unsafe. The studies focused on a safe location and placement of PFS's [112]. A safe site for a PFS is one of the ways that helps to reduce occurrences of unwanted scenarios but it is not the only approach. There are many potential hazards associated with PFS's that have been highlighted by many researchers in their studies on a case to case basis. The one way to make a PFS safe is with the availability of a checking and corrective action approach. Although various safety audits and control measures are available for implementation, the improvement in safety standards is not significant. No comprehensive checklist of attributes was found that can help to manage safety matters at the PFS.

2.13. Checking and Review Plan

Petro Filling Stations can be considered as small refinery within city and rural areas. Fire hazards, static electricity, and air pollution induced by aromatic organic compounds are major causes of accident/incident occurrences at petrol filling station. There are other hazards abounding in fuel station operations which make them unsafe. Activities such as carelessness, maintenance, housekeeping, slips, trips and falls, transportation hazards, major and minor injuries, robberies and snakebites all have a potential to create unsafe conditions. The level of risk of these hazards varies according to the location and country. To control these hazards, there is a need for a specific checking, review and corrective action plan for petrol filling stations. SMS's have been developed to reduce occurrences of fatalities, accidents, incidents and near miss cases but these are still occurring continuously. It shows either a failure of or weaknesses in the SMS. It's a good approach but lengthy and detailed. Therefore, in this study a specific checking and corrective action plan for PFS was developed, tested and proposed for further implementation. It is a seven step process and based upon HSE non-compliances. It helps to identify risky behaviour related to fuel station operations and helps to make them safer. It incorporates the determination of risk with the help of an improved safety and risk assessment model.

2.14. Mitigation Strategies

Mitigation strategies are consists of trainings, refresher training courses, safety briefings, tool box talks, meeting with employees and any other form of education that conducts for workers education. These programs are short duration training programs that organize by safety professionals. The training program can be organize by internal safety professionals or outside safety experts. Topics covered for these trainings are related to company's work activities. Task oriented workers are selected for participation in training programs. The occupational safety and health training programs effectiveness in reducing work related accident, incident and near miss cases were reported by [113]. The enhancement of workers knowledge related to workplace hazards, changes in workers behaviour to ensure compliance to promote safe work practices and risk reduction of occupational injuries are the potential benefits of training and development was also investigated by [114]. During study various safety programs and training courses were organized to improve the unsafe acts and unsafe conditions so that the chances for occurrences of fatalities, accident, incident near miss cases can be reduced significantly. More importantly as the PFS also located within an urban and rural environment and little negligence may result to cause any catastrophic event, therefore to educate workforce at PFS is necessary. With application of mitigation strategies during operation and maintenance of PFS noticeable reductions in HSE non-compliances were recorded.

2.15. Research Work Application

The research conducted in this study has potential application. Although for study the data collected from PFSs located in Pakistan but the designed research objectives and targets have broader application perspectives. It was noticed that especially in developing countries like Pakistan, India, Malaysia, Thailand, Cambodia, Indonesia and etc the conditions of PFSs have similarities. In addition to economical conditions, government rules & regulations, country law and order situation was also same. Therefore, if the data collected from one country for research and development and identification of associated hazards, it can be equally useful for other countries as well. The results may differ slightly but have significant meaningful impact for other countries. Therefore, the research outcomes and contribution to the body of knowledge with reference to this research is not only viable for Pakistan and Malaysia but equally important for developing countries too. The data from Pakistan was used for this study work because it was easy to gather. If data may start to collect from Malaysia then it may become impossible to achieve the set objectives with reference to the research work in stipulated time frame.

The HSE non-compliances classification system with reference to hazards contributing factors and occurrences of fatality, accident, incident and near miss cases can be applied on PFSs everywhere in the world. The development of risk and safety analysis model by using statistical tool SPSS (Statistical Package of Social Sciences v 18.0) or any other mathematical model with application of proposed approach/methodology can be developed and applied successfully. This strategy is not only useful for PFSs but can be equally applied in other industrial sectors. The development of safety triangle for PFSs is equally important in broader context especially for PFSs operating companies and safety professionals. It gives an approximate idea for the occurrences of fatality, accident, incident and near miss cases occurrences. Various statistical tools such as exponential smoothing for hazard forecasting, analytical hierarchy process (AHP) and classification system is equally beneficial for industries.

Therefore it can be noticed that the proposed research work is equally important pertaining to its application in various countries. It is hope that in any country successful results with application of this research work can be achieved and occurrences of fatality, accident, incident an near miss cases can be reduced significantly.

2.16. Summary of the Chapter

The literature review for the proposed research work was studied from the year 1958 to 2011. Various hazards to the PFS during operation and maintenance stage were reviewed in detail. The literature review was consisted of international journals, books, conference papers, masters and PhD theses, company's reports, national and international code of practices, legislations and newspapers. The safety records related to the PFS in developing countries found significantly good as compared to the developing countries. Transportation hazards, environmental pollution, hazards to the workers health, carelessness, leakages of underground storage tanks, fire hazards and risk to the PFS surrounding area were found to be the potential hazards associated to the PFS. It was also recorded that the PFS operating companies were ISO 14001 and OHSAS 18001 certified but the accidents were happening at their retail outlets. The significant contributory cause for the occurrences of these accidents was identified as the use of inappropriate risk assessment approach. Based upon the current literature review and with identification of potential hazards at PFS the data pertaining to HSE non-compliances was collected from petrol filling stations located in various cities of Pakistan. Various hazards were recorded to be occurring continuously. Noticeably, the hazards related to transportation of fuel. Based upon these HSE non-compliances an improved safety and risk analysis model for PFS was developed and presented in this study for further implementation.

CHAPTER 3

METHODOLOGY

3.1. Introduction

The study is comprised of 3.5 years of data that was collected from 2500 petrol filling stations located in various cities of Pakistan. The duration of the data collection was from July 2007 to December 2010. The site layout, location, road configuration, available facilities, underground fuel storage capacity, and climatological conditions were found to be different from one petrol filling station to another. Figure 3.1 shows the map of the study area with identification of PFS location cities.

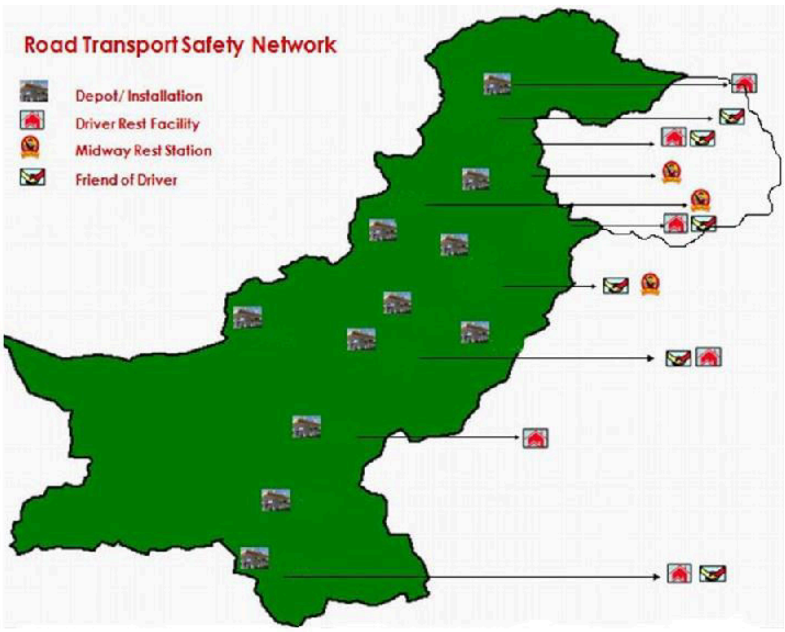

Figure 3.1: Map of the Study Area Showing the Location of Different Cities Containing PFS

Health safety and environment (HSE) non-compliances during operation and maintenance of petrol filling stations were recorded. A total number of 3,216 HSE non-compliances were recorded. PFS's were found to be equally important for urban and rural areas. Within an urban environment, the PFS's were found to be closer to residential areas, schools, colleges, hospitals, commercial areas, and shopping complexes as well as along the adjacent sites of roads, parks, and public open areas. In rural areas, PFS's were found along the highways adjacent to roadsides, in open areas closer to fields etc. PFS's located in rural areas were found to be of larger sizes and underground fuel storage capacity as compared to PFS's that are located within urban areas. During this study it was also found that PFS's also located closer to water bodies within urban and rural areas. The arrival and departure of private vehicles, cars, motorcycles, buses, containers, and trailers to take fuel is the normal routine operation at PFS's. These vehicles arrive at PFS for a short duration period and create a homogeneous safety culture. It becomes more hazardous if the visiting vehicle may contain combustible or explosive materials. With minor negligence any catastrophic event may occur. Therefore, PFS needs more safety attention towards inside facility existing hazards as well as hazards that may be arise due to external factors. During study period many cases reported in which customer's vehicles collided with vehicles taking fuel at PFS and allied facility components. The movement of T/Ls to fuel underground fuel storage tanks is another important consideration.

In this study, 3.5 years qualitative data of HSE non-compliances was collected from 2500 PFS located in various cities in Pakistan. The data was collected with the assistance of HSE representatives at PFS. The PFS where HSE representative was not available focal persons were assigned the data collection responsibility. These HSE non-compliances were categorized into three main distributions, i.e. hazard contributing factors and to cause fatality, accident, incident & near miss cases and their impacts on environment, people and company assets. The third classification .i.e. distribution of HSE non-compliances based upon their impacts on environment, people and company assets is not covered in this scope of study. The significant numbers of HSE non-compliances recorded were due to various factors during operation and maintenance of PFS. The HSE non-compliances were classified into two categories i.e. hazards contributing factors and occurrences of fatality (F), accident (A), incident (I) and near miss (NM) cases. The hazards contributing factors were then further classified into 8 categorize. These were Housekeeping (HK), Transportation Hazard (TH), Slips, Trips and Falls (STF), Carelessness (C), Fire Risk (FR), Electrical Faults (EF), Miscellaneous Cases (MC) and Medical Treatment Cases (MTC). A monthly, quarterly and seasonal categorization of HSE non-compliances was carried out to see the hazard occurrences flow pattern for the two categories. The risk assessment of the hazards was carried out and prioritized by using three different widely used risk assessment methods. These were, as low as reasonably practicable (ALARP), risk matrix criterion and risk ranking criterion. Gaps were identified and finally data was evaluated by using new developed risk and safety analysis model for PFS. The hazard prioritization results by using each risk assessment model were found different. The use of appropriate risk assessment model to prioritize hazard is very important. With the use of irrelevant risk assessment model the hazard is merely shifts within the system but not eliminate. Therefore, availability of base data for development of risk assessment model is needed. The year 2009 data was analyzed by using above mentioned three widely used risk assessment models. Different result of hazards prioritization was recorded. It shows the gaps in risk assessment approaches already in practice. Critical analysis was done and gaps were identified in existing risk assessment methods. No base data was found with reference to development of risk assessment models. No guidelines available regarding the choice of risk assessment model. The criteria to reach the decision was also found missing in risk assessment criteria's. Based upon data collected a new statistical safety and risk assessment model was developed with reference to statistical association among the hazard contributing factors. The proposed safety and risk assessment model was based upon seasonal occurrences of hazard contributing factors. The model was validated and finally, hazards were prioritized and mitigation strategies were proposed to control the occurrences of these hazards.

3.2. Classification of HSE Non-Compliances

A petrol filling station is the only source of fuel supply to automobiles. It stores and sells flammable and hazardous material within urban and remote areas. Many studies conducted as highlighted in literature reviews have demonstrated that researchers have considered the effects of hazardous substances on human health and the surrounding area significantly. There are other hazards such as fire hazards, static electricity, fuel tank explosions, transportation hazards, air pollution evoked by aromatic organic compounds, effects of the PFS's on the surroundings and loss to human life and other hazardous effects that could arise were not highlighted in the studies pertaining to PFS's. These HSE non-compliances can be caused either due to unsafe acts or unsafe conditions. To make PFS's safe it is necessary to address the unsafe acts and unsafe conditions that make them unsafe. During the 3.5 years study period, 2500 PFS's were monitored that were located in different areas of Pakistan. Due to them being at various locations, i.e., urban and rural areas, along primary and secondary highways and in the close vicinity of populated areas, any catastrophic event could arise due to minor human errors or mishandling. It has been highlighted in many studies that PFS's are not safe and contain harmful effects that have the tendency to cause catastrophic scenarios.

The recorded HSE non-compliances were compared with the following set guidelines as described in Table 3.1. If any activity found not inline it considers as non-compliance;

Table 3.1: Criteria for HSE Non-Compliances

1-	Housekeeping (HK)	Clean surfaces free from oil and moistures. No garbage and no scattered material.
2-	Transportation Hazards (TH)	Accident free movement of Tank Lorries from oil depot to the PFS. No speed violations. Private vehicles safe entry and exit from PFS.
3-	Slips, trips and falls (STF)	Workable safe conditions of equipment and tools. Work area free from obstacles and uneven surfaces. Follow standard operating procedures during working.
4-	Carelessness (C)	Work performance by employees according to standard operating procedure and company's guidelines during working hours. Work with full concentration and responsibility.
5-	Fire Risks (FR)	Safe handling of fuel. Safe disposal and cleaning of spilled product. Follow good HK practices. No smoking. Safe underground storage tank (UGST) filling operation. Good condition of fire fighting equipment. Safe use of electrical appliances and electric heaters.
6-	Electrical Faults (EF)	Acceptable condition of electrical appliances. Electrical sparks, improper earthing of T/Ls during (UGST) filling operation. Use of unstandardized electrical components.
7-	Miscellaneous Cases (MC)	Oil spillages, water leakages, snakebite cases, minor damages, maintenance issues, robbery, theft, natural disasters/wind storms, law and order situations.
8-	Medical Treatment Cases (MTC)	Workers medical complaints. Reporting of major and minor injury cases.

The HSE non-compliances recorded were classified by using three different ways. In the 1st classification, the HSE non-compliances recorded were divided into 8 main hazard contributing factors. These were:

1. Housekeeping (HK)
2. Transportation Hazards (TH)
3. Slips, trips and falls (STF)
4. Carelessness (C)

5. Fire Risks (FR)
6. Electrical Faults (EF)
7. Miscellaneous Cases (MC)
8. Medical Treatment Cases (MTC)

In the 2nd classification, the recorded HSE non-compliances were studied with reference to cause fatality (F), accident (A), incident (I) and near miss (NM) cases. It was recorded that the occurrences of fatality, accident, incident and near miss cases were due to the hazard contributing factors.

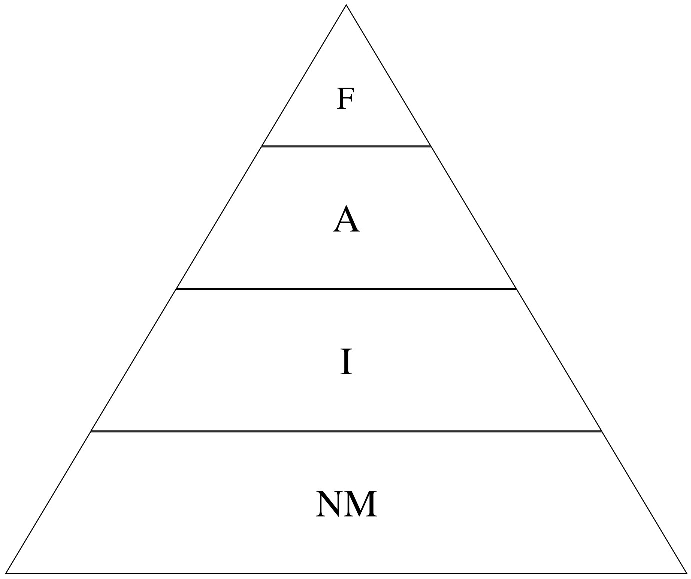

Figure 3.2: Distribution of HSE Non-Compliances based upon Fatality, Accident, Incident and Near Miss Cases

Figure 3.2 shows a pyramid of the distribution of HSE non-compliances. In Figure 3.2, fatalities are represented by F, accident cases by A, incidents by I, and near miss cases by NM.

In the 3rd classification the impacts of HSE non-compliances were studied according to their impacts on environment, people and company assets.

3.2.1. Hazard Contributing Factors (HCF) Occurrences Pattern

Hazard contributing factors have the tendency to create unwanted scenarios during the operation and maintenance of PFS's. In-depth study was conducted to see the occurrence frequency of HCFs. During the study period it was recorded that the frequency of HCFs was not constant. The occurrence frequency of HCFs depends upon many factors such as the safety conditions at PFS, surrounding area condition, law and order situation, at risk behaviours of employees, unsafe conditions, management commitment, safety culture and employee aptitude. Hazard occurrence patterns fluctuate on a monthly, quarterly and seasonal basis. Variations in the number of HSE non-compliances can be seen by observing the data collected during the study period. In the years 2007, 2008, 2009 and 2010, the numbers of recorded HSE non-compliances were 674, 1203, 902 and 437, respectively. The data collected was studied on a monthly, quarterly and seasonal basis.

3.2.2. Fatality, Accident, Incident and Near Miss Cases Occurrences Pattern

The recorded HSE non-compliances were categorized according to cause fatality, accident, incident and near miss cases. Monthly, quarterly and seasonal flow of fatality, accident, incident and near miss cases occurrences was studied in detail.

3.2.3. Impacts on Environment, People and Company Assets

In 3rd classification the HSE non-compliances were studied in detail based upon their impacts on environment, people and company assets. This section was not covered completely in this study.

A detailed study of the HSE non-compliances was carried out with reference to their combination as well. The impact of 8 hazard categories was carried out with reference to cause fatality, accident, incident and near miss cases. The significance of the 8 hazard categories was reviewed as to their causing of harmful effects on the environment, humans and property. Finally, the effects of fatality, accident, incident and near miss events were studied as to their creation of harmful effects on the environment, humans and property.

3.3. Monthly, Quarterly and Seasonal Distribution of HSE Non-Compliances

Monthly, quarterly and seasonal distribution of all three proposed classifications of HSE non-compliances were carried out. The trend of monthly, quarterly and seasonal distribution was studied in detail and root cause for their occurrences was identified.

3.3.1. Analysis of Activities

An analysis of the activities was carried out by using Microsoft office 2010 and the statistical package of social sciences (SPSS) version 18.0.

3.3.2. Statistical Association among HCFs

A statistical association among two classifications .i.e. Hazard Contributing Factors and fatality, accident, incident & near miss cases was performed by using the statistical package of social sciences (SPSS) version 18.0. It was found that hazards were not independent; they were interdependent with each other. A test of the correlation and multiple regression analysis was performed. The correlation is the degree of similarity or difference between the variables. A statistical association or correlation was noticed among the hazards. The correlation can be positive or negative. The Pearson correlation was performed on the data. The range of the Pearson correlation is from -1 to +1. The correlation coefficient is 'unit free'; it is used to compare the degree of association between variables.

3.4. Risk and Safety Analysis Models

Risk assessment models helps to determine the risk associated with the work related activities. They help to identify the risky activities that have the potential to cause harm to workers, the environment and company assets. The risk and safety analysis models analyzed past HSE non-compliance and were used to minimize them in the future. They also help in forecasting safety requirements and guidance to take the necessary measures to prevent losses. Many risk assessment criteria are being implemented in many organizations. Only the use of a relevant risk assessment method to evaluate risk is helpful to identify the associated hazards at a workplace. Use of an irrelevant risk assessment model will not be helpful in the elimination of the risks. Furthermore, it may just shift the hazards from one zone to another and the risks remain in the system and ultimately the net safety of the system remains same.

Hence, in this study, a safety and risk assessment model for the PFS was developed using the 3.5 years of HSE non-compliance data collected from the different petrol filling stations located at various cities in Pakistan. Analysis of the HSE non-compliances was carried out and the risks associated with them was evaluated and prioritized. The monthly and quarterly classifications based upon hazard contributing factors and an occurrence of fatality, accident, incident and near miss cases was used. A variation in results was noticed. A seasonal classification was also used for development of safety and risk assessment model. The study data for 3.5 years duration was categorized according to four seasons and analyzed. A Multiple Regression Analysis (MRA) approach was used. The MRA was performed by using statistical package of social sciences (SPSS) version 18.0. Further detail of risk assessment model development is presented in the following sections. A generalized flow diagram used for risk identification, assessment and evaluation is shown in Figure 3.3.

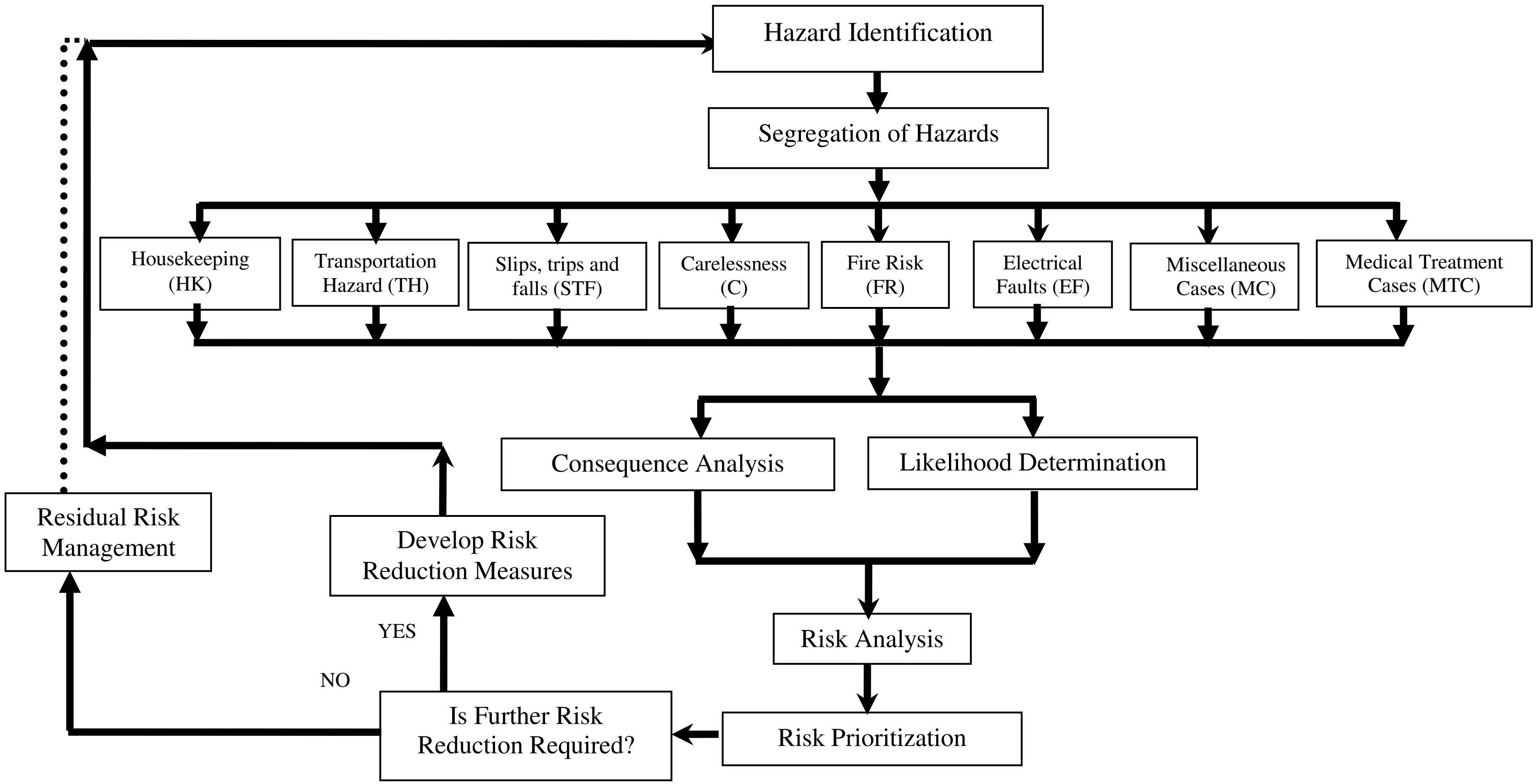

Figure 3.3: Risk and Safety Analysis Model Development Framework

Figure 3.3 illustrates a framework for the safety and risk assessment model for the PFS. The risk assessment process starts with the hazard identification process at the PFS. After identification of hazards it requires to carry out hazard segregation. For the development of safety and risk assessment model the hazards were segregated into 8 principal hazards contributing factors. These were Housekeeping (HK), Transportation Hazard (TH), Slips, trips and falls (STF), Carelessness (C), Fire risk (FR), Electrical Fault (EF), Miscellaneous Cases (MC) and Medical Treatment Cases (MTC). In 3rd step the consequence and likelihood analysis was carried out and risk was calculated. The risk assessment further followed by risk prioritization, development of risk reduction measures and residual risk management, if necessary.

The methodologies adopted for the development of each risk assessment model are presented in the following sections.

3.4.1. Risk and Safety Analysis Model Based upon HCFs

A risk and safety analysis model (RSAM) was developed based upon HSE Non- Compliances distributed into 8 HCFs. The 8 categorized HCFs were:

1. Housekeeping (HK)
2. Transportation Hazards (TH)
3. Slips, Trips and Falls (STF)
4. Carelessness (C)
5. Fire Risks
6. Electrical Faults (EF)
7. Miscellaneous Cases (MC)
8. Medical Treatment Cases (MTC)

The safety and risk assessment model was developed by using the Multiple Regression Analysis (MRA) approach. The MRA was performed by using the Statistical Package of Social Sciences version 18.0 (SPSS 18.0). MRA process is use to determine the relationship among the variables [115, 116]. The use of the MRA determines the proportion of risk associated to the dependent variable with the independent variables. To calculate the un-standardized and standardized co-efficient for HK, the HK was kept as a dependent variable and the remaining seven HCFs as independent variables. The un-standardized and standardized co-efficients for TH were determined by keeping TH as the dependent variable and the remaining seven HCFs as independent variables. In a similar manner, the un-standardized and standardized co-efficients for STF, C, FR, EF, MC, and MTC were calculated by keeping the respective HCF dependent and the other seven HCFs as independent variables. The severity of each HCF was calculated by using the following equation:

$$S_{HK} = \text{Un-standardized Co-efficient} + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{FR}(FR) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.1)$$

$$S_{TH} = \text{Un-standardized Co-efficient} + S_{HK}(HK) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{FR}(FR) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.2)$$

$$S_{STF} = \text{Un-standardized Co-efficient} + S_{HK}(HK) + \beta_{TH}(TH) + \beta_{C}(C) + \beta_{FR}(FR) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.3)$$

$$S_{C} = \text{Un-standardized Co-efficient} + \beta_{HK}(HK) + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{FR}(FR) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.4)$$

$$S_{EF} = \text{Un-standardized Co-efficient} + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{FR}(FR) + \beta_{HK}(HK) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.5)$$

$$S_{FR} = \text{Un-standardized Co-efficient} + \beta_{HK}(HK) + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.6)$$

$$S_{MC} = \text{Un-standardized Co-efficient} + \beta_{HK}(HK) + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{EF}(EF) + \beta_{FR}(FR) + \beta_{MTC}(MTC) \quad (3.7)$$

$$S_{MTC} = \text{Un-standardized Co-efficient} + \beta_{HK}(HK) + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{EF}(EF) + \beta_{FR}(FR) + \beta_{MC}(MC) \quad (3.8)$$

Where,

S_{HK} = Severity level of Housekeeping

S_{TH} = Severity level of Transportation Hazard

S_{STF} = Severity level of Slips, trips and falls

S_{c} = Severity level of Carelessness

S_{EF} = Severity level of Electrical Faults

S_{FR} = Severity level of Fire Risk

S_{MC} = Severity level of Miscellaneous Cases

S_{MTC} = Severity level of Medical Treatment Cases

β_{HK} = Standardized coefficient for Housekeeping

β_{TH} = Standardized co-efficient for Transportation Hazard

β_{STF} = Standardized co-efficient for Slips, trips and falls

β_{C} = Standardized co-efficient for Carelessness

β_{EF} = Standardized co-efficient for Electrical Faults

β_{FR} = Standardized co-efficient for Fire Risk

β_{MC} = Standardized co-efficient for Miscellaneous Cases

β_{MTC} = Standardized co-efficient for Medical Treatment Cases

After calculating the "Severity" of each HCF, the likelihood of the respective HCFs was calculated. The likelihood was calculated by dividing the respective HCFs' occurrences by the total number of occurrences during that particular year. The risk associated with each individual HCF was calculated by multiplying the severity and likelihood. Finally, it was ranked based upon the risk score.

3.4.2. Risk and Safety Analysis Model Based upon F, A, I and NM Cases

The risk and safety analysis model was developed based upon HSE non-compliances distributed into 4 categories. These were:

1. Fatality (F) Cases
2. Accident (A) Cases
3. Incident (I) Cases
4. Near Miss (NM) Cases

A Multiple Regression Analysis (MRA) was performed by using the Statistical Package of Social Sciences version 18.0 (SPSS 18.0). To calculate the un-standardized and standardized co-efficient for Fatality, F was kept as the dependent variable and the remaining three variables, i.e., A, I and NM were kept as the independent variables. The un-standardized and standardized co-efficient for the A, I and NM cases were also calculated by keeping the respective variable as dependent and the remaining three as independent variables.

The severity of each variable was calculated by using the following equation:

$$S_F = \text{Un-standardized Co-efficient} + \beta_A(A) + \beta_I(I) + \beta_{NM}(NM) \quad (3.9)$$

$$S_A = \text{Un-standardized Co-efficient} + \beta_F(F) + \beta_I(I) + \beta_{NM}(NM) \quad (3.10)$$

S_I = Un-standardized Co-efficient$+\beta_A(A) + \beta_F(F) + \beta_{NM}(NM)$ (3.11)

S_{NM} = Un-standardized Co-efficient $+ \beta_A(A) + \beta_F(F) + \beta_I(I)$ (3.12)

Where,

F	=	Fatality
A	=	Accident
I	=	Incident
NM	=	Near Miss
β_F	=	Standardized co-efficient for Fatality
β_A	=	Standardized co-efficient for Accident
β_I	=	Standardized co-efficient for Incident
β_{NM}	=	Standardized co-efficient for Near Miss
S_F	=	Severity of Fatality
S_A	=	Severity of Accident
S_I	=	Severity of Incident
S_{NM}	=	Severity of Near Miss
R_F	=	Risk of Fatality occurrence
R_A	=	Risk of Accident occurrence
R_I	=	Risk of Incident occurrence
R_{NM}	=	Risk of Near Miss occurrence

After calculating the "Severity" for the variables, i.e., fatality, accident, incident and near miss cases, the likelihood of each variable was calculated. The likelihood was calculated by dividing the respective variable occurrences by the total number of occurrences during that particular year.

The risk associated with each individual variable was calculated by multiplying the severity and likelihood. Finally, it was ranked based upon the risk score.

3.4.3. Risk and Safety Analysis Model Based upon Seasonal Occurrences of HCFs

The risk and safety analysis model prepared based upon monthly occurrences of hazard contributing factors and fatality, accident, incident and near miss cases. The results obtained were compared and fewer relevancies among the results in each year were noticed. It was due to significant fluctuations of HSE non-compliances each year on monthly basis. The noticeable fluctuations were also observed in quarterly distribution of HSE non-compliances. Therefore, to develop the safety and risk assessment model by using monthly and quarterly distribution of data was not found the right choice. The risk assessment models developed by using monthly distribution of HSE non-compliances may give better results by using large sets of data. So that It can be tested and validate. The development of safety and risk assessment model based upon monthly and quarterly distribution of HSE non-compliances may be successful in other industrial sectors. The final model developed should be test and after validation may be use for further implementation.

A less fluctuations were observed in seasonal distribution as compared to monthly and quarterly distribution of HSE non-compliances. A similar flow was observed in four seasons of each year. By considering this aspect the results of seasonal distribution of HSE non-compliances were used for development of safety and risk assessment model. A methodology used for the development of risk and safety analysis model based upon monthly distribution was also used for development of safety and risk analysis model based upon seasonal distribution of HSE non-compliances. A Multiple Regression Analysis (MRA) approach was used. A MRA was performed by using Statistical Package of Social Sciences version 18.0 (SPSS 18.0). For the year 2007, the un-standardized and standardized co-efficient for S1 was calculated by keeping S1 as dependent variable and the remaining two seasons .i.e. S3 and S4, as independent variables. The un-standardized and standardized co-efficient for S3 was determined by keeping S3 as dependent variable and the remaining two seasons S1 and S4 as independent variable. Finally, the un-standardized and standardized co-efficient for S4 was determined by keeping S4 as dependent variable and S1 and S3 as independent variable.

In a similar manner, the un-standardized and standardized co-efficient for each season S1, S2, S3 and S4 for the year 2008, 2009 and 2010 was calculated by keeping respective season dependent and other three seasons as independent variables in each year.

As the data collected for the year 2007 was consisted of six months duration period and it was categorized into 3 season’s .i.e. S1, S3 and S4. Therefore, to calculate severity for the year 2007 following equations were used;

S_{S1} = Un-standardized Co-efficient + β_{S3} (S3) + β_{S4} (S4) (3.13)

S_{S3} = Un-standardized Co-efficient + β_{S1} (S1) + β_{S4} (S4) (3.14)

S_{S4} = Un-standardized Co-efficient + β_{S3} (S3) + β_{S1} (S1) (3.15)

A twelve months data for the year 2008, 2009 and 2010 was used and it was distributed among four seasons .i.e. S1, S2, S3 and S4. Therefore following equations were used to calculate the severity;

S_{S1} = Un-standardized Co-efficient + β_{S3} (S3) + β_{S4} (S4) + β_{S2} (S2) (3.16)

S_{S2} = Un-standardized Co-efficient + β_{S3} (S3) + β_{S4} (S4) + β_{S1} (S1) (3.17)

S_{S3} = Un-standardized Co-efficient + β_{S1} (S1) + β_{S2} (S2) + β_{S4} (S4) (3.18)

S_{S4} = Un-standardized Co-efficient + β_{S1} (S1) + β_{S2} (S2) + β_{S3} (S3) (3.19)

Where,

S_{S1} = Severity level of Season 1 (Cold Season)

S_{S2} = Severity level of Season 2 (Hot Season)

S_{S3} = Severity level of Season 3 (Warm Season)

S_{S4} = Severity level of Season 4 (Monsoon Season)

β_{S1} = Standardized coefficient for Season 1 (Cold Season)

β_{S2} = Standardized coefficient for Season 2 (Hot Season)

β_{S3} = Standardized coefficient for Season 3 (Warm Season)

β_{S4} = Standardized coefficient for Season 4 (Monsoon Season)

After calculating the "Severity" of each season, the likelihood of respective seasons were calculated. Likelihood was calculated by dividing the respective season occurrences by the total numbers of occurrences during that particular year. A risk associated with each individual season was calculated by multiplying severity and likelihood. Finally, it was ranked based upon the risk score.

3.5. Methodology for Development of Checking and Review Process Based upon HSE Non-Compliances

The proposed safety measurement checking and review process based upon HSE non-compliances was developed during study period. The study period was comprised of the data collection period from July 2007 to December 2010. A generalized checking and review process based upon HSE non-compliances was implemented in year 2009 and 2010. The framework for checking and review process based upon HSE non-compliances model is presented in Figure 3.4.

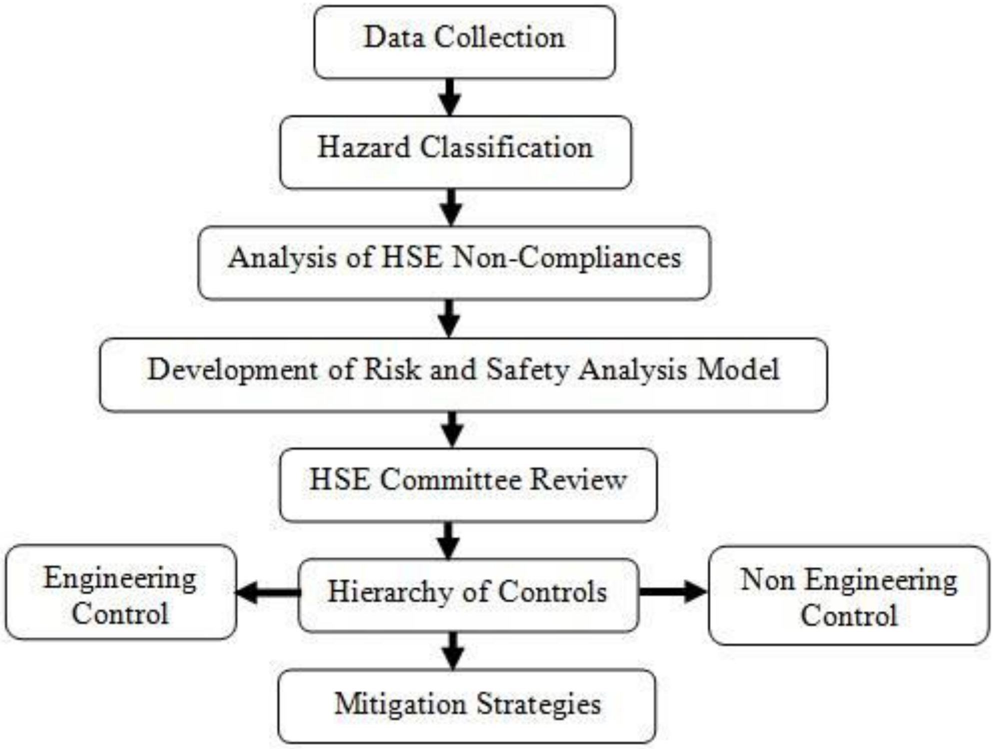

Figure 3.4: Flow Diagram of Checking and Review Process Based upon HSE Non-Compliances

The checking and review process developed in this study consisted of seven steps. These were:

1. Data Collection
2. HSE Non-compliances Classification
3. Analysis of HSE Non-Compliances
4. Risk & Safety Analysis Model Development
5. HSE Committee Review Meetings
6. Hierarchy of Control
7. Mitigation Strategies

3.5.1. Data Collection

Data collection pertaining to HSE non-compliances was formulated first step for the development of checking and review process. Focal persons were assigned the responsibility of data collection at respective PFS. A qualitative form of data was collected. Dedicated personnel's (HSE focal persons) were nominated at PFSs to record the HSE non-compliances occurrences. Training programs and workshops were arranged at head office as well as at PFSs sites to educated HSE focal persons pertaining to data collection process. The data related to HSE non-compliances was collected with reference to Table 3.1. The data was collected from 2500 PFSs. The PFSs were monitored 24 hours a day and 7 days a week during 3.5 years data collection period. Data collected pertaining to HSE non-compliances was sent to HSE representative at head office on weekly basis. Continuous support was provided to HSE focal persons during data collection process by the head office HSE representative. Head office HSE representative also visited PFSs sites time to time to further strengthen the data collection process.

3.5.2. HSE Non-Compliances Classification

After data collection the categorization of HSE non-compliances were carried out based upon HCFs and occurrences of fatality, accident, incident and near miss cases.

3.5.3. Analysis of HSE Non-Compliances

HSE non-compliances were classified into monthly, quarterly and seasonal distributions. Graphical representations were plotted. A test of correlation and multiple regression analysis was performed by using statistical package of social sciences (SPSS v 18.0) to see the significance level of HSE non-compliances.

3.5.4. Risk & Safety Analysis Model Development

A detailed methodology for development of risk and safety analysis model was described in section 3.4.

3.5.5. HSE Committee Review Meetings

The HSE committee review meetings normally organized on quarterly basis. A company that operates fields, HSE review meetings arranged on fields on quarterly basis and annual HSE review committee meeting arranged in head office only in first quarter of the year. The topics discussed in four HSE review meetings in fields were considered as agenda for this annual HSE review committee meeting. Unscheduled meetings may be called at any time on the direction of chairman. These meetings provide a platform for the exchange of new ideas with open discussion, evaluation of the inputs from concerned departmental heads and assess the opportunities for continual improvement in HSE management system. In HSE committee meetings the review of HSE activities were carried out. Adequacy, effectiveness and progress of activities were measured with reference to annual HSE objective and targets. Management committee staff and departmental heads confirm the implementation and effectiveness of ongoing HSE checking and review process. Following topics were reviewed and discussed in HSE committee meetings:

- Review the minutes with current status of HSE management system review, conducted last year
- HSE policies, objectives & targets
- Internal and external HSE audits
- Environmental aspects and impact analysis
- Internal and external communication, induction and training
- Hazard identification and risk assessment
- Accident/incident statistics
- Recommendations for improvements in HSE management system
- Any other HSE issue with the permission of Chair person

3.5.6. Hierarchy of Control

Prior to the proposed mitigation strategies consideration was given to reduce the risks according to the following hierarchy [117];

- Reduce / Eliminate Hazard
- Substitution of hazardous activity
- Engineering controls
- Administrative controls / Signage(s)
- Use of Personnel Protective Equipment

3.6. Mitigation Strategies

Training and short duration courses related to workers were found very helpful to reduce the occurrences of unsafe acts by the workers. It was recorded that many accidents were the results of unawareness by the workers of how to perform the assigned task. Mitigation strategies were comprised of training programs, short training courses, refresher courses and other forms of knowledge sharing sessions that were normally provided by the organizations to the workers to improve work productivity. These programs were designed according to the job requirements. Training was normally provided by the in house concerned departments and outside training and consultancy bodies.

3.6.1. Methodologies for Development of Mitigation Strategies

Six months of data were collected related to HSE non-compliances from PFS's. The first three months of data related to HSE non-compliances were taken by the PFS's operating company. The data was analyzed and areas for major improvements were highlighted. To reduce HSE non-compliances in specific areas, mitigation strategies were developed. These mitigation strategies were based upon literature review, case studies and expert opinions. After setting out these mitigation strategies, briefings were given to the management committee to take approval for the practical application. Three months of data collection with application of these strategies was requested and granted by the management committee. During a one month duration period, the initial description/contents of the mitigation strategies were elaborated to the management. Goals and objectives of the programs were defined for the management. Briefings were also given to all stakeholders, contractors and client personnel about the application of the strategies to improve safety statistics in the head office as well. The areas of improvement highlighted were carelessness, electrical faults, use of hand brakes, mechanical problems, housekeeping and maintenance issues. Analysis results of HSE non-compliances for the data provided by the management were presented and deficiencies highlighted to all the groups. Mitigation strategies were elaborated and desirable outcomes were introduced to the client and contractor personnel. After providing briefings, the management put forward their apprehensions that the same message may be conveyed to all the staff members at all sites. This was to make sure that the workers aware about the safety improvement program. The time allotted to cover all of the training material awareness sessions at their specific petrol filling station was four weeks. Off and on site visits to see the strategies applied in daily routines were also scheduled. The flow diagram of mitigation strategies application process is shown in Figure 3.5 below.

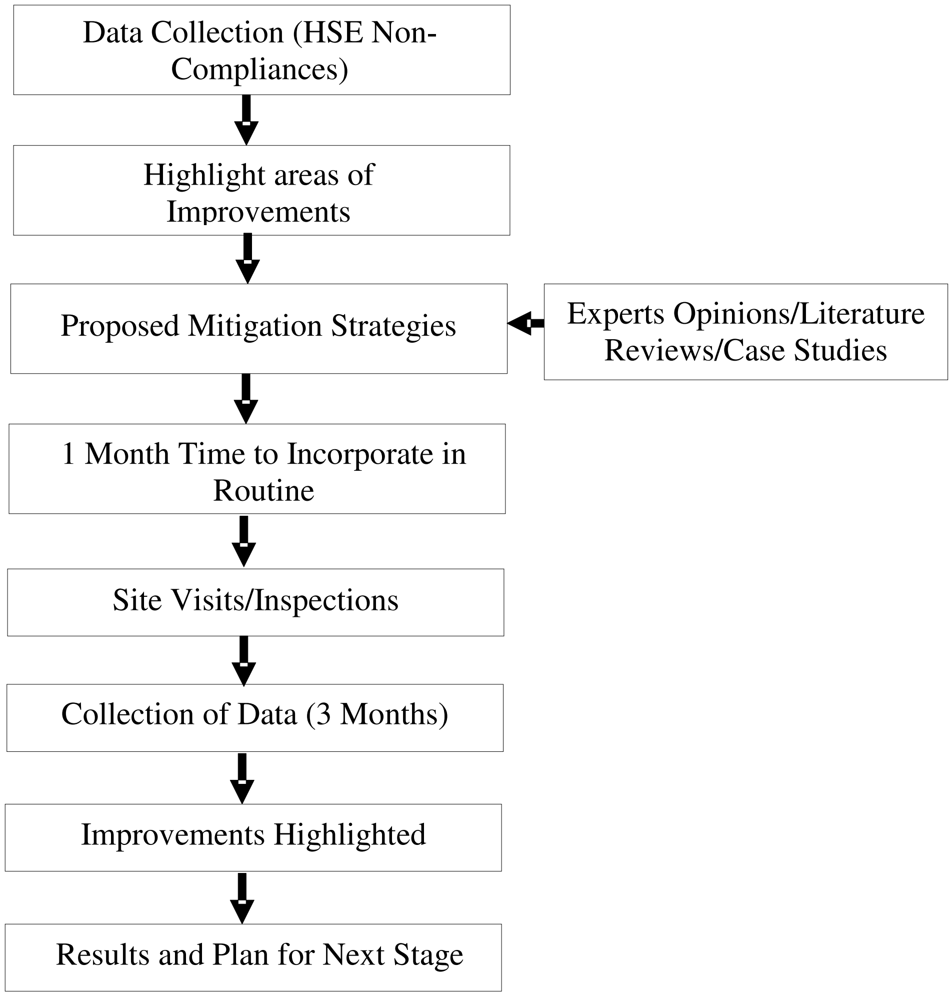

Figure 3.5: Mitigation Strategies Application Process Flow Diagram

90 persons from non-management and 233 persons from management were trained. The staff selected for the training consisted of all disciplines. Priority was given to training focal persons of specific sites. Consideration was also given to those persons who dealt with safety related matters at their sites.

3.6.2. HSE Alerts

The following Alerts were issued during three months of the data collection period with the application of mitigation strategies:

- Preventing Slip/trips and falls
- Health guidelines in Ramadan
- Tips for good Foot Health.
- Computer Safety
- Flu
- Safety Measures in Fog
- Driver and Vehicle Safety

During the data collection period, HSE alerts were used as a safety reminder to the staff. These alerts covered the most important causes of unsafe act occurrences. Employees were continuously alerted about these so that they could incorporate these safe practices in their normal daily working situations.

3.7. Development of Safety Triangle for Petrol Filling Stations

The occurrences of fatality, accident, incident and near miss cases were found interdependent and it was noticed that they possessed a strong relationship with each other. With the help of this study, the data was categorized into fatality, accident, incident and near miss cases; then, a safety triangle for PFSs was developed. The safety triangle was prepared by taking the weighted average of fatality, accident, incident and near miss occurrences for the 3.5 years of study data.

3.8. Analytical Hierarchy Process (AHP)

In this section, the AHP has been proposed to prioritize the hazard contributing factors (HCFs) to support the HSE professionals in their decision making. It aims to rank the HCFs. In the AHP, the HCFs are presented in a hierarchical structure and the decision maker is guided throughout a subsequent series of pair wise comparisons to express the relative strength of the elements in the hierarchy. In general, the hierarchy structure encompasses three levels; the top level represents the HCFs, and the lowest level has the duration in which the HSE non-compliances occurred. The intermediate level contains the evaluated criteria under which each HCF was evaluated. Figure 3.6 depicts the structure of the AHP model.

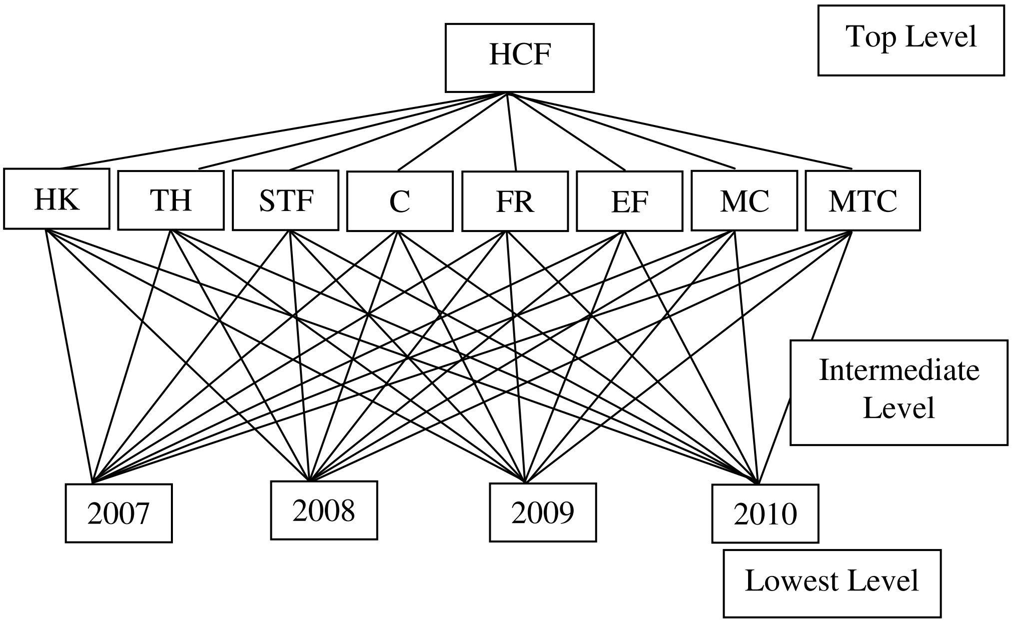

Figure 3.6: AHP Model

There are many ways to obtain a preference: the measurement scale proposed by [118] was used in many studies. Table 3.2 illustrates a glimpse of the decision maker's judgment and preference of the criteria with pair wise comparisons. This measurement scale enables the HSE professionals to determine the significance level among the criteria. This measure scale includes 1-9 scale points, each point represents a different degree of preference.

Table 3.2: AHP Measure Scale

Value	Preference
1	Equal Importance
3	Moderate Importance
5	Strong Moderate Importance
7	Very strong Moderate Importance
9	Extreme Moderate Importance
2,4,6,8	For comparison between the above values

Source: [118]

By using the measure scale and comparing each HCF to another, the original matrix of the criteria will be composed. The data used in the original matrix of the criteria produced an accurate estimate of the criteria weights. The weights provide a measure of the relative strength and importance of each criterion. The whole process can be broken down into the following steps:

1. Compute the total values in each column
2. Divide each single value by its column total
3. Calculate the averages of each row

The final scores obtained for each HCF across each criterion was determined by multiplying the weight of each criterion with the weight of each HCF. The HCF that got the highest score was suggested as the most significant HCF.

3.9. Forecasting of Upcoming Hazards

The exponential smoothing method was used to forecast the future occurrences of fatality, accident, incident and near miss cases. The data for the years 2007, 2008, 2009 and 2010 was used to forecast the number of fatality, accident, incident and near miss cases for the years 2011, 2012 and 2013.

The equation for an exponential smoothing forecast is:

$$F_t = (1 - \alpha) F_{t-1} + \alpha A_{t-1} \quad [119] \qquad (3.20)$$

Where;

F_t	=	Exponentially smoothed forecast for period t
F_{t-1}	=	Exponentially smoothed forecast made for the prior period
A_{t-1}	=	Actual demand in the prior period
α	=	Exponential smoothing constant

The equation states that the new forecast is equal to the old forecast plus a portion of the error (the difference between what actually occurred and the previous forecast).

3.10. Data used for the Study

The data for the study work was consisted of 3.5 years period (July 2007 to December 2010). The data for the year 2011 was received in mid of the year 2012. The data collection activity was remained continuous at PFSs but head office HSE representatives were busy in company auditing process in first quarter of the year 2012. Therefore available 3.5 years period data (July 2007 to December 2010) was used to meet the study objectives and targets. The results of study were published in international journals and conferences in the year 2011. PhD dissertation write up was started in the end of year 2011 and submitted for PhD viva in second quarter of the year 2012. It was not possible to include data for the year 2011 in this study due to time limitations. The study results were compared with the year 2011 and successful results were noticed.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Introduction

In this chapter, the results of the hazard contributing factors, risk and safety analysis models, mitigation strategies and the checking and review process will be presented. The chapter will also discuss the adverse effects of petrol filling stations within an urban and rural environment. The study was conducted based upon 3.5 years of data collected from 2,500 petrol filling station retail outlets located in different areas of Pakistan. Retail outlets were spread all around the country and monitored from July 2007 to December 2010.

The results of study will be presented and discussed in this chapter according to the following flow;

- Distribution of HSE non-compliances based upon Hazard Contributing Classification (HCF)
- Statistical Analysis of HCFs
- Distribution of HSE non-compliances based upon Fatalities, Accidents, Incident and Near Miss Cases
- Distribution of HSE non-compliances based upon their impacts on People, Environment and Company Assets
- Statistical Analysis for Fatality, Accident, Incident and Near Miss Causation
- Relationship among HCFs and occurrences of Fatalities, Accident, Incident and Near Miss Cases
- Quarterly Distribution of HSE non-compliances based upon HCFs
- Quarterly Distribution of HSE non-compliances based upon Fatality, Accident, Incident and Near Miss cases
- Seasonal Distribution of HSE non-compliances based upon HCFs

- Seasonal Distribution of HSE non-compliances based upon Occurrences of Fatality, Accident, Incident and Near Miss cases
- Risk Evaluation for Risk and Safety Analysis Models
- Validation for Safety and Risk Analysis Model developed based upon seasonal occurrences of Hazard Contributing Factors.
- Mitigation Strategies Results and Discussion
- Checking and Review Process Results Based upon HSE non-compliances.
- Safety Triangle for Petrol Filling Station
- Analytical Hierarchy Process (AHP) Evaluation Results
- Forecasting of Hazards for the Year 2011, 2012 and 2013

4.2. Distribution of HSE Non-Compliances based upon Hazard Contributing Factors (HCFs) Classification

This section will cover the detailed description of the monthly hazard classification for the year 2007, 2008, 2009 and 2010. Causes of HSE non-compliances occurrences for each year will be highlighted and discussed in this section. The data collected was from July 2007 to December 2010. For the year 2007, 6 months of data (July to Dec) were used- whereas, for the years 2008, 2009 and 2010, 12 months of data were used for the study (Appendix A). 3,216 HSE non-compliances were recorded during the operation and maintenance of the petrol filling stations. The data collected based upon their impact to cause harmful effects to the personnel, environment and company assets were classified into 8 groups. These were housekeeping (HK), transportation hazard (TH), slips trips and falls (STF), carelessness (C), fire risks (FR), electrical faults (EF), miscellaneous cases (MC) and medical treatment cases (MTC). Each HCF component was studied in detail and the causes of the occurrences of HSE non-compliances pertaining to them will be described in the following section.

4.2.1. Housekeeping (HK)

HSE non-compliances related to HK practices were collected during the 3.5 year data collection period. A total of 156 non-compliances were recorded due to HK practices. The monthly hazard contributing patterns for HK from July 2007 to December 2010 are shown in Figure 4.1. It can be observed in Figure 4.1 that during the 3.5 year data collection period, in the month of August 2007, the highest number of non-compliances was recorded with 22 cases. In the years 2007, 2008, 2009 and 2010, the total HK yearly non-compliances recorded were 54, 55, 42 and 5, respectively.

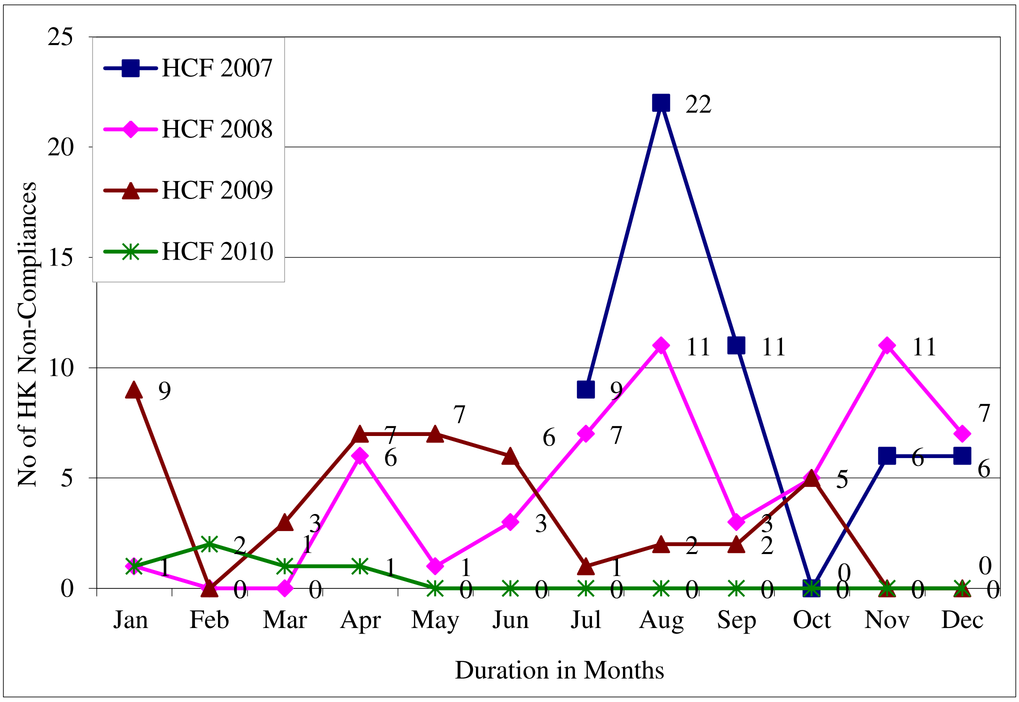

Figure 4.1: Annual Trend of HK for 3.5 Years Data Collection Period

Multiple causes of HSE non-compliances were recorded throughout the data collection period. It can be observed in Figure 4.1 that the HK non-compliance pattern for the 3.5 year data collection period was not constant, it was fluctuating. This was due to the variation in safety measures at the different PFS's. Recurrence causes were also observed in different months. The identified root causes were due to:

1- Slippery surfaces were identified at gantry, stairs, washrooms and in office block areas.
2- The growth of grass and wild bushes was observed on the tank pad in the tank zone and at the main gate.
3- Excessive growth of tree branches was also observed in the surroundings of the PFS's especially in the rural areas. It was recorded that the tree branches were touching 11 KV power supply cables.

4- Due to poor HK practices, bee hives were observed behind office blocks, fire boxes, electrical panels and under stairs.
5- There were cases reported in which staff members observed snakes and scorpions in the facility. First aid treatment cases were reported due to snakebite cases. Scorpion sting cases was also reported.
6- Garbage, empty cartons, and unused materials were observed on the drive way.
7- Metal wire pieces were found near the boundary wall and at the lube ware-house, earthing cables were found at the unloading bay, and old electrical poles and foundations were strewn in the tank zone. Oil soaked cotton waste was found near the T/L filling gantry.
8- Live electrical cables were also observed to be lying on the floor during the PFS operation that could be a potential cause of sparks and occurrences of fire.
9- The storm water drainage system was found to be blocked.
10- Unsatisfactory HK practices were recorded in handling fire-fighting equipments. Hose pipes were found scattered on the platform of the decantation area.

Snakebite cases were reported significantly to those petrol filling stations that were located in rural areas. Since the smell of petrol vapours can spread easily far apart in rural areas due to high winds and open spaces. It is the possibility that it may attract the snakes. Therefore, staff awareness and first aid treatment response training programs are essentially needed especially to those PFS that are located in rural areas. Trenches around periphery of PFS to minimize the entrance of snakes is recommended. However, from Figure 4.1, it can be observed that a significant reduction in HK non-compliance was observed in the year 2010 due to improvements in the HK practices.

4.2.2. Transportation Hazard (TH)

A total of 739 HSE non-compliances were reported due to TH throughout the 3.5 years data collection period. The monthly hazard contributing patterns for TH from July 2007 to December 2010 is shown in Figure 4.2.

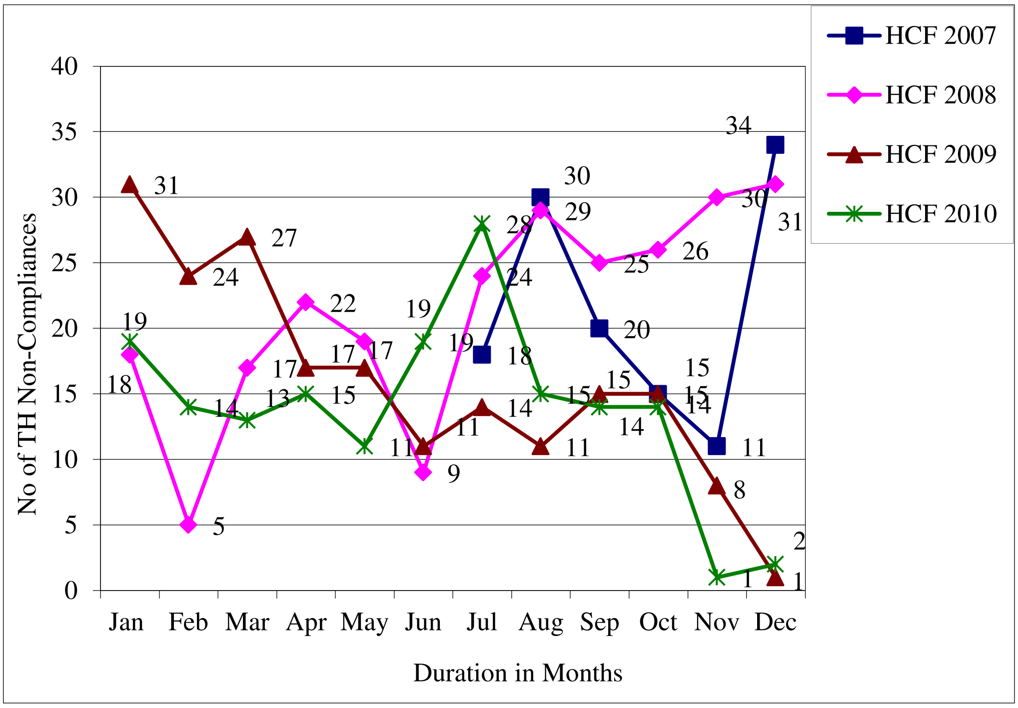

Figure 4.2: Annual Trend of TH for 3.5 Years Data Collection Period

In the years 2007, 2008, 2009 and 2010, the number of HSE non-compliances recorded due to TH was 128, 255, 191 and 165, respectively. TH contributed 23% in the overall hazard contributing factors that occurred during the 3.5 year duration. It can be observed in Figure 4.2, that there were noticeable fluctuations in the TH pattern.

The number of HSE non-compliances pertaining to TH was found to increase from the year 2007 to 2008. It was noticed that for the year 2009 and 2010 the HSE non-compliances significantly reduced due to the driver's safe attitude, organizing of driving safety programs, facility design modifications and refresher courses.

It can be observed that, in 2007, the hazard contributing pattern was very unstable. In July 2007, the number of HSE non-compliances under TH was 18 and then increased to 30 in August. It then reduced to 20, 15 and 11, in the months of September, October and November, respectively. However, the number of HSE non-compliances rose to 34 cases in December. It was noticed that the PFS operation has extensive movement of T/Ls. Therefore, unsafe practices recorded within and outside the PFS's happened due to T/Ls. In the month of December, out of the 34 cases, 27 cases recorded were due to the collision of T/Ls with other private vehicles during the transportation of fuel. The collision of T/Ls resulted in severe damages to private vehicles. Accident investigations of TH cases were not carried out in detail; hence, the root causes were not identified. However, it was observed that TH cases occurred due to the driver's negligence, road configuration, vehicle conditions and the adjacent vehicles drivers' attitude.

It can be observed in Figure 4.2 that the TH patterns for the year 2008 were unstable. The total number of non-compliances pertaining to TH cases recorded in the year 2008 was 255. Even though there was a drop in the number of cases in the months of February and June, there was an increasing trend in the number of cases for the whole year. There were 93 major accidents that occurred due to the collisions of T/Ls within and outside the facilities. Brake failures, tyre bursts and mechanical/maintenance problems were identified as potential causes of TH hazards during the year 2008. Two fatality cases were reported related to TH during the year 2008. The first fatality causing event occurred on 28th February 2008, two persons were reported dead. A customer's car using a compressed natural gas (CNG) cylinder burst during the filling operation. The second event occurred on 13th April 2008 when a T/L entering into the facility hit the worker near the gantry. The worker died at the scene.

A reduction in the number of HSE non-compliances due to TH was observed in Figure 4.2 for the year 2009. The total number of non-compliances related to TH during the year 2009 was 191. The number of cases that contributed to the result in a significant loss to the company assets was 75. During the 12 months data collection period, the highest and lowest HSE non-compliances due to TH were found to be 31 and 1, respectively.

During the year 2010, the total HSE non-compliances recorded were 437 in which 165 (37.7%) cases were recorded due to TH. The number of HSE non-compliances throughout 2010 seemed to be approximately stable. However, it can be observed in Figure 4.2 that in July the number of HSE non-compliances increased to 28. In November and December the number of HSE non-compliances dropped drastically to 1 and 2, respectively.

The causes of most of the HSE non-compliances in TH were found to be similar in all 3.5 years of the data collection period. The identified potential causes of TH cases were as follows:

1. The unsatisfactory maintenance of company vehicles was the potential cause of the TH cases. Most accidents occurred due to failures in the vehicles interlocking system and axle break down.
2. T/Ls were found to be over speeding within and outside the PFS facilities while private vehicles were found to be over speeding within the facilities. Collisions of T/Ls with facility elements such as dispenser units, infrastructure, main gate, boundary wall, swing ladder, I-land beams of gantry, safety signs, filling gantry, service hydrants and dispensing units also occurred.
3. Most of the T/Ls were found to have deteriorated tyres.
4. Workers were found to be careless towards T/Ls. It was observed that some drivers of the T/Ls were sleeping beneath the T/Ls. Cleaners were driving the T/Ls or found to be cleaning the T/Ls' tyres under the T/Ls.
5. Weather conditions contributed to the non-compliances related to TH cases at PFSs. Poor visibility and skidding of T/Ls on the road was found to be a potential concern.
6. T/Ls hijacked due to weak security measures during fuel transportation to retail outlets via road networks. Product was spilled by opening the T/Ls' valves and wasted.
7. Traffic sign violations were noted within and outside the facilities by T/Ls.
8. The T/Ls' movement damages to PFS components such as canopies, islands, and gantries, and collision with other vehicles were identified under potential TH non-compliances. Other heavy vehicles that visited PFS's such as trucks, trailers, and buses also collided with other vehicles and associated components. The root cause identified was an improper facility design especially regarding the T/Ls' turning radii.
9. Overtaking of T/Ls during fuel transportation was also observed as one of the causes.
10. In cold and monsoon season the accidents were recorded due to poor visibility conditions.

The allowable speed limit was set at only 5km/hr. Moreover, incomplete accident investigation may be the potential cause of TH recurrences. Transportation accidents caused damages to T/Ls, company vehicles, infrastructure and private vehicles.

4.2.3. Sips, Trips and Falls (STF)

Slips, trips and falls were the third highest HCF in HSE non-compliances during the 3.5 year data collection period. A total of 137, 215, 202 and 49 cases were reported due to slips, trips and falls during the years 2007, 2008, 2009 and 2010, respectively. Figure 4.3 shows the graphical representation of slips, trips and falls for 3.5 years.

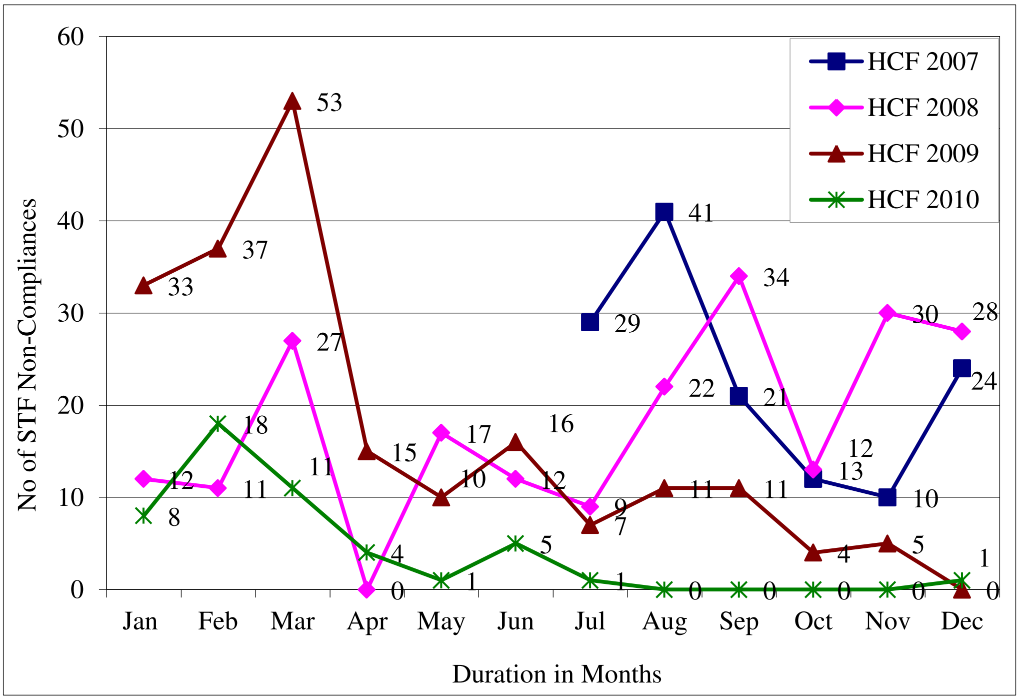

Figure 4.3: Annual Trend of STF for 3.5 Years Data Collection Period

STF cases occurred due to tripping of workers and falling of equipment & material from higher levels. The fluctuations in STF cases during the year 2007 can be viewed in Figure 4.3. The highest and lowest cases recorded during the year 2007 were 41 and 10, respectively. It can be observed that the number of STFs dropped gradually from Aug. to Nov. 2007. Generally, an increment in STF cases during the year 2008 can be seen in Figure 4.3. However, the number increased again to 24 cases in Dec. 2007. The average number of slips, trips and falls recorded were approximately 18 cases every month. However, no STF case was reported during the month of April. In 2008, the peaks of STF cases recorded were 27, 34, 30 and 28 during the months of March, Sept., Nov. and Dec., respectively.

In the year 2009, a total number of 202 HSE non-compliances pertaining to STF cases were reported. In 2009, there seemed to be an increase in the STF cases from Jan. to March. In the month of March 53 cases were recorded and this was the highest throughout the 3.5 year study period. However, a drop in the STF pattern in 2009 from March to May was observed in Figure 4.3. The number of STF cases during the year 2010 was low. Throughout the year only 49 cases were reported. The highest STF of 18 cases was reported in the month of March. A gradual reduction in STF cases was observed from March to May. No STF cases were reported in the months of Aug., Sept., Oct. and Nov. Only one non-compliance case was reported in the month of Dec.

Multiple causes of STF cases were recorded throughout the period. The main contributing factors for the occurrences of the STF cases were:

1. Fall cases were due to falling of materials, equipment or workers from stairs, ladders, platforms, loading docks, truck roofs, jumping of workers from one T/L to another T/L or to the fuel gantry.
2. There was a collapse of a roof/ceiling of an office area to the ground. It caused damages to computers and other accessories. However, no injury was reported to the staff members.
3. Working tools fall on workers. These include flanges, gate valves, valve pit covers and roof plates.
4. Workers working with damaged equipment/tools that were not fit to be used for repairing and maintenance work.
5. Slippery surfaces were observed within the facilities. Significantly slippery surfaces were found on top of T/Ls.
6. Trees were fallen due to heavy winds, rains and storms.
7. Insufficient equipment for material transportation during routine and maintenance operations caused ergonomic problems.
8. Falling of workers from heights and from same level during construction work was noted.

9. Material falling from forklift. It included chutes, GI (Galvanized Iron) sheets, product information sign sheets, valve pit covers and pallets.
10. Workers accidentally fell into tank during welding operation.
11. Some workers had their foot trapped in the damaged T/L ladders.

4.2.4. Carelessness (C)

Carelessness (C) cases happened due to the unsafe practices of the workers during the PFS operation. Figure 4.4 shows the graphical patter of HSE non-compliances due to carelessness for the 3.5 year data collection period. Carelessness caused increased slip, trip and fall cases which consequently resulted in the increase of medical treatment cases. During the 6 month period (July-Dec.) in the year 2007, 87 non-compliances were recorded. An increment in carelessness cases can be seen in Figure 4.4 for the year 2008. A total number of 224 cases were reported related to carelessness out of 1,203 HCFs during the year 2008. Carelessness contributed 18.6% in the year 2008. The highest and lowest cases pertaining to carelessness recorded were 40 and 3, in November and May, respectively. However, a reduction in carelessness cases was observed for the years 2009 and 2010. One fatality case was reported on 5th September 2009. A worker fell down due to carelessness from the high speed diesel (HSD) filling point. He was filling the T/L. Dizziness was identified as the root cause of his fall. In the years 2009 and 2010, 97 and 41 carelessness cases were reported, respectively. On 9th October 2010 one fatality case was reported. A driver of a T/L who was waiting outside the terminal premise was crushed to death by another T/L when he was sleeping beneath the T/L.

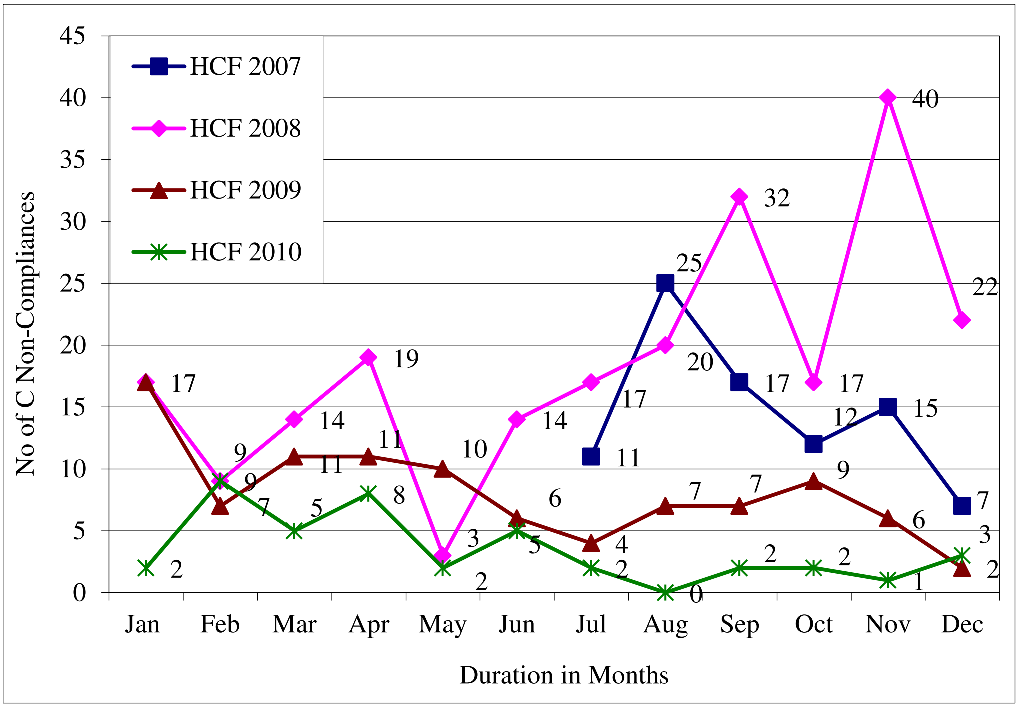

Figure 4.4: Annual Trend of C for 3.5 Years Data Collection Period

Cases recorded related to carelessness consist of a variety of causes such as:

1. Failure of an employee to use appropriate personal protective equipment (PPEs) during the work.
2. Use of cell phones during fuel transfer from a T/L to an underground storage tank.
3. Improper supervision and standing/sitting on T/L during movement.
4. Cleaners and drivers found sleeping under the T/L shade.
5. Workers walking on fuel supply pipe lines.
6. Inadequate medicine in the first aid box.
7. Fire extinguishers were found to be expired during inspection and the decanting hose pipes were found lying around improperly. The water level in the fire water tank was found not up to the optimum level.
8. Due to carelessness, a spillage of fuel case was reported at the tank wagon gantry; 60 litres of petrol spilled. In another case, a T/L hit the angle iron of decantation bay. It caused the rupturing of the tank and flowing out of the product.
9. During a distillation test, the distillation flask was broken and caused the generation of volatile vapours and minor flames.

10. Broken loading arms of T/L filling points due to driver negligence.
11. Collision of T/Ls with the angle iron of the decantation bay. Rupturing of the tank and spillage of fuel from T/Ls were reported.
12. A T/L was driven by a cleaner.
13. A private car, after refueling rushed away while the nozzle of the dispensing unit was still in the vehicle tank.
14. It was observed that a T/L driver started the T/L with earthing clamp still attached.
15. Medical treatment record of workers was not maintained.
16. Improper maintenance of fire-fighting equipment.
17. Electrician found working on electric panel with energized board.

Carelessness cases mainly occurred due to at-risk behaviour and workers unsafe work practices. The at risk behaviour of workers can be significantly reduced with the help of the e-ARBAIS [82] model. Improvements can also be observed with worker training programs and the application of mitigation strategies. The following of safe work practices, standard operating procedures and work instructions by workers would be helpful to significantly reduce the occurrences of HSE non-compliances pertaining to carelessness.

4.2.5. Fire Risk (FR)

Occurrences of fire cases during the operation and maintenance of the PFS's creates explosions and heavy losses to the PFS operating company. PFS's normally contain large amounts of hazardous and flammable material for sell. The arrival and departure of T/Ls to fill the underground storage tanks are quite common activities throughout the PFS operational hours. The chances of a fire become increased when underground storage tank filling is in process. Fire cases were reported in which T/Ls caught fire due to carelessness, theft and terrorists attacks at PFS's. The fire cases reported during the 3.5 year data collection period were 79. Fire cases got the 7th ranking among HCFs. Although it contributed only 2.45% during the whole 3.5 year period, the severity is the maximum among the 8 HCFs. The majority of fire cases that were recorded during the data collection period affected the sells operation, damaged infrastructure, affected the company's reputation and caused heavy monitory losses to the company. Figure 4.5 shows the graphical representation of the fire hazard during the 3.5 year data collection period. Normally, the quantity of the product at the underground storage tanks (UGST) ranges between 60,000 litres to 80,000 litres. PFS's are located within an urban environment, along the road, in congested areas and in residential areas. Most of the PFS's were found very close to one another on adjacent road sides. The distance between them was even less than 1 km. Therefore the occurrence of fire at PFS has the tendency to generate more losses as the other PFS is located nearby so the fuel capacities of both PFS combine together and may create any catastrophic event.

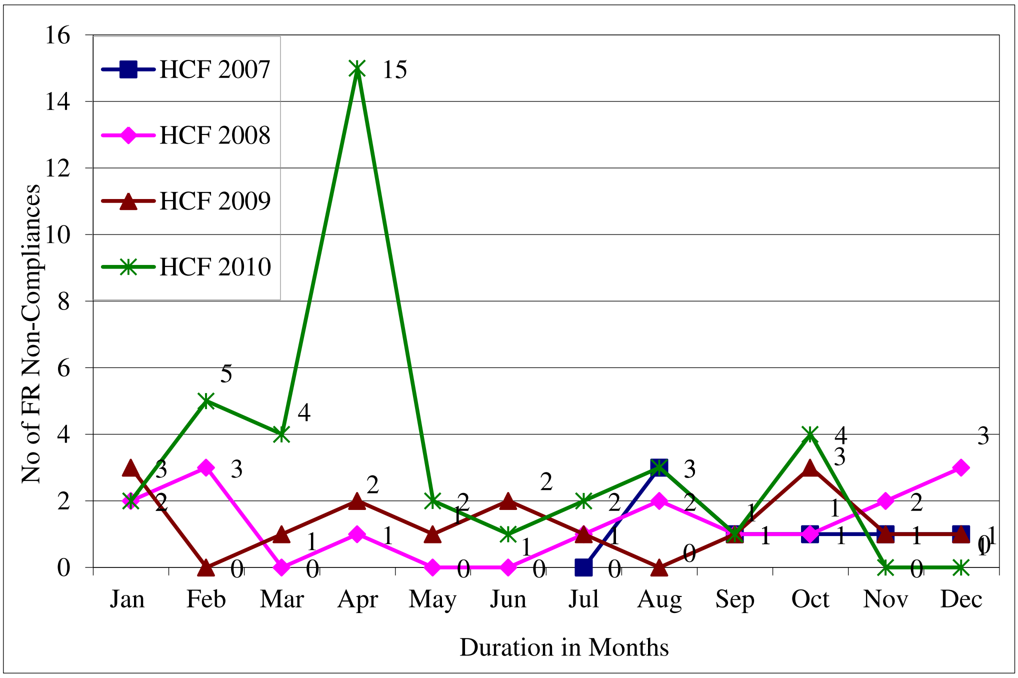

Figure 4.5: Annual Trend of FR for 3.5 Years Data Collection Period

It can be observed from Figure 4.5 that total of 7 cases were reported due to the occurrences of fires during 6 months of the year 2007. Among them 3 fire cases were reported in the month of August. No fire case was reported in the month of July. In September, October, November and December 1 case was reported in each month. In the year 2008, 17 fire induced cases were reported. It contributed only 1.4% of all the HCFs throughout the year 2008 but contained the highest severity level. In January, February and December, every month 3 fire eruption cases were reported. No fire incident was reported in March, May or June.

During the year 2009, 16 cases were reported pertaining to fire. In both the months of January and October, 3 cases were reported, each. 3 cases were also reported in both months of April and June, each. No fire case was reported in the month of February or August. Whereas, 1 fire case was recorded in the months of March, May, July, September, November and December, respectively. It can be observed in Figure 4.5 that a maximum of 15 cases were reported during the 3.5 year data collection phase in the month of April 2010. A total 39 cases were recorded in the year 2010. Fatalities occurring due to the fire cases were 7 during the year 2010. Weak security measures and disturbed law & order situations were identified as the potential causes of fatality cases and fire eruptions. In the month of April 2010, armed persons did continuous firing on T/Ls. 11 T/Ls were caught on fire and fully burnt. In the same month during a robbery incident at a PFS, 4 police officers died, 4 T/Ls were completely burnt and heavy losses occurred to the retail outlet.

Fire incident cases created major and minor losses to the company. During the operation and maintenance of the PFS's, the causes of fire eruption cases occurrences at the PFS's were due to;

1. A fire broke out in the change-over switch and distribution board due to rain storms causing short circuiting was reporting.
2. Generation of fire cases were also reported during aircraft fuelling at the terminal. The fires were extinguished with sand.
3. PFS's sell compressed natural gas (CNG). A CNG blast took place at a retail outlet. As a result, the walls of the distribution room, doors, electrical fixtures, slogan wall skin, and the canopy false ceiling was completely damaged. Two employees got severe injuries. Gas leakage from the CNG supply system was identified as the root cause.
4. A fire broke out in a T/L, while it was parked at a filling gantry. The root cause of fire eruption was identified as creation of minor spark during filling operation.
5. During normal operation, smoke was observed from the generator in the power house and the lighting tower. Fire was generated due to the entrance of water inside the lighting tower. Minor fire eruptions and sparks in production cases were reported due to twisted electrical cables, bracket fan couplings,

short circuiting and circuit breakers. They were found to be of poor quality and not consistent with the relevant system.

6. Use of unsafe electrical heaters was also reported to be the cause of electrical fires.
7. Within one facility, a dispensing unit, main circuit board and water cooler caught fire.
8. Fire cases were also reported during the filling of T/Ls. While filling the 4^{th} chamber of a T/L at a filling point, when the driver inserted the loading arm into the chamber, after filing 79 litres of the product, a fire broke out inside the chamber.
9. Bad housekeeping practices inside and around the PFS also generated fires. Wild grass and shrubs caught fire close to the PFS boundary wall. The fire was extinguished by staff immediately with the help of sand buckets, fire extinguishers and other fire-fighting equipment. Cotton waste in the gantry parking area caught fire.
10. An oil soaked cloth of a worker caught fire from an electrical heater. Burn marks were reported on the worker's body.
11. During the decantation of 20,000 litres in a T/L, a flame was seen. Initially the fire was extinguished but the driver tried to take the T/L out without detaching the hose pipe and the fire again broke out and got out of control.
12. A fire erupted in a monolith tower. The monolith circuit breaker tripped off and smoke was generated.

Some causes of fire occurrences could be controlled but some were difficult, as they occurred due to external factors. Inside facilities, fire generation events can be minimized with competent personal and appropriate fire-fighting equipments.

Fire events recorded due to external factors were due to:

1. A passenger train passed through a railway siding at Track No.1. A flame appeared from the engine, bushes near the passenger track caught on fire.
2. A T/L was hijacked on a super highway. It was taken to an unknown place in an attempt to steal the product. While stealing the product T/L caught fire.
3. Natural conditions have also caused fire generation events during the operation and maintenance (O & M) of PFS's. Due to thunder storms and,

lighting volatile fumes caught fire but the fire was extinguished by the rainfall.

4. A car engine, rickshaw and a motor cycle caught fire during refuelling.
5. Two events were reported due to rocket fire. A rocket was fired by terrorists at a PFS. Underground storage tanks (UGSTs) are normally located closer to the boundary wall; the rocket was fired through the boundary wall into the UGST. It caused a 6 inch diameter hole in the boundary wall. Fuel leaked and contaminated the ground. An UGST caught fire but the fire was extinguished by the staff immediately.
6. Fuel storage tanks are also located above the ground level. In another event, a rocket launcher was fired into an above ground fuel storage tank. A hole appeared in the tank but only a minor fire erupted as the tank was empty.
7. A fire erupted in a timber market adjacent to a PFS. Due to the excessive heat the following damages were reported:
   - 8 blue bars burnt
   - Distribution units melted
   - Product plates of monolith tower burnt
   - Spreaders, waste bins, bucket and green segments burnt
8. A T/L caught fire during fuel transportation. A cleaner and the driver were severely burnt.
9. T/Ls caught fire due to the nonstop firing by armed persons. 11 cases were reported during the year 2010.
10. A fire occurred due to the burning of tyres at the roof of a repair and maintenance shop at a PFS.

An accident was reported on 23rd April 2010 in which a T/L was exploded at a welding shop. As a result of the explosion, five pedestrian fatalities and four major injuries were reported. The incident took place at a gas welding shop. During the welding of a T/L cover, when the welder ignited a torch, due to the fuel availability in the T/L, it caught fire and the T/L exploded. Security measures within and outside PFS facilities were identified as one of the potential causes of fire occurrences. During fuel transportation, the T/Ls were completely burnt and within the facility, apart from T/L burning cases, other PFS elements such as dispenser units and canopy were also burnt. The occurrence of the PFS and T/L burning cases were more hazardous at those PFS's that were located closer to the residential areas, especially to those PFS's that operate closer to schools, hospitals and shopping centres. In case of fire events, there is a potential tendency of huge losses to the people's lives and surrounding infrastructure. Unstable law and order situation, poor housekeeping practices, bad conditions of electrical appliances and carelessness were identified as the root causes of fire eruption cases. Regular monthly fire fighting drills in collaboration with local and government fire fighting authorities are recommended to reduce the occurrences of fire eruption cases at PFSs. The government and local fire fighting authorities should be provide various route maps to reach the PFS within a shortest time period to respond to any emergency case. If the PFS are located closer to each other in congested areas the fire hydrant shall be provided by the fire fighting authorities along the road. So, that in case of any unwanted event the hose pipes can be connected directly to these hydrants immediately for fire fighting.

4.2.6. Electrical Fault (EF)

Electrical Faults cases during operation and maintenance of PFSs were reported due to defects in the electrical components, accessories and appliances. Electrical faults cases were reported to be major and minor in nature. Fluctuations in the electrical fault cases during the 3.5 year data collection period can be observed in Figure 4.6. In the year 2007, during the six month data collection period from July to December, 34 cases were reported due to electrical faults. The total number of electrical fault cases decreased in the year 2008, 2009 and 2010 with 97, 69 and 18 cases reported, respectively.

In the year 2007, the number of cases reported due to electrical faults was 7, 8 and 4 during the months of July, August and September, respectively. However, from October to December 5 cases were identified monthly.

Considerable fluctuations in electrical fault cases can be observed in Figure 4.6 for the year 2008. A total of 97 cases reported were related to electrical faults in the year 2008. It contributed to 8% in the HCFs for the year. It can be observed that the number of electrical fault cases fluctuated throughout the year and reached to 9 cases.

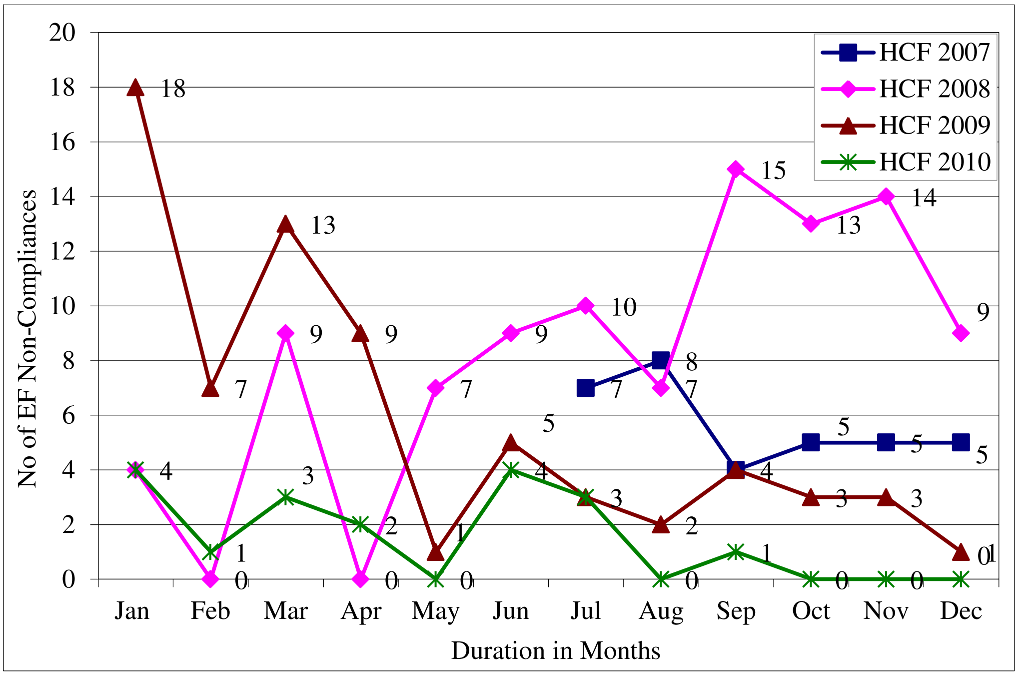

Figure 4.6: Annual Trend of EF for 3.5 Years Data Collection Period

However, there was a sudden increment in electrical fault cases in Jan. 2009 to 18 cases. However, with some minor fluctuations in some months, the trend of electrical faults seemed to reduce till the end of the year. The drop in the electrical fault cases continued to be recorded in the year 2010. During the year 2010, 18 cases were reported. One fatality case was reported due to electric shock during cleaning of a signboard.

The root causes of electrical fault cases were identified as follows:

1. Damage was found in internal parts of the main master switch of the battery and stabilizer jacks.
2. Short circuits, poor electrical appliance conditions and voltage fluctuations in the 800 watt turbine used for filling the main water tank, sockets, power plug of biometric machine, transformer coil, magnetic contactor of the HSD motor and a case where the winding of the water pump motor was burnt.
3. Overheating of the single pole 220 Volt supply breaker caused the light pole to be burnt. Bad wiring conditions generated sparks in the motor.
4. Unsafe electrical wiring was identified as the cause of damage to electrical components.

5. Defects in the electrical components of the uninterruptible power supply (UPS) system of the closed circuit television (CCTV) went out of order, and while refuelling the refueller, the polyurethane tube burst.
6. An improper earthing current was found in the pole.
7. The spark arrestor of the T/L was found to be missing.
8. The power supply of the dispenser unit, air conditioner wiring, electrical sockets, distribution fuses and electrical heaters were reported burnt.
9. Electrical short circuiting cases were reported due to the heating up of power plugs and switch gears. Electrical fixtures such as tube lights and bulbs were burnt in the canopy and laboratory due to the usage of incompatible wiring and fixtures.

Electrical effects posed a higher tendency to generate fire. The availability of volatile organic compounds in the PFS environment can cause a fire to erupt on a large scale and create a catastrophic loss to humans, property and the environment. The root causes of cases were identified as the poor condition of electrical appliances and electrical wiring. Electrical appliances include electrical heaters, air conditioners, distribution control panel boards, disconnect switches, circuit breakers, and motor control centres. The condition of the electrical equipment can be improved and can significantly reduce electrical fault cases with the appropriate planning and scheduling. Some cases were reported due to natural conditions such as blinking of lights at PFS's and the causation of fire in blue bars and company electrical signages. These cases are beyond the control of human beings but they can be minimized by using good quality electrical appliances. Another cause of electrical sparks is the use of an incompatible electrical lighting system within the facility. A normal lighting system is not suitable as volatile organic compounds may generate ignitable fumes. During the PFS inspection, it was recorded that at many PFS's, the normal electrical systems were found not to be in good condition. Scheduled inspections and close monitoring of the electrical equipment may be worthwhile to reduce electrical fault cases during the operation and maintenance of the PFS's. The severity of the electrical fault cases could be minor or major. Minor cases are mostly from minor sparks of electrical faults and fire. On a major scale, it has the potency to cause fatal electrical shocks.

4.2.7. Miscellaneous Cases (MC)

Oil spillages, water leakages, snakebite cases, minor/major damages, maintenance issues, robbery, theft, natural disasters/wind storms and law & order situations were grouped under miscellaneous cases (MC). A graphical representation of the 3.5 year data collection period of MC on an annual basis is represented in Figure 4.7.

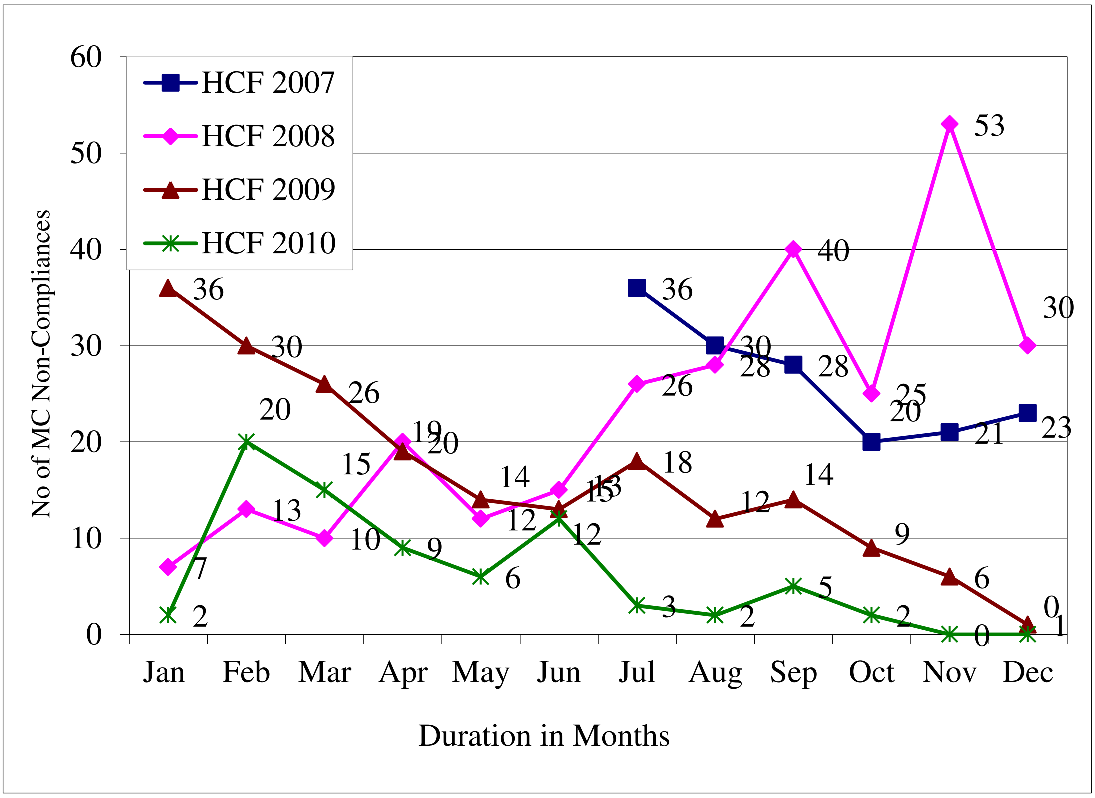

Figure 4.7: Annual Trends of MC for 3.5 Years Data Collection Period

Noticeable increments and decrements in MC can be observed in Figure 4.7 during each year. Throughout the data collection period, 716 cases pertaining to MC were reported. They contributed to 22.3 % of the HCFs for the data collection period. Overall, MC was found to be the 2nd most occurring cases in the HCFs. During six month duration of the year 2007, 158 non-compliances were reported. Whereas, for the year 2008, 2009 and 2010, the number of non-compliances reported were 279, 198 and 81, respectively.

For the six month duration of the year 2007, the MC flow pattern was not constant. On average, 26 cases related to MC were recorded each month. The maximum and minimum number of cases reported was 36 and 20, in the months of July and October, respectively.

A sudden reduction in non-compliances can be observed from December 2007 to January 2008. In Figure 4.7, it can be noticed that the overall hazard contributing pattern progressed continuously. It increased from the beginning of the year till November 2008. The maximum number of non-compliances reported was 53 in the month of November. However, in the month of December, it fell abruptly to 30 cases. It can be observed in Figure 4.7 that in the year 2008 highest non-compliances were recorded in comparison to the years 2009 and 2010.

For the year 2009 a gradual reduction in MC was observed in Figure 4.7. From January to December, the non-compliances decreased linearly at a constant rate. The maximum of 36 and the minimum of 1 non-compliance MC was reported during the year.

Slight fluctuations were observed in Figure 4.7 in non-compliances patterns for the year 2010. No non-compliance was recorded in the month of November or December. On average, 7 cases were recorded monthly. The lowest number of non-compliances was reported in the year 2010 in comparison to the years 2008 and 2009. It might have been due to the successful implementation of control measures to reduce occurrences of unsafe acts and unsafe conditions during the operation and maintenance of the PFS's.

The non-compliances under MC were recorded due to:

1. Worn out of refuellers and buffer couplings at high speed diesel (HSD) filling points and oil leakage cases were reported. Leakages were also reported due to pin holes in the mechanical seals of pumps, loose couplings and packaging deterioration of gate valves.
2. The loading arm used to fill oil in T/Ls found to leak.
3. The gasket packing of the T/L valves recorded to be completely worn out which caused the spillage of the product during the filling of the T/L compartment.
4. Leakages in the delivery valve which caused 15 litres of spillage of the product.
5. The poppet seal of the hose coupling found to have leaked during aircraft refuelling.

6. Crack development at the bottom of the foam mobile unit; l0 leakage cases were recorded.
7. The use of incompatible couplings were recorded during filling of UGST.
8. The air release valve of T/Ls found to leak.
9. Thunder storms/cyclones causing falling of signboards, trees, dispenser units and the breaking of window glass.
10. The joints of stairs and swing ladders found to be damaged.
11. Tyre hub studs found in deteriorated conditions.
12. Walkway steps, roof sheets of T/Ls, boundary wall barbed wires and splash trays found in deteriorated conditions.
13. Decantation hose found damaged and emergency fuel shut off system of the refuelling not working appropriately.
14. HSD splashes by a worker during connecting the tank wagon hose pipe with the product transferring pipe.
15. Intruders entered into the facility and taking away valuable items from the PFS.
16. A bomb blast incident was reported on 25th October 2010 in front of a PFS. It caused damage to spreaders, IN/Out signs, company name plate, company signboard tower and C-store signage.
17. Snatching case reported in which three snatchers entered into the retail outlet and took cash and the mobile phones of the retail outlet staff.
18. A rally passing by in front of the retail outlet; some angry people entered into the fuel station and damaged a display board of the distribution unit, spreaders and lube signs.
19. A filling operator being just saved from a bullet, which was fired by a nearby person outside the facility. The bullet just passed close to the filling operator; fortunately the operator was saved.
20. A bomb blast occurred at the Marriott Hotel Islamabad; glasses of shop & office blocks were broken at the two retail outlets.
21. A tank was over flown and 86 liters of oil was spilled.
22. Leakages observed from the pneumatic valves, aircraft couplings and pipes. A trestle wheel was also reported broken during refuelling of an aircraft.

23. On site leakages reported due to improper maintenance and equipment handling at the loading arm of the gantry from skin valves, deadman pipe of the refueller and the pump shaft coupling valve.
24. Cases of trees falling on vehicles and transformers being reported.
25. The falling of trees due to hurricanes and heavy storms on barbed wires at boundary walls and inside the facilities' walkways also reported.

Occurrences of robberies cases were also reported at PFS's. Major and minor injuries to staff were reported during these events. Major injuries/burns were also reported due to compressed natural gas (CNG) explosions in office blocks. Product leakages from T/Ls during fuel transportation were also reported. The occurrences of miscellaneous cases could be controlled with appropriate scheduled inspections and close monitoring.

4.2.8. Medical Treatment Cases (MTC)

The occurrences of major and minor injuries during the operation and maintenance of petrol filling station generate lost time injury events or absence of workers from the workplace. Ultimately, it affected the safety statistics of the operating company. Medical treatment cases include injury cases on face, eyes, head, neck, arms, hands, legs, feet, trunk, back and in internal body parts. Most of the major and minor injury cases were recorded during normal routine fuel station operational hours. Apart from these, a strong correlation of medical treatment cases noticed with transportation hazards, slips, trips and fall, carelessness and housekeeping practices.

The fluctuations in MTC can be observed in Figure 4.8. Hazard contributing factors recorded during the 3.5 year data collection period pertaining to MTC contributed to approximately 7.9%. In the six month duration period of the year 2007, 69 MTC were recorded. For the years 2008, 2009 and 2010, the number of MTC due to unsafe acts and unsafe conditions was 61, 87 and 39, respectively. The maximum number of MTC was recorded in the year 2009 but the year 2007 could be considered as the highest MTC period, as in this year, 69 major and minor injuries were reported.

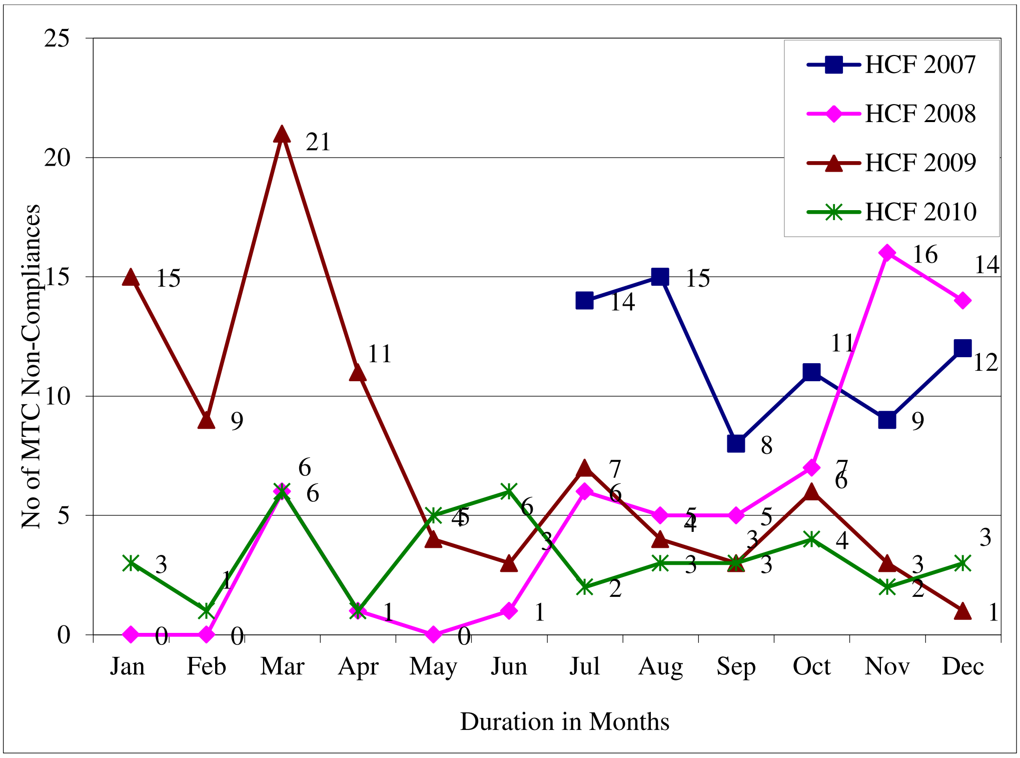

Figure 4.8: Annual Trends of MTC for 3.5 Years Data Collection Period

The highest and lowest number of MTC recorded in the months of August and September was 15 and 8 cases, respectively.

Medical treatment cases reported during the year 2008 were mainly due to slips, trips and falls, carelessness and transportation hazards. A total of 61 MTC were recorded in the year 2008. A maximum of 16 cases were reported in the month of November. During January, February and May, no MTC were recorded.

It can be observed in Figure 4.8 that the number of occurrences of MTC in the year 2009 was significantly high. Noticeable fluctuations can be observed in the first four months of the year. A maximum number of 21 cases due to MTC was observed in the month of March. The MTC cases from May to September were found to be slightly unstable. A slight increase in cases was recorded in the month of October and then it reduced gradually to 1 case in the month of January.

The number of MTC reported in the year 2010 was not significantly high as compared to the years 2007, 2008 and 2009. Only 39 cases were reported during the whole year. In the month of March, 6 and in the month of February, 1 case was recorded.

The MTC recorded were due to:

1. Breathing problems reported due to prolonged working hours at PFS's under VOCs. Stomach pain was reported due to food poisoning by the workers.
2. Cases pertaining to raise of workers blood pressure levels, unconsciousness, nausea; low blood pressure, lung problems and severe head pain were also reported.
3. Workers' trips and slips, where they sustained major and minor injuries on their legs, hands and arms.
4. Minor MTC which included insect attacks on workers during shift hours were reported. Although workers with severe bites were taken to the nearby hospital. Allergies and swelling observed on affected body parts. The affected body parts were face, legs and hands.
5. HSD and paint drops splashed into workers eyes. Severe pain and irritation were reported. Eyes were washed and eye ointment was applied. Carelessness was found to be the root cause.
6. Various office places in the PFS's found to be ergonomically unfit. Workers also complained of back pain due to ergonomically unfit workplace.
7. Workers slipped due to unsatisfactory housekeeping conditions at T/Ls stairs and in the wash room. Workers sustained major and minor injuries.
8. Workers' dizziness and unconsciousness cases reported due to volatile organic carbons.
9. While robbery incident at PFS, injuries on the cashier's leg and other body parts were reported.

Minor injuries were handled with first aid treatment that was available at the site while for the major injuries, the patients were taken to the nearby hospital. One fatality was reported on 11th November 2008. Heart attack was identified as the root cause of the patient's death. In another event, a driver became unconscious due to severe pain in his chest; he was taken to the hospital. The cause of chest pain was confirmed as heart attack by the doctors. MTC also occurred either due to unsafe acts or due to unsafe conditions at the workplace.

4.3. Statistical Analysis of Hazard Contributing Factors

A test of correlation was performed on the data collected during the study period. The test was performed to determine the dependency of the HCFs on each other. The statistical analyses of the monthly HCFs were performed using a statistical package of social sciences (SPSS) version 18.0. However, for the year 2007, the test of correlation was performed using only six months of data (July to December). All correlation analyses results were presented as a correlation matrix for the data collection period. Pearson's correlation was performed among the 8 HCFs. The correlation matrix contained 8 rows and 8 columns. The1st row and 1st column represented the HCFs. Each cell showed the correlation among the variables in the rows and the respective columns and contained 3 values: the correlation coefficient, level of significance and N, number of months. The results of the correlation tests for the 3.5 year study period, i.e., for the year 2007, 2008, 2009 and 2010 are presented in the following sections.

4.3.1. Correlation within the HCFs for the year 2007

A test of correlation within the HCFs for the year 2007 was conducted and presented in the correlation matrix in Table 4.1. It can be observed that there is a strong correlation existing among HK, STF and C.

Table 4.1: Correlation Matrix for the Year 2007

		HK	TH	STF	C	FR	EF	MC	MTC
HK	Pearson Correlation	1							
	Sig. (2-tailed)	.							
	N	6							
TH	Pearson Correlation	.488	1						
	Sig. (2-tailed)	.326	.						
	N	6	6						
STF	Pearson Correlation	**.865(*)**	.698	1					
	Sig. (2-tailed)	**.026**	.123	.					
	N	**6**	6	6					
C	Pearson Correlation	**.811**	.055	.498	1				
	Sig. (2-tailed)	**.050**	.918	.314	.				
	N	**6**	6	6	6				
FR	Pearson Correlation	.717	.473	.536	**.805**	1			
	Sig. (2-tailed)	.109	.344	.273	**.053**	.			
	N	6	6	6	**6**	6			
EF	Pearson Correlation	.666	.309	**.797**	.472	.450			
	Sig. (2-tailed)	.148	.552	**.058**	.344	.370			
	N	6	6	**6**	6	6			
MC	Pearson Correlation	.590	.184	.728	.247	**-.077**	.619	1	
	Sig. (2-tailed)	.217	.727	.101	.637	**.885**	.190	.	
	N	6	6	6	6	**6**	6	6	
MTC	Pearson Correlation	.485	.509	**.788**	.183	.334	**.922(**)**	.546	1
	Sig. (2-tailed)	.329	.302	**.063**	.729	.517	**.009**	.262	.
	N	6	6	**6**	6	6	**6**	6	6

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

The correlation of HK with STF and C was found to be 0.865 and 0.811, with a significance value of 0.026 and 0.050, respectively. This indicates that STF and C non compliances were mainly contributed by HK. TH was found not to be correlated to any of the other 7 variables (level of significance >0.05). FR has a correlation value of 0.805 with a significance level of 0.053 with C. It was found that EF correlates to MTC and STF, with a correlation co-efficient of 0.797 and 0.922, with a significance value of 0.058 and 0.009, respectively.

4.3.2. Correlation within the HCFs for the year 2008

A test of correlation was performed for the year 2008. A total number of 1,203 HCFs were analyzed. The results of the correlation are represented in Table 4.2.

Table 4.2: Correlation Matrix for the Year 2008

		HK	TH	STF	C	FR	EF	MC	MTC
HK	Pearson Correlation	1							
	Sig. (2-tailed)	.							
	N	12							
TH	Pearson Correlation	.761(**)	1						
	Sig. (2-tailed)	.004	.						
	N	12	12						
STF	Pearson Correlation	.176	.441	1					
	Sig. (2-tailed)	.584	.151	.					
	N	12	12	12					
C	Pearson Correlation	.629(*)	.626(*)	.554	1				
	Sig. (2-tailed)	.028	.030	.062	.				
	N	12	12	12	12				
FR	Pearson Correlation	.221	.152	.064	.25	1			
	Sig. (2-tailed)	.490	.638	.843	.42	.			
	N	12	12	12	12	12			
EF	Pearson Correlation	.320	.533	.682(*)	.57	-.29	1		
	Sig. (2-tailed)	.311	.074	.014	.05	.35	.		
	N	12	12	12	12	12	12		
MC	Pearson Correlation	**.746(**)**	**.700(*)**	**.560**	**.9(**)**	.16	**.656(*)**	1	
	Sig. (2-tailed)	**.005**	**.011**	**.058**	**.00**	.61	**.021**	.	
	N	12	12	12	12	12	12	12	
MTC	Pearson Correlation	**.652(*)**	**.726(**)**	**.629(*)**	**.7(**)**	.24	**.629(*)**	**.777(**)**	1
	Sig. (2-tailed)	**.022**	**.008**	**.029**	**.00**	.44	**.029**	**.003**	.
	N	12	12	12	12	12	12	12	12

*Correlation is significant at the 0.05 level (2-tailed).
**Correlation is significant at the 0.01 level (2-tailed).

It can be observed in Table 4.2 that HK has strong correlation with TH, C, MC, and MTC. The correlation level of HK with these 4 HCFs was considerably high. The correlation of HK with TH, C, MC and MTC was found to be 0.761, 0.629, 0.761 and 0.652, respectively. It indicates that a significant number of HCFs recorded during the year 2008 occurred due to TH, C, MC and MTC. It can be viewed that C was significantly correlated with HK, TH, EF, MC and MTC. Perfect significance was found between C and MC. The cases recorded pertaining to FR during 2008 was found to be less in correlation and significance level with the remaining 7 variables. The variables STF, C, MC and MTC were recorded in high correlation and significance level with EF. It can also be observed in Table 4.2 that MC and MTC have low values of correlation co-efficient and significance levels with FR; although, MC and MTC have high co-efficient of correlation and significance levels with the remaining 7 variables.

4.3.3. Correlation within the HCFs for the year 2009

A test of correlation was performed among 902 HCFs recorded during the year 2009. The results of the correlation matrix are presented in Table 4.3.

Table 4.3: Correlation Matrix for the Year 2009

		HK	TH	STF	C	FR	EF	MC	MTC
HK	Pearson Correlation	1							
	Sig. (2-tailed)	.							
	N	12							
TH	Pearson Correlation	.471	1						
	Sig. (2-tailed)	.122	.						
	N	12	12						
STF	Pearson Correlation	.164	.835(**)	1					
	Sig. (2-tailed)	.611	.001	.					
	N	12	12	12					
C	Pearson Correlation	.782(**)	.827(**)	.557	1				
	Sig. (2-tailed)	.003	.001	.060	.				
	N	12	12	12	12				
FR	Pearson Correlation	.727(**)	.237	-.060	.537	1			
	Sig. (2-tailed)	.007	.457	.853	.072	.			
	N	12	12	12	12	12			
EF	Pearson Correlation	.490	.834(**)	.788(**)	.805(**)	.424	1		
	Sig. (2-tailed)	.106	.001	.002	.002	.169	.		
	N	12	12	12	12	12	12		
Misc	Pearson Correlation	.378	.946(**)	.827(**)	.713(**)	.128	.843(**)	1	
	Sig. (2-tailed)	.225	.000	.001	.009	.691	.001	.	
	N	12	12	12	12	12	12	12	
MTC	Pearson Correlation	.328	.843(**)	.868(**)	.696(*)	.219	.864(**)	.787(**)	1
	Sig. (2-tailed)	.298	.001	.000	.012	.494	.000	.002	.
	N	12	12	12	12	12	12	12	12

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05 level (2-tailed)

It can be observed that during the year 2009, HK was found in significant correlation with C and FR. HK was recorded in correlation with C and FR with values of 0.782 and 0.727, respectively. TH was found in correlation with STF cases, C cases, EF cases, MC and MTC with values of 0.835, 0.827, 0.834, 0.946, and 0.843, respectively. TH was found in perfect correlation with MC. It can also be seen in Table 4.3 that STF was highly correlated with a good significance level with TH, EF, MC and MTC. Perfect correlation can be observed between EF and MTC.

4.3.4. Correlation within the HCFs for the year 2010

A test of correlation for the year 2010 was performed on 437 HCFs. The correlation matrix for the year 2010 is represented in Table 4.4.

Table 4.4: Correlation Matrix for the Year 2010

		HK	TH	STF	C	FR	EF	MC	MTC
HK	Pearson Correlation	1							
	Sig. (2-tailed)								
	N	12							
TH	Pearson Correlation	-.075	1						
	Sig. (2-tailed)	.817							
	N	12	12						
STF	Pearson Correlation	.186	.154	1					
	Sig. (2-tailed)	.562	.632						
	N	12	12	12					
C	Pearson Correlation	.166	.090	.755**	1				
	Sig. (2-tailed)	.606	.782	.005					
	N	12	12	12	12				
FR	Pearson Correlation	.095	.191	.238	.596*	1			
	Sig. (2-tailed)	.770	.553	.456	.041				
	N	12	12	12	12	12			
EF	Pearson Correlation	-.178	.665*	.400	.335	.104	1		
	Sig. (2-tailed)	.580	.018	.197	.288	.747			
	N	12	12	12	12	12	12		
MC	Pearson Correlation	.242	.099	.846**	.850**	.318	.293	1	
	Sig. (2-tailed)	.448	.759	.001	.000	.314	.355		
	N	12	12	12	12	12	12	12	
MTC	Pearson Correlation	.192	.028	-.068	-.231	-.379	.245	.095	1
	Sig. (2-tailed)	.550	.932	.834	.470	.224	.442	.769	
	N	12	12	12	12	12	12	12	12

*. Correlation is significant at the 0.05 level (2-tailed).

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

A perfect correlation between MC and C can be observed in Table 4.4 with co-efficient of correlation of 0.850. It showed that during the year 2010, mainly MTC occurred due to C. The lower value of the correlation co-efficient indicated that during the year 2010, the HCFs were found less inter-related with each other in comparison to the years 2007, 2008 and 2009. It was due to the improvement in workers unsafe behaviour and management supervision.

A summary of the correlation tests for the 3.5 year study, i.e., for the years 2007, 2008, 2009 and 2010 are presented in Table 4.5.

Table 4.5: Summary Table for Test of Correlation for the Study Period

	2007	2008	2009	2010
HK	STF, C	TH, C, MC, MTC	C, FR	
TH		HK, C, MC, MTC	STF, C, EF, MC, MTC	EF
STF	HK	EF, MC, MTC	TH, EF, MC, MTC	C, MC
C	HK	HK, TH, EF, MC. MTC	HK, TH, EF, MC, MTC	TH, FR, MC
FR	C, MC		HK	C
EF	STF, MTC	TH, STF, C, MC, MTC	TH, STF, C, MC, MTC	TH
MC	FR	HK, TH, STF, C, EF, MTC	TH, STF, C, EF, MTC	STF, C
MTC	STF, EF	HK, TH, STF, C, EF, MC	TH, STF, C, EF, MC	

Table 4.1, Table 4.2, Table 4.3 and Table 4.4 can be summarized with the help of Table 4.5. It can be seen in Table 4.5 that during the six month duration of the year 2007, HCFs were found to be less dependent upon each other. In the years 2008 and 2009, the dependency among the HCFs increased due to a significant number of HSE non-compliance occurrences. In the year 2010, again the dependency among the HCFs was reduced due to improvements in working conditions and good management supervision. In the year 2010, a significant number of HCFs were reported particularly to that HCF category. Improvement in that area can be achieved with specifically designed safety training programs, worker education and standard operating procedures.

4.4. Distribution of HSE Non-Compliances based upon F, A, I and NM Cases

Occurrences of HSE non-compliances reported during the operation and maintenance of PFS's were categorized into four categories: fatality, accident, incident and near miss cases.

4.4.1. Fatality Causation

The number of fatality cases recorded during the 3.5 year data collection period for the study was plotted in Figure 4.9. In Figure 4.9, it was observed that 9 fatality cases were reported throughout the period. No fatality case was reported during the six month duration period for the year 2007. During the year 2008, 4 fatality cases were reported in the months of February, April, September, and November, respectively. During the year 2009, 1 fatality case was reported in the month of July. In the year 2010, the occurrences of fatality cases were found again to increase with 1 fatality case each in the months of April, July, August and October.

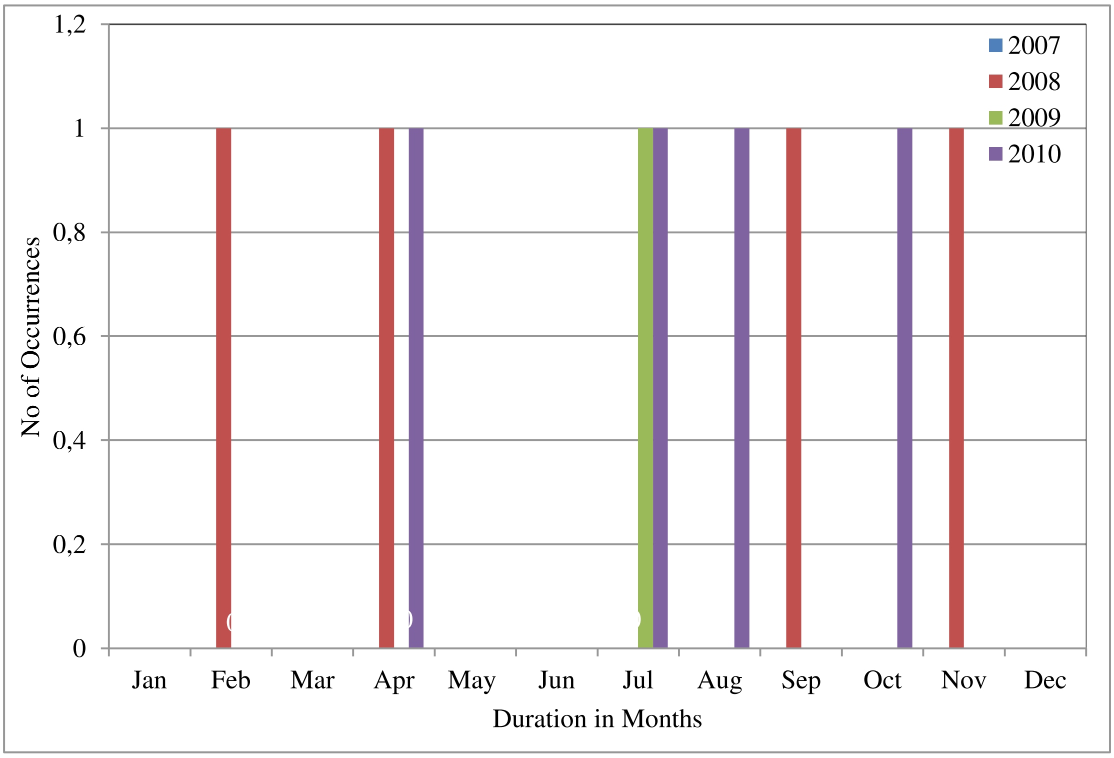

Figure 4.9: Annual Trends of Fatality Cases Occurrences for 3.5 Years Data Collection Period

4.4.2. Accident Causation

An accident was defined as "unexpected happenings that may cause loss or injuries to people who are not at fault for causing the injuries". Significant fluctuations in accident occurrences during the 3.5 year data collection period were plotted in Figure 4.10.

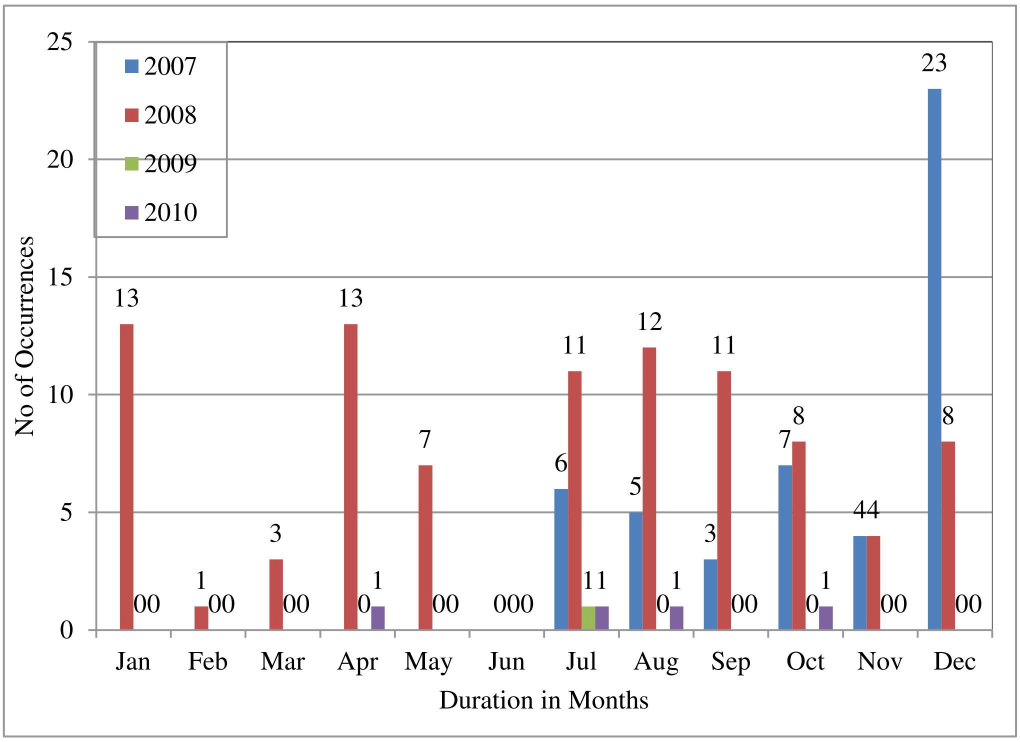

Figure 4.10: Annual Trends of Accident Cases Occurrences for 3.5 Years Data Collection Period

In Figure 4.10, it was observed that a total number of 428 accident cases were recorded during this study period. In the years 2007, 2008, 2009 and 2010, the number of accident cases recorded was at 48, 91, 101, and 188, respectively. Various causes of the accident occurrences were identified.

In the year 2007, 48 accident cases were recorded due to transportation hazards (TH). The highest number of accident cases was reported in the month of July with 23 cases. In the year 2008, 91 accident cases were reported due to TH, FR and MC. The accident cases reported were mainly due to TH. In each month of August and October, 1 accident case was reported due to FR. Also, 1 accident case was reported in the month of April due to MC.

For the year 2009, 101 accident cases were recorded. Accident cases mainly occurred due to TH. During the year 2009, 93 accident cases were recorded due to TH. 1 accident was reported due to FR. The number of accident cases reported due to EF and MTC, was 4 and 3, respectively.

In the year 2010, 188 accident cases were reported. In the month of July, the highest number of accident cases reported was 38. Multiple causes of accident occurrences were noticed in the year 2010. TH remains to be the significant contributory factor for accident causation during the years 2007, 2008 and 2009. Other contributory factors were C, FR, MC and MTC. During the year 2010, 139, 4, 21, 3, 9 and 12 cases were recorded due to TH, C, FR, EF, MC and MTC, respectively.

4.4.3. Incident Causation

An incident can be defined as "An undesired event which, under slightly different circumstances, could have resulted in harm to people or loss of process". The number of incident cases recorded during the 3.5 year data collection period for this study was plotted in Figure 4.11. In Figure 4.11, it can be observed that the incident occurrences pattern was unstable throughout the data collection period. During the 3.5 year study period, 975 incident cases were reported. It contributed to 30.3% of the overall hazardous events recorded. During the six month duration of the year 2007, 239 incident cases were reported. A total number of 352, 238 and 146 incident cases were reported in the years 2008, 2009 and 2010, respectively.

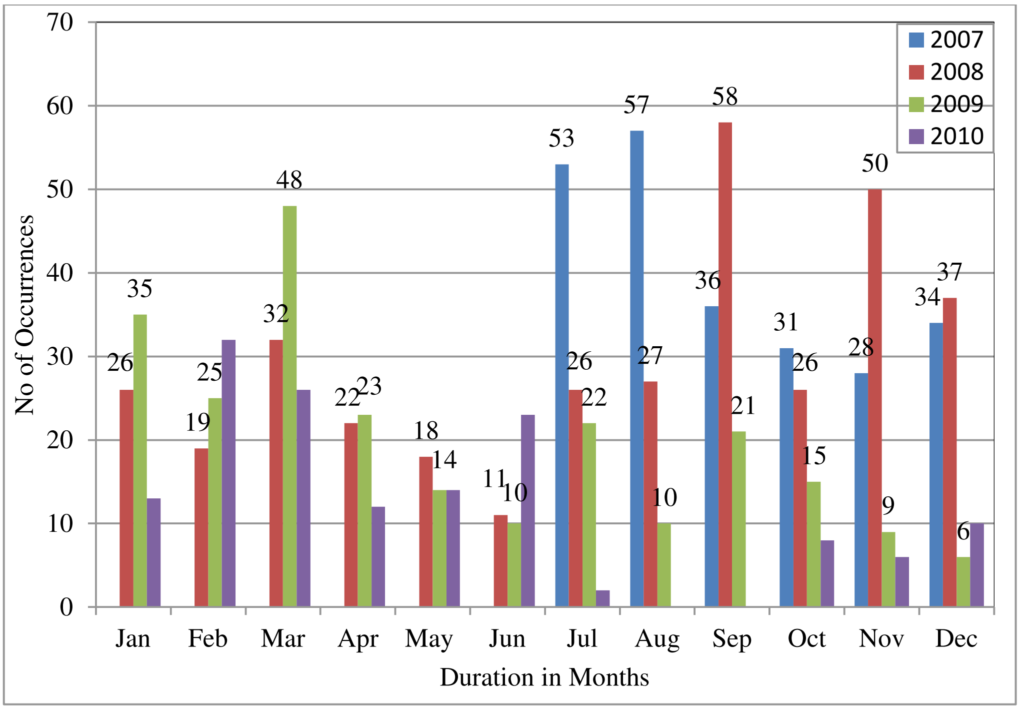

Figure 4.11: Annual Trends of Incident Cases Occurrences for 3.5 Years Data Collection Period

In the year 2007, 239 incident cases were reported. These cases were reported for the six month duration period. The flow pattern of incident occurrences can be observed in Figure 4.11. The highest, 57, and the lowest, 34 number of incident cases were reported in the month of August and December, respectively. Multiple causes of incident occurrences were noticed. Incident cases pertaining to MTC were 65 and were the highest. It shows that the occurrences of major and minor injuries to workers causing the incident cases were of high significance. STF and MC were also found to be high in causing incident cases. A total of 104 incident cases were recorded due to STF and MC. STF and MC each caused 52 cases. The number of incident cases reported pertaining to TH were 40. The number of incident cases reported was 10, 9, 6 and 5 due to EF, C, FR and HK, respectively. Noticeably, 6 incidents pertaining to FR were recorded during the six month duration. It shows a high tendency of any catastrophic incident due to FR at PFS's to possess a high potential. Minor negligence could be the cause of multiple injuries to workers, as well as accidents and fatalities. The FR also has the tendency to cause significant loss to the company assets, residents near the PFS's and to the environment.

A total number of 353 incident cases were reported during the year 2008. The highest was 58 and the lowest was 11 incident cases reported in the months of September and June, respectively. Incident cases occurred in all 8 HCFs with multiple causes. The dominant incident cases were caused due to STF and MC. During 2008, 76 and 73 incident cases occurred due to STF and MC, respectively. Carelessness also contributed significantly to cause incident cases. A total number of 61 incident cases occurred due to C during the year. The importance of TH to cause incident cases remained significant during the year. It was found that incidents pertaining to TH happened within the facility and outside the facility. The number of incident cases recorded due to TH was 56. No incident cases were found to be due to HK practices. FR and EF also contributed to cause incident cases. The number of incident cases related to FR was12 and EF was16 as recorded during the year.

In the year 2009, 238 incident cases were reported. The highest number of 58 cases was recorded in the month of March. Every month on an average basis, 20 cases were reported. The lowest number of 6 cases was recorded in the month of December. Various root causes for incident occurrences were noticed. The incident cases mainly occurred due to MTC, STF, TH, MC, C, FR and EF. No incident case was reported due to HK practices. A significant number of incident cases occurred due to MTC and STF. The number of incident cases reported were 81 and 68 due to MTC and STF, respectively. The number of incident cases reported due to TH, MC, C, FR and EF were 27, 26, 16, 15 and 13, respectively.

In the year 2010, 149 incident cases were reported. It can be observed in Figure 4.11 that no incident case was reported in the month of August and September. The highest of 32 and the lowest of 2 incident cases were recorded in the months of February and July, respectively. All 8 HCFs caused occurrences of incidents except HK. A significant number of incident cases was reported due to MC and STF. The number of incident cases reported due to MC and STF were 41 and 28, respectively. The number of incidents cases reported due to MTC, TH, FR, C and EF were 25, 20, 15, 12 and 7, respectively.

4.4.4. Near Miss Causation

A near miss can be defined as "The hazardous event that possess a tendency to cause fatality, accident or incident cases". Near miss cases were associated with the working environment. A total number of 1,804 near miss cases recorded during the 3.5 year data collection period for this study were plotted in Figure 4.12. The highest number of near miss cases was recorded during the year 2008.

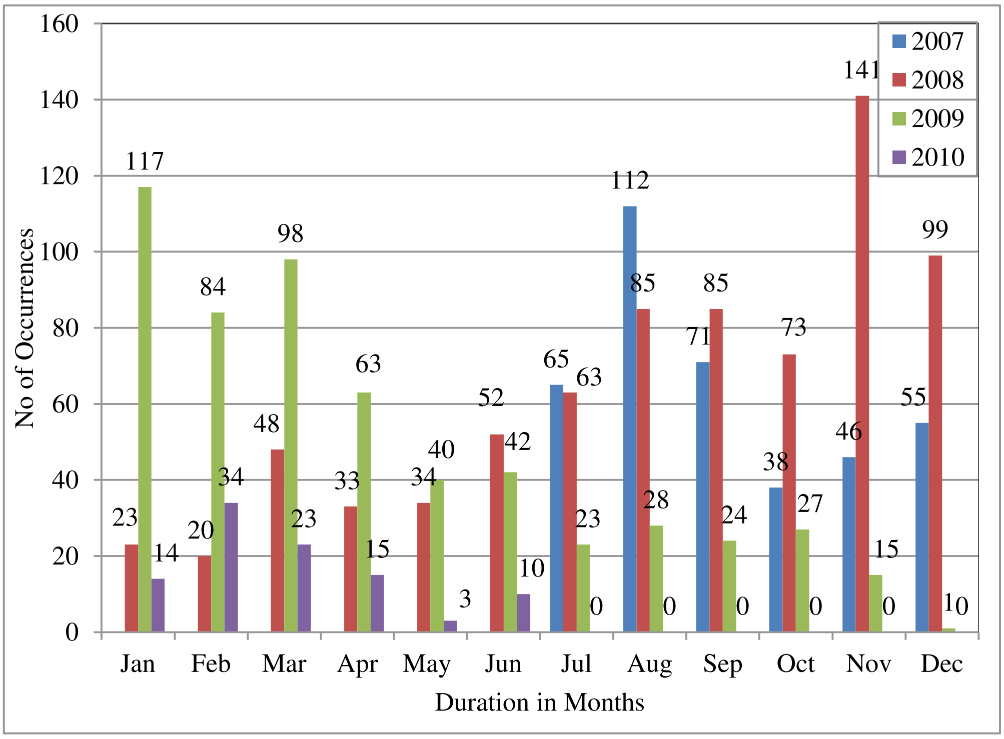

Figure 4.12: Annual Trends of Near Miss Cases Occurrences for 3.5 Years Data Collection Period

In the year 2007, during the 6 month period, 387 near miss cases were recorded. It can be observed in Figure 4.12 that the highest number of 112 near miss cases was reported in the year 2007 during the month of August. The lowest number of 38 cases was reported in the month of October. On average, 65 near miss cases occurred in each month.

A progressing near miss occurrence pattern for the year 2008 can be observed in the Figure 4.12. A total number of 756 near miss cases was recorded during the12 month duration of the year. On average, 63 near miss cases were reported in each month. The highest, 144, and the lowest, 20, cases were recorded in the month of

November and February, respectively. In the months of August, September and December, the number of near miss cases recorded was 85, 85 and 99, respectively.

In the 12 month data collection period for the year 2009, 562 near miss cases were recorded. The highest, 117, and the lowest, 1, near miss case was recorded in the months of December and January, respectively. A significant fluctuating trend of near miss occurrences can be observed in Figure 4.12. A significant number of near miss cases was recorded during the initial months of the year. It was found that the near miss cases which occurred throughout the year consisted mainly of 7 HCFs. No near miss case was recorded due to FR. A significant number of near miss cases was reported due to MC, STF, C and TH. Due to MC, 172; STF, 134; C, 89 and TH, 70 cases were recorded. The number of near miss cases recorded due to EF, HK and MTC were 52, 42, and 3, respectively.

A noticeable reduction in near miss cases for the year 2010 can be observed in Figure 2.12. During the 12 month duration of 2010, only 99 near miss cases were recorded. From the period of July to December no near miss case was reported. The highest, 34, and the lowest, 3, near miss cases were recorded in the months of February and May, respectively. In the year 2010, a significant number of near miss cases were recorded due to MC. Due to MC, C, and STF, the number of near miss cases recorded were 31, 24, and 21, respectively. Whereas due to EF, TH, MTC and FR, the number of near miss cases reported was 8, 7, 4, 2 and 1, respectively.

Safety conscious companies make a near miss a big deal. Near misses are not funny; they are often deadly. Reporting of near misses should be encouraged in organizations. In initial stage for similar near miss cases immediate action need to be taken to prevent recurrences. Near misses can be considered as warnings that something or someone is not performing the job correctly.

4.5. Distribution of HSE Non-Compliances based upon their Impact on People, the Environment and Company Assets

The third distribution of HSE non-compliances on the 3.5 year duration data was carried out with reference to their impact on people, the environment and company assets. A monthly and quarterly distribution of HSE non-compliances was performed. The mutual effects of all three classifications were studied. It includes:

1. The effects of HCFs to cause Fatality, Accident, Incident and Near Miss cases,
2. The effects of HCFs with reference to effects on people, the environment and company assets, and
3. The relationship among Fatality, Accident, Incident and Near Miss cases with reference to their effects on people, the environment and company assets.

The tables attached in Appendix-D highlight the relationship among the mutual effects of all three classifications on a monthly and quarterly basis. This section was not covered completely in this study. The effects of the HCFs and HSE non-compliances to cause Fatality, Accident, Incident and Near Miss cases were covered and discussed in detail.

4.6. Statistical Analysis for F, A, I and NM Causation

A test of correlation was performed by using the windows based SPSS (statistical package of social sciences) version 18.0. Pearson's correlation test was performed. It can be observed in Table 4.6 that N=6 because for the year 2007, 6 months of data was analyzed. Whereas, for the years 2008, 2009 and 2010, 12 months of data was analyzed therefore N=12.

4.6.1. Correlation within F, A, I and NM cases for the year 2007

Test of correlations within 674 HSE non-compliances for the year 2007 was conducted and presented in the correlation matrix in Table 4.6.

Table 4.6: Correlations between F, A, I and NN Cases for the Year 2007

		F	A	I	NM
F	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	6			
A	Pearson Correlation	-.119	1		
	Sig. (2-tailed)	.822			
	N	6	6		
I	Pearson Correlation	-.357	-.178	1	
	Sig. (2-tailed)	.487	.736		
	N	6	6	6	
N	Pearson Correlation	-.495	-.194	**.822***	1
	Sig. (2-tailed)	.318	.712	**.045**	
	N	6	6	6	6

*. Correlation is significant at the 0.05 level (2-tailed).

The level of correlation was significant at the level of 0.05. It can be observed in Table 4.6 that a significant correlation with a value of 0.045 exists among the incident and near miss cases. No significant correlation was found among the other variables.

4.6.2. Correlation within F, A, I and NM Cases for the year 2008

A test of correlation was performed for the year 2008. A correlation matrix for the test of correlation was presented in Table 4.7.

Table 4.7: Correlations between F, A, I and NM Cases for the year 2008

		F	A	I	NM
F	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	12			
A	Pearson Correlation	.075	1		
	Sig. (2-tailed)	.817			
	N	12	12		
I	Pearson Correlation	.247	.231	1	
	Sig. (2-tailed)	.440	.470		
	N	12	12	12	
NM	Pearson Correlation	-.011	.008	**.708***	1
	Sig. (2-tailed)	.972	.979	**.010**	
	N	12	12	**12**	12

*. Correlation is significant at the 0.05 level (2-tailed).

A correlation among 1,203 HSE non-compliances was calculated with reference to four variables, i.e., fatality, accident, incident and near miss cases. In the 12 month duration of the year 2008, 5 fatalities, 90 accidents, 352 incidents and 756 near miss cases were recorded. A significant correlation can be observed in Table 4.7 among the incident and near miss cases. The Pearson Correlation co-efficient among incidents and near misses was 0.708 with a significance level of 0.10. The correlation among the variables was significant at the 0.05 level.

4.6.3. Correlation within F, A, I and NM Cases for the year 2009

Test of correlation within 902 HSE non-compliances for the year 2009 was conducted and presented in the correlation matrix in Table 4.8.

Table 4.8: Correlations between F, A, I and NM Cases for the Year 2009

		F	A	I	NM
F	Pearson Correlation	1			
	Sig. (2-tailed)	.			
	N	12			
A	Pearson Correlation	.052	1		
	Sig. (2-tailed)	.871	.		
	N	12	12		
I	Pearson Correlation	.056	.151	1	
	Sig. (2-tailed)	.862	.639	.	
	N	12	12	12	
NM	Pearson Correlation	-.209	.089	**.836(**)**	1
	Sig. (2-tailed)	.515	.782	**.001**	.
	N	12	12	**12**	12

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

For the year 2009, 902 HSE non-compliances were recorded and these contributed to 1 fatality, 101 accidents, 238 incidents and 562 near miss cases. The correlation among the variables was found to be significant at the level of 0.01. In the year 2009, a strong Pearson's Correlation can be observed in Table 4.8 between incident and near miss cases. The Pearson Correlation coefficient among incident and near miss was 0.836 with significance level of 0.001.

4.6.4. Correlation within F, A, I and NM Cases for the year 2010

Test of correlation within 437 HSE non-compliances for the year 2010 was conducted and is presented in the correlation matrix in Table 4.9.

Table 4.9: Correlations between F, A, I and NM Cases for the Year 2010

		F	A	I	NM
F	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	12			
A	Pearson Correlation	**.515**	1		
	Sig. (2-tailed)	**.086**			
	N	**12**	12		
I	Pearson Correlation	-.206	-.475	1	
	Sig. (2-tailed)	.521	.118		
	N	12	12	12	
NM	Pearson Correlation	.016	-.273	**.874****	1
	Sig. (2-tailed)	.962	.390	**.000**	
	N	12	12	**12**	12

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

For the year 2010, 437 HSE non-compliances were recorded and contributed to 7 fatalities, 186 accidents, 146 incidents and 99 near miss cases. During one hazardous event 4 fatality cases were reported.

The correlation among the variables was found to be significant at the level of 0.01. In the year 2010, a strong Pearson's Correlation can be observed in Table 4.9 between fatality and accident cases. The Pearson's Correlation co-efficient among fatality and accident cases was 0.15 with a significance level of 0.086. A perfect Pearson Correlation with a value of 0.874 among near miss and incident cases was also recorded.

4.7. Relationship among HCFs and occurrences of F, A, I and NM Cases

The relationship among the HCFs and the occurrences of fatalities, accidents, incidents and near misses is depicted in Table 4.11, Table 4.12 and Table 4.13.

Table 4.10: Relationship Among HCFs and Occurrences of Fatality Cases

Period	Fatality							
	HK	TH	STF	C	FR	EF	MC	MTC
2007	0	1	0	0	0	0	0	0
2008	0	3	0	1	0	0	1	0
2009	0	1	0	0	0	0	0	0
2010	0	0	0	1	5	1	0	0
Total	0	5	0	2	5	1	1	0

It can be observed in Table 4.10 that a total number of 14 fatality cases were reported during the 3.5 year study period. TH and FR can be observed as the most significant cause of fatality cases. A total number of 5 fatality cases were reported each due to TH and FR. C and EF contributed to cause 2, and 1, fatality cases, respectively. 1 fatality case was reported due to MC.

Table 4.11: Relationship Among HCFs and Occurrences of Accident Cases

Period	Accident							
	HK	TH	STF	C	FR	EF	MC	MTC
2007	0	47	0	0	0	0	0	0
2008	0	87	0	0	2	1	0	0
2009	0	93	0	0	1	4	0	3
2010	0	139	0	4	21	3	9	12
Total	0	366	0	4	24	8	9	15

In Table 4.11, the relationship among the HCFs and accident cases can be observed. It can be viewed that TH caused a dominant number of accidents as compared to the remaining seven HCFs. A total number of 366 accident cases were reported due to TH during the study period. The highest number, at 139 accident cases, was reported due to TH in the year 2010. 24 accident cases occurred due to FR. The number of accident cases reported due to EF, MC and MTC was 8, 9, and 15, respectively.

Table 4.12: Relationship Among HCFs and Occurrences of Incident Cases

Period	Incident							
	HK	TH	STF	C	FR	EF	MC	MTC
2007	5	40	52	9	6	10	52	65
2008	0	56	76	61	12	16	73	58
2009	0	27	68	8	15	13	26	81
2010	0	20	28	12	15	7	41	25
Total	5	143	224	90	48	46	192	226

Table 4.12 highlights the relationship among the HCFs and incident cases. It can be observed in Table 4.12 that the highest number of incident cases, 226, was reported to be MTC. STF were also identified as significant contributory factors to cause incident cases. A total number of 224 incidents cases were reported due to STF. The 3rd and 4th incident occurring HCFs identified were MC and TH. The total number of incident cases reported due to MC, and TH was 192, and 143, respectively. Incident cases were also caused by C, FR and EF. The number of cases reported due to C, FR and EF was 90, 48 and 46, respectively. HK also contributed to cause 5 incident cases.

Table 4.13: Relationship Among HCFs and Occurrences of Near Miss Cases

Period	Near Miss							
	HK	TH	STF	C	FR	EF	MC	MTC
2007	49	40	85	78	1	24	106	4
2008	55	109	139	162	3	81	205	2
2009	42	70	134	89	0	52	172	3
2010	4	7	21	24	1	8	31	2
Total	150	226	379	353	5	165	514	11

In Table 4.13, the relationship among the HCFs and near miss cases can be observed. It can be viewed that the highest number of near miss cases, 514, was reported due to MC. A total number of 379 and 353 near miss cases were reported due to STF and C cases. A significant number of near miss cases were reported due to TH and HK practices. The total number of near miss cases reported due to TH, and

HK was 226, and 150, respectively. The near miss cases reported due to MTC and FR were 11 and 5, respectively.

4.8. Quarterly Distribution of HSE Non-Compliances based upon the HCFs

Data collected during the study period was reviewed on a quarterly basis. The year 2007 data contains two quarters due to the availability of only 6 months of data. The years 2008, 2009 and 2010 data were grouped into 4 quarters in each year. The quarterly distribution of HSE non-compliances was carried out based upon the occurrences of HCFs and to cause fatality, accident, incident and near miss cases. Detailed results of the quarterly distribution for the years 2007, 2008, 2009 and 2010 pertaining to the HCFs are attached in Appendix-A. Graphical representation of the quarterly distribution of HSE non-compliances based upon the HCFs and to cause fatality, accident, incident and near miss causation can be observed from Figure 4.13 to Figure 4.16.

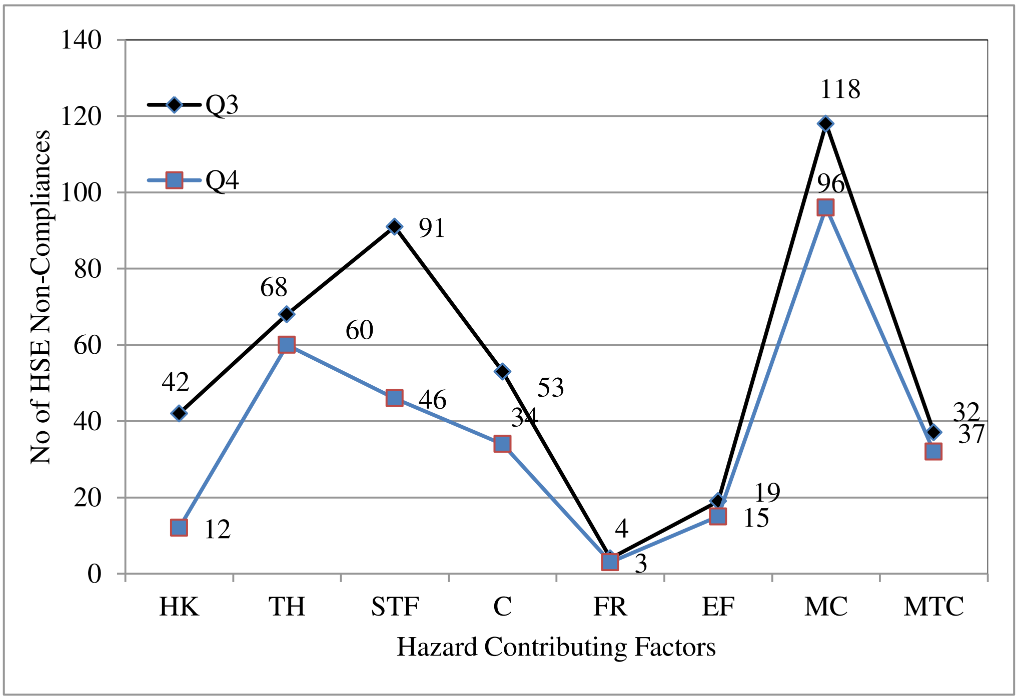

Figure 4.13: Quarterly Distribution Pattern of HSE Non-Compliances Based upon HCFs for the Year 2007

The quarterly distribution of the HCFs for the year 2007 can be observed in Figure 4.13. In quarter 3 and quarter 4, 408 and 266 HCFs were recorded. In both quarters significant numbers of HCFs were recorded pertaining to MC. The number of MC recorded in quarter 3 and quarter 4 was 94 and 64, respectively.

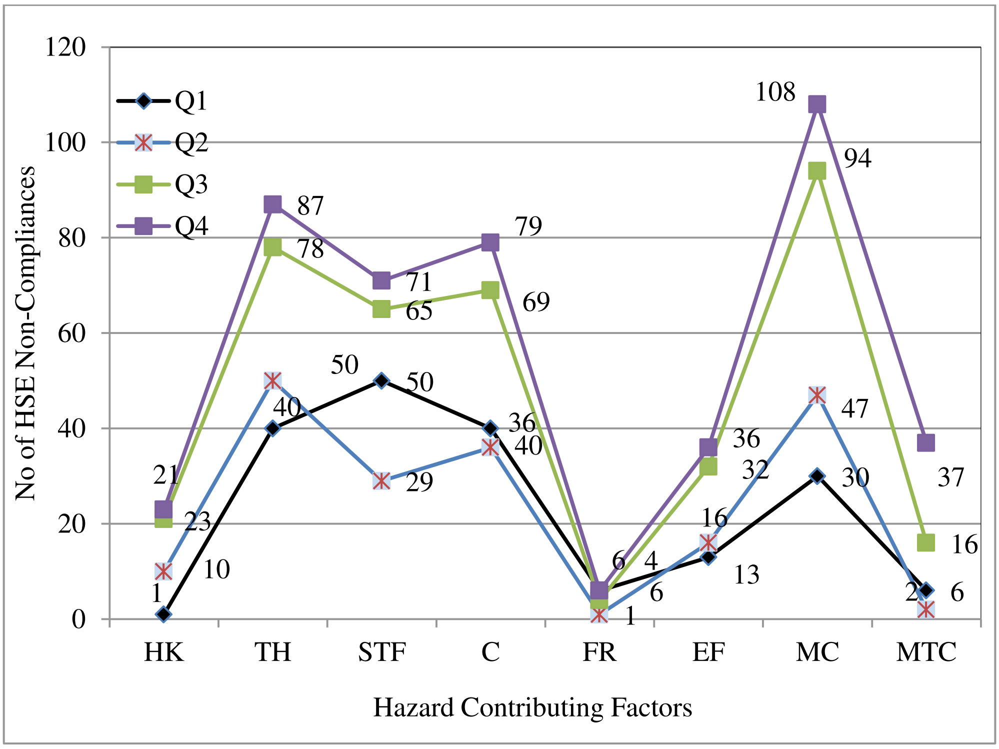

Figure 4.14: Quarterly Distribution Pattern of HSE Non-Compliances Based upon HCFs for the Year 2008

The quarterly distribution of HCFs for the year 2008 can be observed from Figure 4.14. Year 2`008 contains quarterly distribution pattern of four quarters of the year 2008. During the year 2008, 1,203 HCFs were recorded. In quarter 1, quarter 2, quarter 3 and quarter 4, the HCFs recorded were 186, 191, 379 and 447, respectively. In quarter 1, highest 50 cases were reported due to STF. In quarter 2, TH found significant. HCFs recorded pertaining to TH, in quarter 2 were 50. In quarter 3 and quarter 4, MCs occurrences found significant. In quarter 3 and quarter 4, 94 and 108 HCFs were recorded.

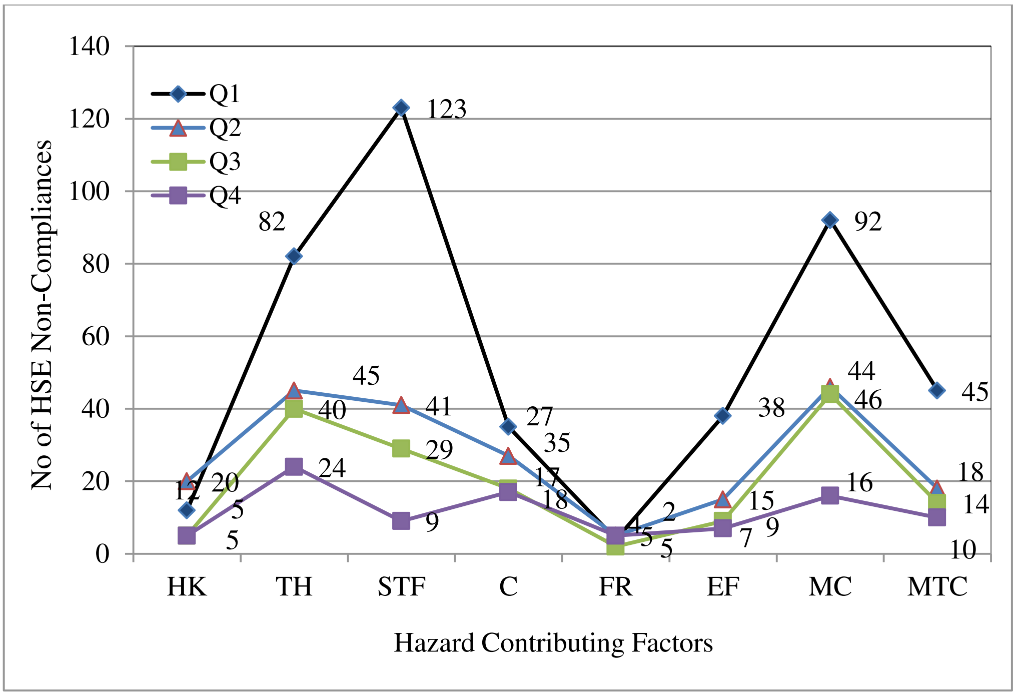

Figure 4.15: Quarterly Distribution Pattern of HSE Non-Compliances Based upon HCFs for the Year 2009

The quarterly distribution pattern for the year 2009 can be observed from Figure 4.15. During the year 902 HCFs were recorded. A highest 431 and lowest 93, HCFs were recorded in quarter 1, and quarter 4, respectively. In quarter 2 and 3, 217 and 161, HCFs were reported. It can be observed from Figure 4.15 that in quarter 1, highest cases, 123 were reported due to STF. In quarter 2 and 3, a highest numbers of 46 and 44 cases were recorded due to MCs. In quarter 4, a significant reduction of HCFs can be noticed. A highest numbers of 24 cases related to TH were recorded in quarter 4.

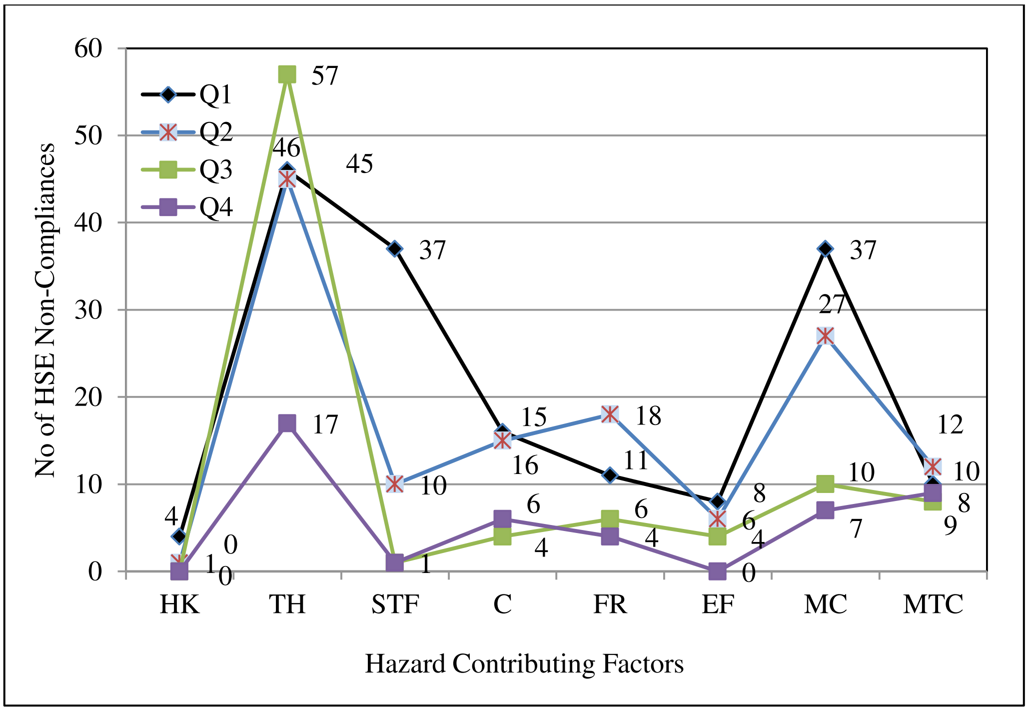

Figure 4.16: Quarterly Distribution Pattern of HSE Non-Compliances Based upon HCFs for the Year 2010

Noticeable fluctuations in quarterly distribution of HCFs for the year 2010 can be observed from Figure 4.16. During the year 437 HCFs were reported. A highest 169 and lowest 44, HCFs were recorded in quarter 1 and quarter 4, respectively. In quarter 2 and quarter 3, 134 and 90, HCFs were recorded. It can be observed from Figure 4.16 that TH caused highest cases in all 4 quarters. In quarter 1, quarter 2, quarter 3 and quarter 4, cases reported due to TH were 46, 45, 57 and 17, respectively.

A difference in occurrences of HCFs can be observed in all quarters. It can be noticed that some quarters the occurrences of HCFs were more and in some quarters it is considerably small. In all 42 quarters of 3.5 years study period fluctuations in occurrences of HCFs can be seen clearly. For each quarter of the year the HCFs were added and presented in Table 4.14 below.

Table 4.14: Summary of Quarterly Distribution of HSE Non-Compliances Based upon HCFs

Duration	Q1	Q2	Q3	Q4	Total
2007			408	266	674
2008	186	191	379	447	1203
2009	431	217	161	93	902
2010	169	134	90	44	437
Total	786	542	1038	850	3216

Table 4.14 depicts the summary of quarterly distribution of HSE non compliances based upon HCFs. With reference to Q1 and Q2, a highest numbers of HCFs were recorded in the first and second quarter of the year 2009. In Q3, a highest numbers of 408, HCFs can be noticed in the year 2007. Whereas, Q4 in the year 2008 were found to be most HCFs occurred period with a total HCFs of 447. Conclusively, a Q3 period was found to be most HCFs occurrences period within 3.5 years study period. In Q3 which consisted of three months duration i.e. July, August and September, a highest numbers of 1038 HCFs were recorded. Whereas, in Q4, Q1 and Q2 the HCFs recorded were 850, 786 and 542, respectively.

4.9. Quarterly Distribution of HSE Non-compliances based upon F, A, I and NM Cases

3.5 years of HSE non-compliance study period data was distributed on quarterly based upon occurrences of fatality, accident, incident and near miss cases. 6 months of data for the year 2007 and 12 months of data for each year 2008, 2009 and 2010 were plotted to observe the trend of HSE non-compliances to cause fatality, accident, incident and near miss cases. The quarterly distribution for each year was attached in Appendix-A while the graphical representation was plotted in Figure 4.17, Figure 4.18, Figure 4.19 and Figure 4.20.

Figure 4.17: Quarterly Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2007

Figure 4.17 illustrates a quarterly distribution pattern of two quarters for the year 2007 based upon fatality, accident, incident and near miss cases. The data for the year 2007 consisted of two quarters from July to December 2007. Each quarter consisted of three month duration. It can observe in Figure 4.17 that quarter 3 is more hazardous as compared to quarter 4. No fatality was reported in either quarter. However, In Q3 and Q4, 34 and 14 accident cases were reported. The number of incident cases increased from 93 to 146 from Q3 to Q4 and the number of near misses also increased from 139 to 248 cases from Q3 to Q4.

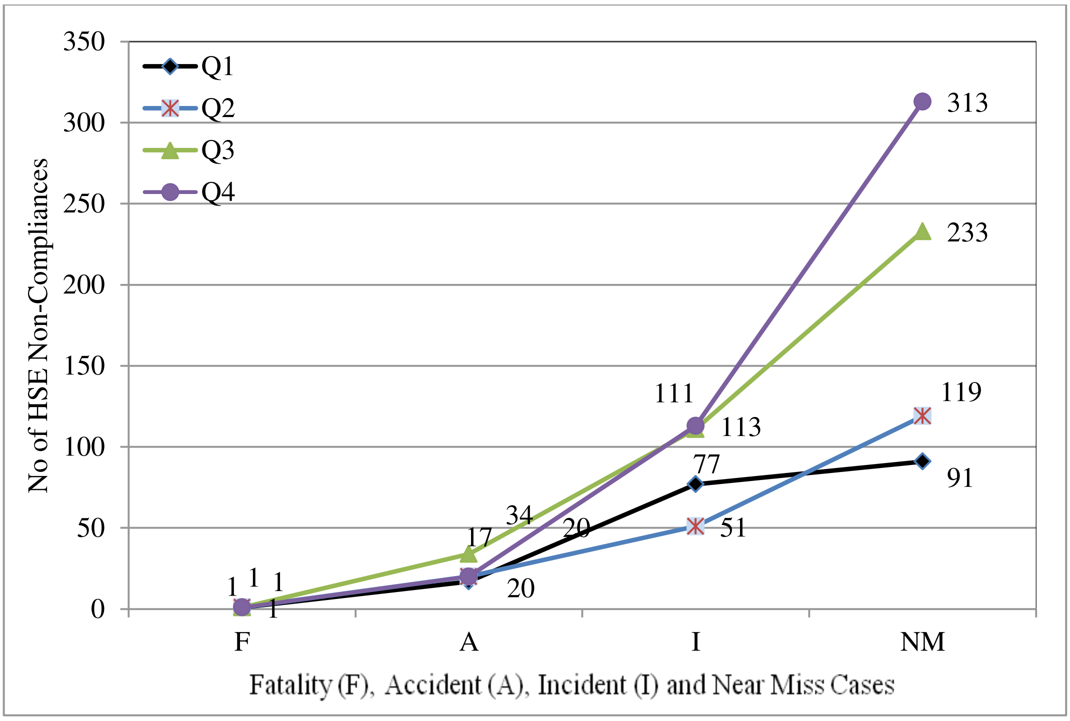

Figure 4.18: Quarterly Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2008

In the year 2008 during quarters 1, 2, 3 and 4, a progressing pattern of fatality, accident, incident and near miss occurrences can be observed in Figure 4.18. In each quarter of the year, one fatality case was reported. The highest, 34, number of accident cases was recorded in quarter 3. In quarter 4, 113 incident and 313 near miss cases were recorded.

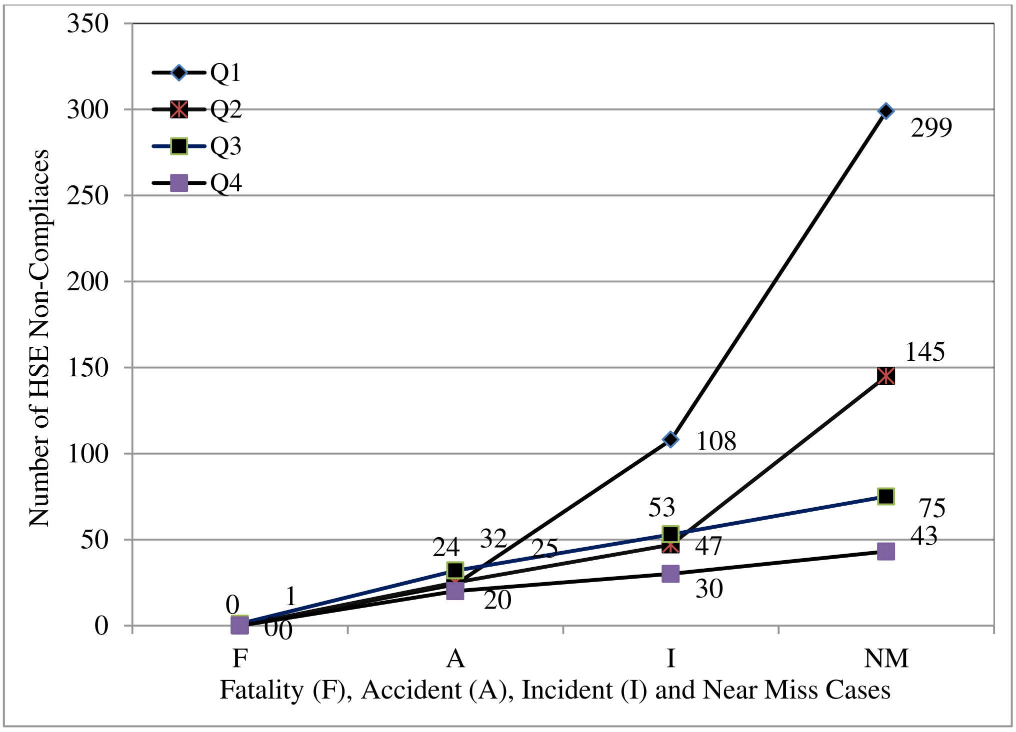

Figure 4.19: Quarterly Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2009

A quarterly distribution pattern of fatality, accident, incident and near miss cases for the year 2009 can be observed in Figure 4.19. During the 4 quarters of 2009, 902 HSE non-compliances were recorded. A significant number of HSE non-compliances were recorded in quarter 1. In quarter 1, 2, 3 and 4, the number of reported HSE non-compliances were 431, 217, 161 and 93, respectively. 1 fatality case was reported in quarter 3. The highest number of accidents, 32, was reported in quarter 3. The highest number of incidents, 108, and near miss cases, 299, was recorded in quarter 1 of the year 2009.

Figure 4.20: Quarterly Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2010

During the 3.5 year data collection period, the lowest number of HSE non-compliances was recorded during the year 2010. In the 12 month duration of 2010, 437 HSE non-compliances were recorded. The quarterly distribution pattern of HCFs based upon fatality, accident, incident and near miss occurrences can be observed in Figure 4.20. During the year 2010, 4 fatality cases were reported. In quarter 3, 2 fatality cases were reported. Whereas, 1 fatality case was reported in each, quarter 2 and quarter 4, respectively. The highest number, 169, and the lowest, 44, of cases were recorded in quarter 1 and quarter 4, respectively. In quarter 2 and quarter 3, 134 and 90 cases were recorded.

Table 4.15: Summary of Quarterly Distribution of HSE Non-Compliances Based upon Occurrences of F, A, I and NM Cases

No	Variable	Q1	Q2	Q3	Q4	Total
1	F	1	2	4	5	12
2	A	68	101	166	93	428
3	I	256	147	312	260	975
4	NM	461	292	556	495	1804
	Total	786	542	1038	853	3219

Table 4.15 depicts the summary of the quarterly distribution of the HSE non compliances based upon the occurrences of fatality, accident, incident and near miss cases. A total number of 12 fatality cases were recorded during the 3.5 year study period. In any year, the highest number of 5 fatality cases was recorded in Q4. The highest number of accident cases was recorded in Q3; whereas the highest number of 312 incident cases was also recorded in Q3. Conclusively, Q3 can be observed as the most reported HSE non compliances in the study period. In Q3, the total number of 1,038 cases was reported. In Q1, Q4 and Q2, the total number of cases reported was 853, 686 and 542, respectively.

4.10. Seasonal Distribution of the HSE Non-Compliances based upon the HCFs

A strong relation among the HCFs with reference to seasons was observed during the 3.5 year study period. The study area contained four seasons: cold, hot, warm and monsoon seasons. The collected data was categorized according to the four seasons. The seasons were named as S1, S2, S3 and S4. Table 4.16 shows the basis for the seasonal distribution of HSE non-compliances.

Table 4.16: Bases for Seasonal Distribution of HSE Non-Compliances

Cold Season (S1)	Hot Season (S2)	Warm Season (S3)	Monsoon Season (S4)
Mid Nov to Mid April	Mid April to June	Mid Sept to Mid Nov	July to Mid Sept

A detailed description of the seasonal hazard occurrences is attached in Appendix-A for the years 2007, 2008, 2009, and 2010. The graphical representation of the seasonal variation of the HCFs illustrated from Figure 4.21 to Figure 4.24.

In Figure 4.21, a seasonal distribution of the HCFs can be viewed. 6 months of data from July to December were categorized according to seasons, S3 and S4.

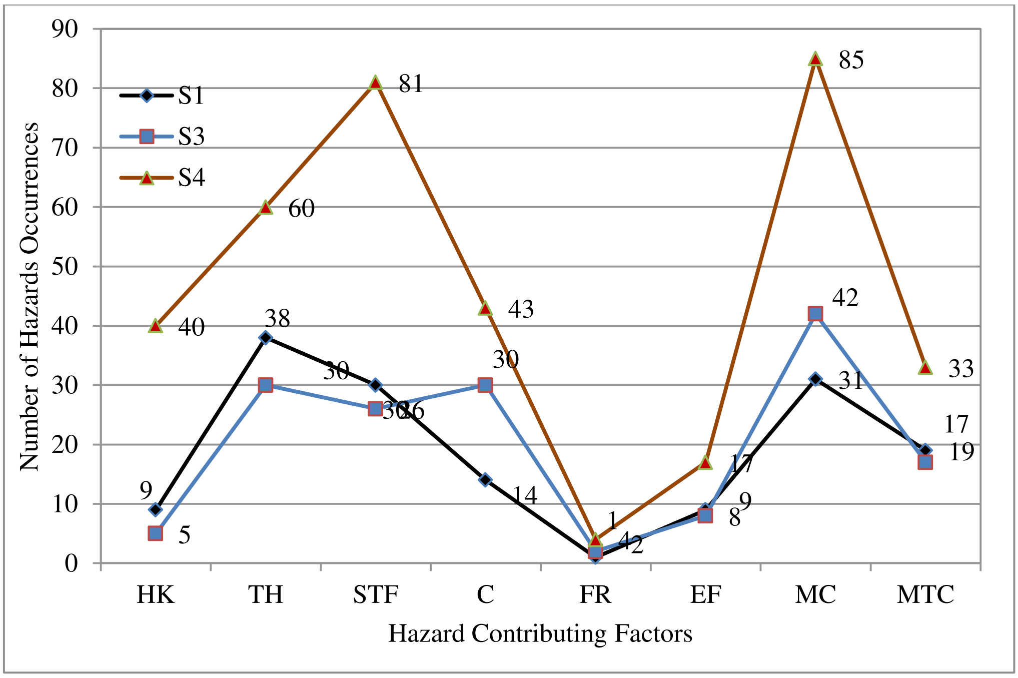

Figure 4.21: Seasonal Distribution of HCFs for the Year 2007

A significant fluctuation pattern of the HCFs pattern can be observed in Figure 4.21. Occurrences of the dominant numbers of HCFs can be viewed in S4. A peak in STF and MC can be observed. A total number of 81 and 85 cases related to STF and MC were reported in S4.

A graphical representation of the seasonal hazard distribution for the year 2008 was plotted in Figure 4.22.

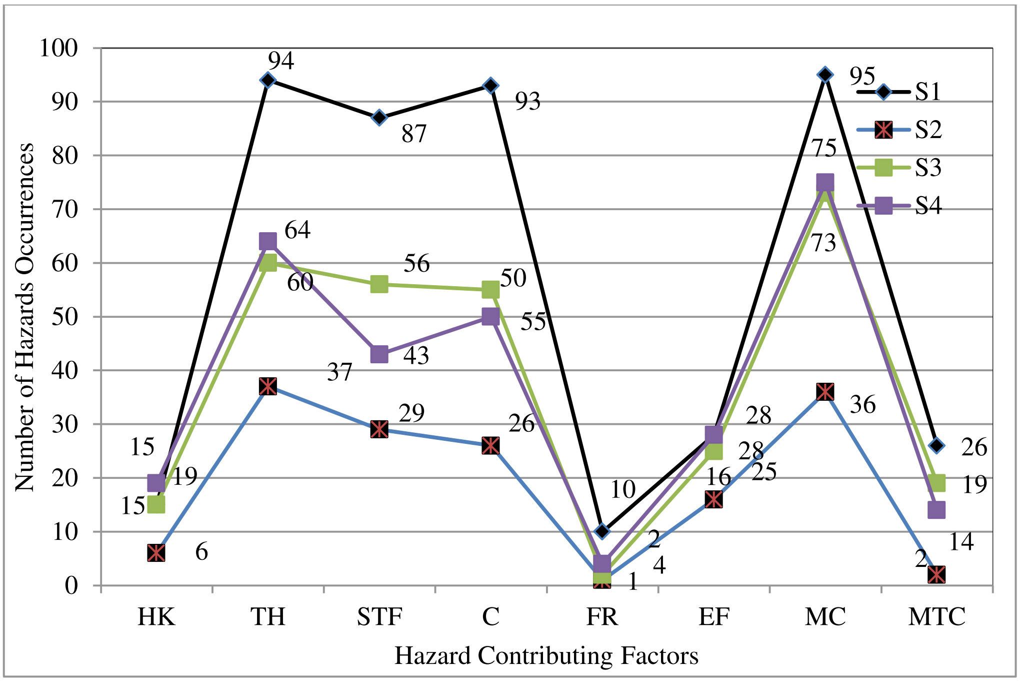

Figure 4.22: Seasonal Distribution of HCFs for the Year 2008

In Figure 4.22, it can be observed that during 2008, the highest number, 448, and the lowest, 153, of HCFs was recorded in S1 and S2, respectively. During the seasons, S3 and S4, the number of HCFs reported was 305 and 153, respectively. It can be observed in Figure 4.22 that during S1, the dominant HCFs recorded were pertained to MC, TH, C, and STF. In S1, TH, MC, C, and STF, caused significant numbers of HCFs. In S3 and S4, the significant HCFs recorded were pertained to MC, TH, STF and C.

In the year 2009, 902 HCFs were recorded. The seasonal distribution of the HCFs for the year 2009 of all 4 seasons was plotted in Figure 4.23.

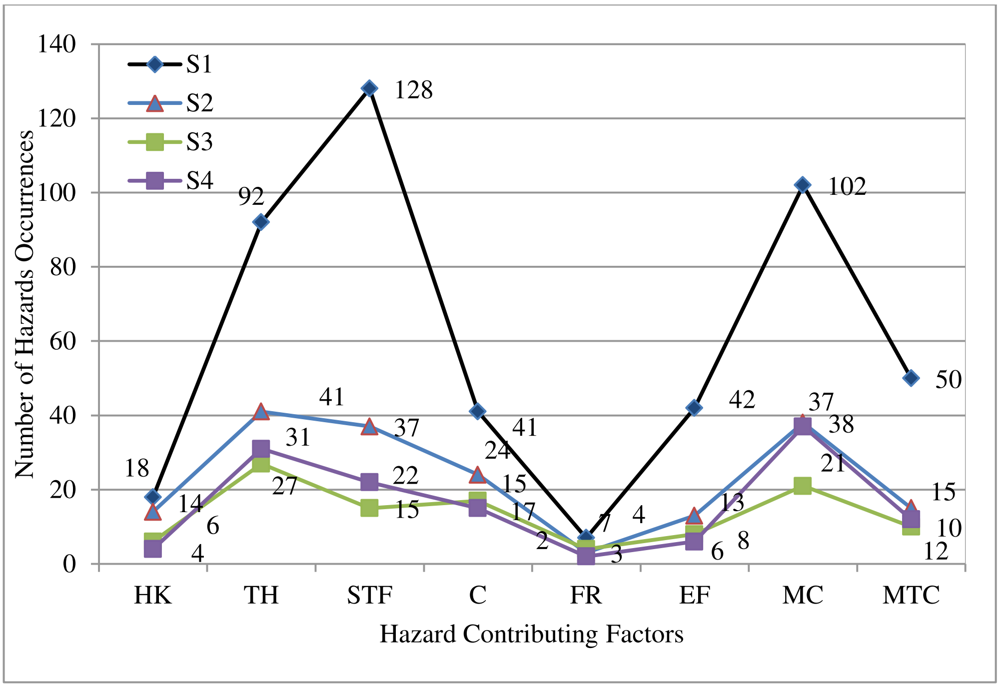

Figure 4.23: Seasonal Distribution of HCFs for the Year 2009

The highest, 480, and the lowest, 108, number of HCFs was recorded in S1 and S4, respectively. During S1, the highest number, 128, of cases was recorded due to STF. In S2 and S3, the highest number, 41 and 27, of cases was recorded due to TH. During S4, a significant number of cases, 37, 31, and 22, were recorded due to MC, TH and STF, respectively.

For the year 2010, 419 HCFs were recorded. The seasonal distribution of the HCFs for the year 2010 of all 4 seasons was plotted in Figure 4.24.

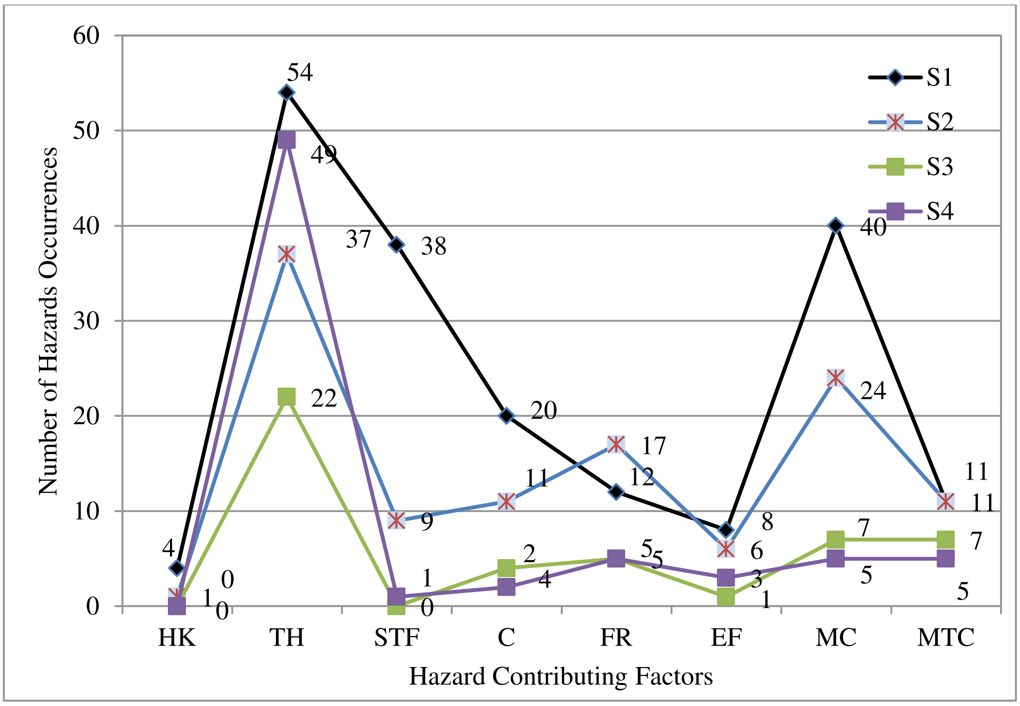

Figure 4.24: Seasonal Distribution of HCFs for the Year 2010

In Figure 4.24, a fluctuating pattern of HCFs for the year 2010 in all 4 seasons can be observed. The highest number of HCFs was recorded in the S1. In all four seasons, hazardous events pertaining to TH were reported significantly. A total number of 54 and 49 hazardous events related to FR were reported in S1 and S4, respectively. Peaks can be observed in Figure 4.24 related to TH and MC cases. The highest number of hazardous events related to FR was reported in the S2.

With reference to the seasonal classification for the years 2007, 2008, 2009 and 2010, it can be concluded that the occurrences of hazardous events also depends upon seasonal changes. Table 4.17 illustrates the summary of hazardous events based upon the seasonal classification during the study period.

Table 4.17: Summary of HSE Non-Compliances Based upon Seasonal Classification

Period	Cold Season (S1)	Hot Season (S2)	Warm Season (S3)	Monsoon Season (S4)
	Mid Nov to Mid April	Mid April to June	Mid Sept to Mid Nov	July to Mid Sept
2007	151	0	160	363
2008	448	153	305	297
2009	480	185	108	129
2010	187	116	46	70
Total	1266	454	619	859

In Table 4.17, it can be observed that the highest number of HSE non-compliances was recorded in the cold season. The cold season contributed to 39.58% of the total occurrences during the study period. During the Monsoon season (S4) that starts from July to Mid September, the second highest numbers of HSE non-compliances were reported. In S4, a total number of 856 HSE non-compliances were reported with a percentage of 28.68% events of the whole study period. During S2 and S3, the number of HSE non-compliances reported was 454 and 619, respectively. It can be concluded that safety consideration at PFS's are more dominantly needed during the cold season that starts from Mid November to Mid April. If attention is given to address safety issues at PFS's during the cold season on a priority basis than occurrences of hazardous events during the year can be reduced significantly. During the cold season, TH and FR contributed more hazardous events therefore they should be specifically dealt with more care.

4.11. Seasonal Distribution of the HSE Non-Compliances based upon the occurrences of F, A, I and NM Cases

The HSE non-compliances recorded during 3.5 year study period were categorized based upon occurrences of fatality, accident, incident and near miss cases. HCFs identified as root causes for the occurrences of fatality, accident, incident and near miss cases. A graphical representation of HSE non-compliances for the year 2007, 2008, 2009 and 2010 was plotted in Figure 4.25, Figure 4.26, Figure 4.27 and Figure 4.28. Whereas, a detail description of seasonal hazards occurrences based upon occurrences of fatality, accident, incident and near miss cases for the year 2007, 2008, 2009, and 2010 is attached as in Appendix-A.

Figure 4.25 was plotted to see the effects of the seasonal variations to cause fatality, accident, incident and near miss cases.

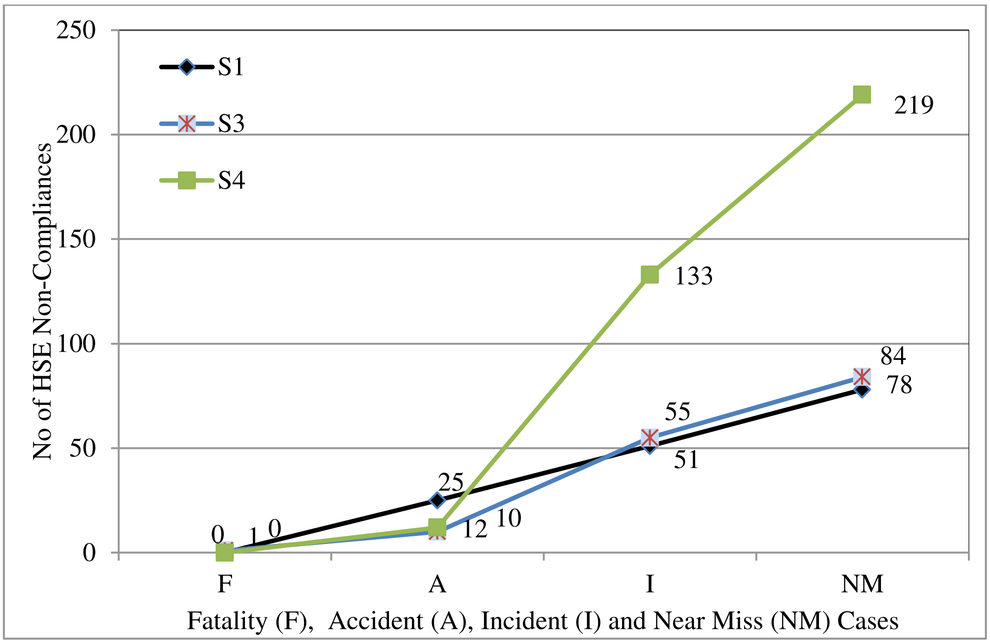

Figure 4.25: Seasonal Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2007

It can be observed in Figure 4.25 that in Season S3, the highest number of accidents, incidents and near miss cases was reported. One fatality case was reported in the warm season, S1, which starts from mid September to mid November.

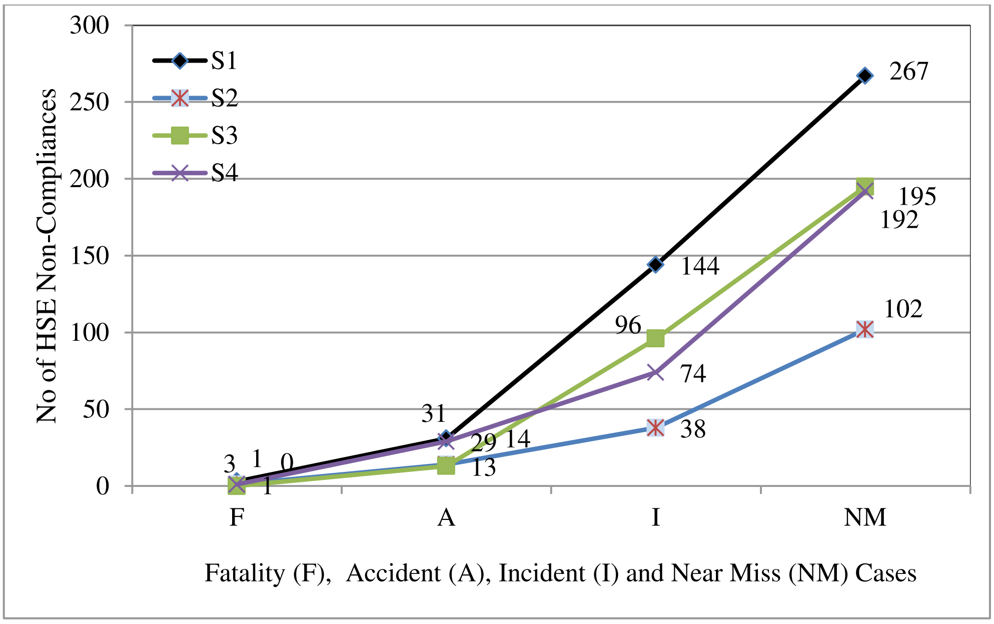

Figure 4.26: Seasonal Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2008

Figure 4.26 depicts the seasonal distribution pattern for the year 2008. It can be viewed in Figure 4.26 that a total number of 445 cases were reported in the cold season, S1. As compared to S2, S3 and S4; S1 can be considered as the most hazardous season during the year 2008.

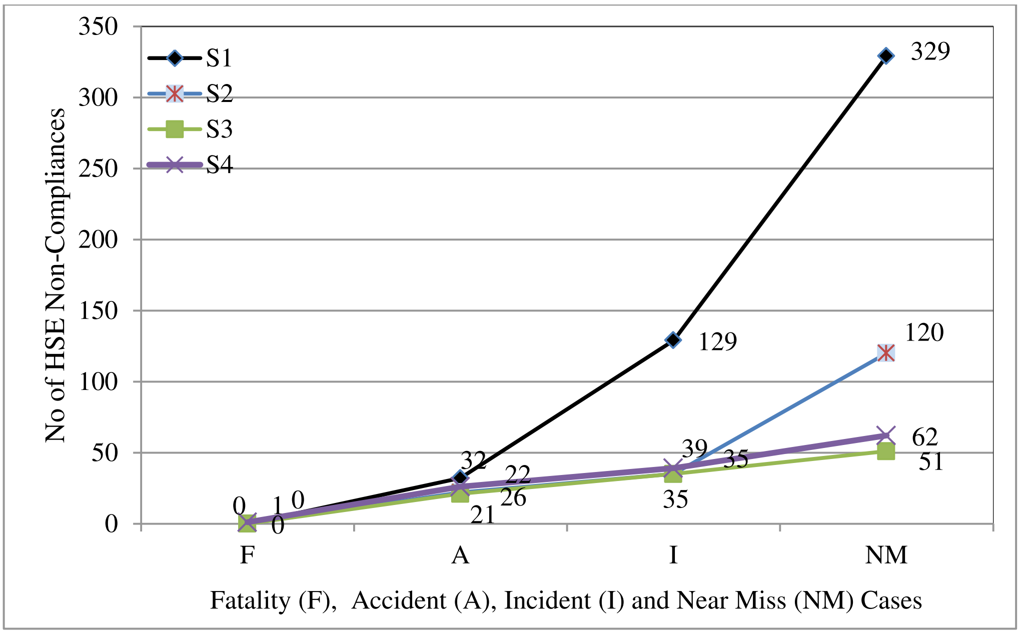

Figure 4.27: Seasonal Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2009

Figure 4.27 depicts the seasonal distribution pattern for the year 2009. It can be observed in Figure 4.27 that the highest number of non-compliances was recorded during S1. One fatality case was reported during S4. A continuous increment in accident, incident and near miss cases can be observed from S1 to S2, then S4 and finally to S3.

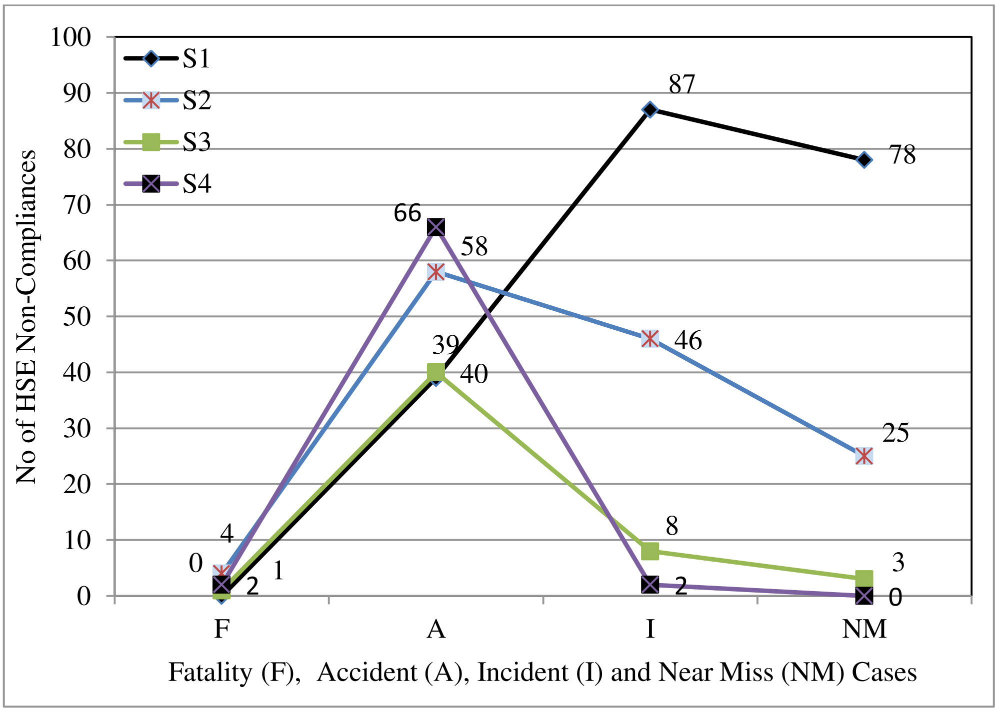

Figure 4.28: Seasonal Distribution Pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for the Year 2010

Figure 4.28 shows the seasonal distribution of the HSE non-compliances based upon the F, A, I and NM cases for the year 2010. Noticeable fluctuations in the occurrences of the HSE non-compliances to cause fatality, accident, incident and near miss cases can be observed in Figure 4.28. During the year 2010, a total number of 8 fatality cases were reported. In the S2, 4 fatality cases were reported. Whereas, in the S3, and the S4, a total number of 1 and 2 fatality cases were reported, respectively. The highest and lowest number of accident cases reported in S4 and S1 was 66 and 39, respectively.

The HSE non-compliances for each year in every season were added and Figure 4.18 was prepared. Table 4.18 shows the summary of the seasonal distribution pattern to cause fatality, accident, incident and near miss cases during the 3.5 year study period.

Table 4.18: Summary of Seasonal Distribution pattern of HSE Non-Compliances Based upon F, A, I and NM Cases for 3.5 Years Study Period

No	Variable	Cold Season (S1)	Hot Season (S2)	Warm Season (S3)	Monsoon Season (S4)
		Mid Nov to Mid April	Mid April to June	Mid Sept to Mid Nov	July to Mid Sept
1	F	3	5	2	4
2	A	127	94	84	133
3	I	411	119	200	248
4	NM	752	247	333	473
	Total	1293	465	619	858

It can be observed Table 4.18 that the highest number of HSE non-compliances was recorded in S1. It may be due to occurrences of mist and fog in the atmospheric environment and the workers' laziness to perform their assigned tasks. A significant number of road accidents were also reported due to the foggy environment. The highest number of slip, trip and fall cases due to slippery surfaces was also reported in the S1. In addition, S1 is also longer in duration as compared to the other seasons. The second highest number, 858, of HSE non-compliances occurred in the S4, and can be observed in Table 4.18 whereas, a total number of 619 and 465 HSE non-compliances were recorded in the S2, and the S3, respectively.

4.12. Risk Calculation by using Existing Risk Assessment Criterion

HSE non-compliances recorded for the year 2008 was analyzed by using existing three risk assessment criteria's. Total number of 1203 HSE non-compliances were recorded and risk was calculated. The detail description of three risk assessment methods was presented in section 1.4.1, 1.4.2 and 1.4.3.

4.12.1. Analysis Results of HSE Non-Compliances by As Low As Reasonably Practicable (ALARP)

1203 HSE non-compliances were analyzed by using ALARP. Table 4.19 showing the analysis result of HSE non-compliances.

Table 4.19: Results of As Low As Reasonably Practicable (ALARP)

CONSEQUENCE					PROBABILITY				
Rating	People	Assets (RM)	Environment	Reputation	A Never Heard of in industry	B Heard of Incident in Industry	C Incident Has occurred in Our Company	D Happens Several Times Per Year in Company	E Happens Several Times Per Year
0	No injury	No Damage	No impact	No impact			8		
1	Slight injury	Slight Damage	Slight impact	Slight impact			85		
2	Minor injury	Minor Damage	Minor impact	Limited impact			552		
3	Major injury	Local Damage	Localized impact	Considerable impact			551		
4	Single fatality	Major Damage	Major impact	Major national					
5	Multiple fatalities	Extensive Damage	Massive impact	Major international	7				

It can be observed from Table 4.19 that 645 HSE non-compliances lying under acceptable risk region. 551 HSE non-compliances fall under yellow region and requires to take risk reduction measure. An immediate control measures or change the process were needed for 7 HSE non-compliances.

4.12.2. Analysis Results of HSE Non-Compliances by using Risk Ranking Criterion

The analysis result of HSE non-compliances recorded by using risk ranking criterion is presented in Table 4.20.

Table 4.20: Evaluated Risk after Multiplying Severity and Likelihood

	LIKELIHOOD			
SEVERITY	Extremely likely Could happen at any time **(E) 10**	Often likely Could happen at sometime (F) 08	Unlikely Could happen but very rarely (G) 06	Very unlikely Could happen but probably never will (H) 04
Death or permanent disability or extreme damage to equipment or property (A) 10	**24**	**158**	**43**	**43**
Long term illness or serious injury or major damage to property or equipment (B) 08		**53**	**121**	
Medical treatment several days off work or minor damage to equipment or property (C) 06	**26**	**107**	**325**	**197**
First Aid needed or negligible property damaged (D) 04			**101**	**77**

It can be observed from Table 4.20 that 24 activities fall under category extremely severe. These hazards could be happen at any time and could cause death or permanent disability or extreme damage to equipment or property. 158 activities fall under category often likely. These activities could happen sometime and can cause death or permanent disability or extreme damage to equipment or property. Total 83 activities, 43 in unlikely and 43 in very unlikely category falls. Unlikely activities could happen but very rarely and can cause death or permanent disability or extreme damage to equipment or property. Very unlikely activities could happen but probably never will occur again, these activities also have a potential to cause death or permanent disability. 53 activities fall under often likely and 121 activities fall under unlikely category. Often likely activities could happen but very rarely. Cumulative of often likely and unlikely activities (53 + 121) have a potential to cause long term illness or serious injury or major damage to property or equipment. 655 activities collectively (26 + 107 + 325 + 197) can result a medical treatment, several days off work or minor damage to equipment or property. Finally 178 activities can be cause first aid cases or negligible property damage.

4.12.3. Analysis Results of HSE Non-Compliances by using Risk Evaluation Criterion

Analysis result of HSE non-compliances by using risk evaluation criterion are presented in Table 4.21.

Table 4.21: Evaluation Scale Results after Calculating Risk by using Risk Evaluation Criteria

Evaluation Scale			
Score	Number of Hazardous Activities	Category	Action Required
80 – 100	182	Critical	Isolate the hazard immediately. Take corrective measures on high priority and eliminate the hazard as soon as possible.
50 – 79	112	Major	Isolate the hazard as soon as practicable. Engineering controls and Administrative controls need to be taken. Regularly monitor the cause(s) until rectification.
30 – 49	534	Moderate	Must fix the cause(s) when time and resources permit. Administrative control is to be taken.
≤ 29	375	Minor	Need to monitor and consider. Administrative control is to be taken & use appropriate PPE.

Table 4.21 shows the evaluation scale results after calculating risk by using risk evaluation criterion. 186 activities fall under critical, 111 activities were major, 579 activities were moderate and 391 activities fall under minor category. Respective actions required with reference to categories also illustrated in Table 4.21.

4.13. Risk Evaluation for Risk and Safety Analysis Models

The detailed methodology for the development of the risk and safety analysis models was elaborated in section 3.4 of chapter 3. This section will present the results and discussion for each risk and safety analysis model.

4.13.1. Risk Evaluation with Reference to the Risk and Safety Analysis Model Based upon the Monthly Classification of HCFs

Risk was calculated by multiplying the likelihood and the severity. The severity of each HCF for the years 2007, 2008, 2009 and 2010 was calculated by using the Multiple Regression Analysis (MRA) process using the Statistical Package of Social Sciences version 18.0 (SPSS 18.0). The output of the MRA for the years 2007 is attached for reference in Appendix-B. The analysis for the year 2008, 2009 and 2010 was also carried out in a same manner. With the help of the MRA output and by using equations 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7 and 3.8 as mentioned in section 3.4.1, the severity of each HCF was calculated. The severity calculation for HK for the year 2007 is described below:

$$S_{HK} = \text{Un-standardized Co-efficient} + \beta_{TH}(TH) + \beta_{STF}(STF) + \beta_{C}(C) + \beta_{FR}(FR) + \beta_{EF}(EF) + \beta_{MC}(MC) + \beta_{MTC}(MTC) \quad (3.1)$$

$$S_{HK} = -14.076 + 0.655(128) + (0)(137) + (0.329)(87) + (0)(7) + (1.283)(34) + (0.271)(158) + (-1.239)(69)$$

$$S_{HK} = 99.336$$

The likelihood of each of the HCF for each year was calculated by dividing particular HCF occurrences with the total numbers of HCFs occurrences in that year. The Risk was then calculated by multiplying the severity with the likelihood of each of the HCF. The results for the calculation for severity, likelihood and risk for the year 2007, 2008, 2009 and 2010 are attached in Appendix-C for reference.

The summary of Severity, Likelihood and Risk values for the year 2007, 2008, 2009 and 2010 are presented in Table 4.22, Table 4.23, Table 4.24 and Table 4.25 below.

Table 4.22: Likelihood, Severity and Risk Score for the Year 2007 with Reference to Risk and Safety Analysis Model Based upon HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	HK	54	0.08	99.336	7.96
2	TH	128	0.19	63.23	12.01
3	STF	137	0.20	140.392	28.54
4	C	87	0.13	29.511	3.81
5	FR	7	0.01	58.459	0.61
6	EF	34	0.05	5.642	0.28
7	MC	158	0.23	285.269	66.87
8	MTC	69	0.10	94.69	9.69
		674			

Table 4.22 shows the likelihood, severity and risk scores for the year 2007. It can be viewed that the MC and EF got the highest and lowest risk scores with a value of 66.87 and 0.28, respectively.

Table 4.23: Likelihood, Severity and Risk Score for the Year 2008 with Reference to Risk and Safety Analysis Model Based upon HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	HK	55	0.05	210.266	9.61
2	TH	256	0.21	52.903	11.26
3	STF	217	0.18	186.493	33.64
4	C	223	0.19	225.162	41.74
5	FR	17	0.01	87.565	1.24
6	EF	97	0.08	231.009	18.63
7	MC	277	0.23	146.801	33.80
8	MTC	61	0.05	156.727	7.95
	Total	1203			

The likelihood, severity and risk score values for the year 2008 are depicted in Table 4.23. It can be noticed in Table 4.23 that C got the highest risk score with a value of 41.47. The severity of C was not the highest, but due to the likelihood value of 0.19 it got the highest risk score. The lowest risk score was calculated due to FR with a severity value of 87.565 and likelihood value of 0.01. Therefore, it can be concluded that while calculating the risk score, not only the final risk score values are important but the respective likelihood and severity values also possess significant importance.

Table 4.24: Likelihood, Severity and Risk Score for the Year 2009 with Reference to Risk and Safety Analysis Model Based upon HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	HK	42	0.05	168.787	7.86
2	TH	191	0.21	230.391	48.79
3	STF	202	0.22	99.906	22.37
4	C	97	0.11	29.342	3.16
5	FR	16	0.02	-133.79	-2.37
6	EF	69	0.08	138.413	10.59
7	MC	198	0.22	315.741	69.31
8	MTC	87	0.10	61.224	5.91
	Total	902			

Table 4.24 shows the results of the risk score for the year 2009. Table 4.24 represents that MC got the highest risk score with a value of 69.31. MC were also the highest risk score value in the year 2007. The risk ranking scores for the year 2009 were followed by TH, STF, EF, HK, C, MTC and FR, respectively.

Table 4.25: Likelihood, Severity and Risk Score for the Year 2010 with Reference to Risk and Safety Analysis Model Based upon HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	HK	5	0.01	28.827	0.33
2	TH	165	0.38	210.33	79.42
3	STF	49	0.11	26.006	2.92
4	C	41	0.09	72.958	6.85
5	FR	39	0.09	-21.197	(1.89)
6	EF	18	0.04	95.019	3.91
7	MC	81	0.19	107.821	19.99
8	MTC	39	0.09	110.474	9.86
	Total	437			

The risk scores for the year 2010 for the HCFs are depicted in Table 4.25. The highest and lowest risk scores were calculated for TH and FR with a value of 79.42, and 1.89, respectively.

Table 4.26: Risk Evaluation for the Year 2007, 2008, 2009 and 2010

Rank No	2007	2008	2009	2010
1	R_{MC}	R_{C}	R_{MC}	R_{TH}
2	R_{STF}	R_{MC}	R_{TH}	R_{MC}
3	R_{TH}	R_{STF}	R_{STF}	R_{MTC}
4	R_{MTC}	R_{EF}	R_{EF}	R_{C}
5	R_{HK}	R_{TH}	R_{HK}	R_{EF}
6	R_{C}	R_{HK}	R_{MTC}	R_{STF}
7	R_{FR}	R_{MTC}	R_{C}	R_{HK}
8	R_{EF}	R_{FR}	R_{FR}	R_{FR}

Whereas,

R_{HK} = Risk score for Housekeeping

R_{TH} = Risk score for Transportation Hazard

R_{STF} = Risk score for Slips, trips and falls

R_{C} = Risk score for Carelessness

R_{FR} = Risk score for Fire Risk

R_{EF} = Risk score for Electrical Fault

R_{MC} = Risk score for Miscellaneous Cases

R_{MTC} = Risk score for Medical Treatment Cases

From the final results of the risk scores for the years 2007, 2008, 2009 and 2010, the HCFs were prioritized and depicted in Table 4.26. It can be observed that for the year 2007, MC got the highest priority that was followed by STF, TH, MTC, HK, C, FR and EF. For the year 2008, C got the highest risk score followed by MC, STF, EF, TH, HK, MTC and FR. During the year 2009, MC got the highest risk score and the 1st priority. TH, STF and EF got the 2nd, 3rd and 4th ranking. For the year 2010, TH got the highest risk score followed by MC, MTC, C, EF, STF, HK and FR.

4.13.2. Risk Evaluation with Reference to the Risk and Safety Analysis Model Based upon F, A, I and NM Cases

The Risk score with reference to the risk and safety analysis model based upon fatality (F), accident (A), incident (I) and near miss (NM) cases was calculated by multiplying the likelihood and the severity. The severity level of the F, A, I, and NM cases for the years 2007, 2008, 2009 and 2010 was calculated by using the Multiple Regression Analysis (MRA) process using the Statistical Package of Social Sciences version 18.0 (SPSS 18.0). With the use of equations 3.9, 3.10, 3.11 and 3.12 and the MRA output as illustrated in section 3.4.2, the severity of each variable, .i.e., F, A, I and NM cases, was calculated. The severity calculation for F during the year 2007 is stated below:

$$S_F = \text{Un-standardized Co-efficient} + \beta_A(A) + \beta_I(I) + \beta_{NM}(NM) \qquad (3.9)$$

$$S_F = 0.729 + (-0.221)\,(47) + (0.142)\,(239) + (387)\,(-0.655)$$

$$S_F = -229.205$$

The equations developed for severity calculations were solved by using Microsoft Excel 2010 spreadsheets. A likelihood and risk score associated with each variable, .i.e. F, A, I and NM cases, was also calculated by using Microsoft Excel 2010 spreadsheets. The spreadsheets for the years 2007, 2008, 2009 and 2010 are attached in Appendix-C for reference. The likelihood of each variable for every year was calculated by dividing the particular variable occurrences with the total number of occurrences in that year.

The determined risk values for the F, A, I and NM cases were found to be negative in different years. These values were considered as modular values during the risk prioritization process. The summary of the Severity, Likelihood and Risk determination for the year 2007, 2008, 2009 and 2010 are presented in Table 4.27, Table 4.28, Table 4.29 and Table 4.30 below.

Table 4.27: Likelihood, Severity and Risk Score for the Year 2007 with Reference to Risk and Safety Analysis Model Based upon F, A, I and NM Cases

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	F	1	0.00	-229.426	-0.340
2	A	47	0.07	-113.606	-7.9220
3	I	239	0.35	344.021	121.989
4	NM	387	0.57	174.541	100.218
	Total	674			

Table 4.27 presents the results of the likelihood, severity and risk scores for the year 2007 with reference to the risk and safety analysis model based upon the F, A, I and NM cases. During the 6 month data collection period for the year 2007, a total number of 674 HSE non-compliances were recorded. The number of highest cases was recorded due to near miss cases with a likelihood value of 0.57 but the severity of the NM cases was calculated as 174.541. Near Miss cases also got the second highest risk score value was 100.218. The highest risk score calculated belonged to the incident cases with a value of 121.989.

Table 4.28: Likelihood, Severity and Risk Score for the Year 2008 with Reference to Risk and Safety Analysis Model Based upon F, A, I and NM Cases

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	F	5	0.00	-109.384	-0.454
2	A	90	0.07	-75.221	-5.627
3	I	352	0.29	561.618	164.330
4	NM	756	0.63	278.886	175.260
	Total	1203			

The likelihood, severity and risk scores for the year 2008 with reference to the risk and safety analysis model based upon the F, A, I and NM cases are depicted in Table 4.28. The risk score for the incident and near miss cases can be observed as significant. The highest risk score, 175.260, was calculated for near miss cases followed by incident cases with the risk score value of 164.330.

Table 4.29: Likelihood, Severity and Risk Score for the Year 2009 with Reference to Risk and Safety Analysis Model Based upon F, A, I and NM Cases

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	F	1	0.00	-293.622	-0.325
2	A	101	0.11	-11.18	-1.2518
3	I	238	0.26	503.983	132.979
4	NM	562	0.62	202.27	126.026
	Total	902			

Table 4.29 presents the results of the likelihood, severity and risk scores for the year 2009 with reference to the risk and safety analysis model based upon the F, A, I and NM cases. It can be observed that incident cases got the first highest risk score with a value of 132.979 and near miss cases got the second highest risk score with a value of 126.026.

Table 4.30: Likelihood, Severity and Risk Score for the Year 2010 with Reference to Risk and Safety Analysis Model Based upon F, A, I and NM Cases

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	F	7	0.02	69.16	1.100
2	A	188	0.43	-46.522	-19.877
3	I	146	0.33	54.436	18.062
4	NM	99	0.23	151.013	33.977
	Total	440			

The results of the likelihood, severity and risk score values for the year 2010 with reference to the risk and safety analysis model based upon the F, A, I and NM cases are highlighted in Table 4.30. Similar to the year 2008, near miss cases got the first highest risk score, i.e., 33.977, followed by incident cases with a risk score value of 18.062.

Table 4.31: Risk Evaluation for the Year 2007, 2008, 2009 and 2010 with Reference to Risk and Safety Analysis Model Based upon F, A, I and NM Cases

No	2007	2008	2009	2010
1	R_I	R_{NM}	R_I	R_{NM}
2	R_{NM}	R_I	R_{NM}	R_I
3	R_F	R_F	R_A	R_F
4	R_A	R_A	R_F	R_A

The risk evaluation/ prioritization results for the years 2007, 2008, 2009 and 2010 are presented in Table 4.31. It can be observed in Table 4.31 that incident and near miss cases got either first or second top risk score values during the study period. During the years 2007 and 2009, incident cases got the highest risk score values while during the years 2008 and 2010, near miss cases got the highest risk score. Risk scores associated to occurrences of fatality cases got the third rank during the years 2007, 2008 and 2010; whereas, during the year 2009, fatality cases got the fourth highest risk value. Risk scores associated to accident cases got the fourth position during the years 2007, 2008 and 2010.

Where,

R_F	=	Risk score for Fatality Cases
R_A	=	Risk score for Accident Cases
R_I	=	Risk score for Incident Cases
R_{NM}	=	Risk score for Near Miss Cases

4.13.3. Risk Evaluation with Reference to Risk and Safety Analysis Model Based upon the Seasonal Occurrences of HCFs

The severity of each season .i.e. S1, S2, S3 and S4 for the year 2007, 2008, 2009 and 2010 was calculated using Multiple Regression Analysis (MRA) process using Statistical Package of Social Sciences version 18.0 (SPSS 18.0). The output of MRA for the year 2007, 2008, 2009 and 2010 are attached in Appendix-B. The severity of each of the season (S1, S2, S3 and S4) was calculated by substituting the unstandardized and standardized coefficients obtained from the MRA output into equations 3.13, 3.14, 3.15, 3.16, 3.17, 3.18 and 3.19 as mentioned in section 3.4.3, respectively. The severity calculation for S1 for the year 2007 is described below;

$$S_{S1} = \text{Un-standardized Co-efficient} + \beta_{S3}\,(S3) + \beta_{S4}\,(S4) \qquad (3.13)$$

$$S_{S1} = 0.921 + 0.377(160) + (0.577)\,(363)$$

$$S_{S1} = 264.292$$

The likelihood of each of the season for each year was calculated by dividing particular seasonal occurrences with the total numbers of occurrences in that year. The risk was then calculated by multiplying the severity with the likelihood of each of the season. The results for the calculation for severity, likelihood and risk for the year 2007, 2008, 2009 and 2010 are attached in Appendix-C for reference.

The summary of Severity, Likelihood and Risk values for the year 2007, 2008, 2009 and 2010 are presented in Table 4.32 Table 4.33 Table 4.34 and Table 4.35 below.

Table 4.32: Likelihood, Severity and Risk Score for the year 2007 with Reference to Risk and Safety Analysis Model Based upon Seasonal Distribution of HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	S1	151	0.22	264.292	59.210
2	S3	160	0.24	245.239	58.217
3	S4	363	0.54	151.739	81.722
		674			

Table 4.32 shows the likelihood, severity and risk scores for the year 2007. It can be viewed that in S1, a highest severity value 264.292 was recorded with risk score of 59.2108. In season S3, and S4 the severity and risk score got second and third ranking.

Table 4.33: Likelihood, Severity and Risk Score for the year 2008 with Reference to Risk and Safety Analysis Model Based upon Seasonal Distribution of HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	S1	448	0.37	251.742	93.75
2	S2	153	0.13	358.441	45.59
3	S3	305	0.25	391.876	99.35
4	S4	297	0.25	156.393	38.61
	Total	1,203			

Likelihood, severity and risk score values for the year 2008 shown in Table 4.33. It can be noticed that S3 got the highest risk score with a value of 99.35. The season S2 got third highest risk value with second highest risk value during the year.

Table 4.34: Likelihood, Severity and Risk Score for the year 2009 with Reference to Risk and Safety Analysis Model Based upon Seasonal Distribution of HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	S1	480	0.53	210.816	112.186
2	S2	185	0.21	302.66	62.0755
3	S3	108	0.12	-36.691	-4.3932
4	S4	129	0.14	239.465	34.25
	Total	902			

A Table 4.34 shows the results of risk score for the year 2009. A severity and risk flow pattern can be observed from Table 4.34. The severity flow recorded with respect to seasons was S2, S4, S1 and S3 whereas, risk ranking pattern with reference to seasons were S1, S2, S4 and S3 can be noticed from Table 4.34. It can be concluded that it is possible that severity of HSE non-compliance of any season may be higher but its risk score can be lower.

Table 4.35: Likelihood, Severity and Risk Score for the year 2010 with Reference to Risk and Safety Analysis Model Based upon Seasonal Distribution of HCFs

No	Variable	Total number of Occurrences	Likelihood	Severity	Risk
1	S1	5	0.45	161.634	72.133
2	S2	165	0.28	91.891	25.442
3	S3	49	0.11	26.006	7.773
4	S4	41	0.17	43.215	7.22
	Total	437			

Risk scores for the year 2010 for HCFs on seasonal basis is shown in Table 4.35. The highest and lowest risk score were calculated for S1 and S4 with a value of 72.133, and 7.22, respectively.

Table 4.36: Risk Evaluation with Reference to Risk and Safety Analysis Model Based upon Seasonal Distribution of HCFs for the year 2007, 2008, 2009 and 2010

Rank No	2007	2008	2009	2010
1	R_{S4}	R_{S3}	R_{S1}	R_{S1}
2	R_{S1}	R_{S1}	R_{S2}	R_{S2}
3	R_{S3}	R_{S2}	R_{S4}	R_{S3}
4		R_{S4}	R_{S3}	R_{S4}

Whereas,

R_{S1} = Risk score for Season S1

R_{S2} = Risk score for Season S2

R_{S3} = Risk score for Season S3

R_{S4} = Risk score for Season S4

The results of risk and safety analysis model based upon seasonal occurrences of HCFs are presented in Table 4.36. Similar results in risk flow pattern were observed during the year 2009 and 2010. In year 2008 the risk associated to S4 got first ranking although the risk flow in S1, S2 and S3 follows consecutive flow pattern. The risk flow pattern for the year 2007 was not found similar to the risk flow for the year 2008, 2009 and 2010. It was due to unavailability of twelve months data that was leads to unequal distribution of HSE non-compliance during the year. The calculated values for likelihood, severity and risk scores for the years 2007, 2008, 2009 and 2010 were calculated different in different periods. It was due to variation in HSE non-compliances during the years.

4.14. Validation for Safety and Risk Analysis Model Developed Based upon Seasonal Occurrences of HCFs

The risk and safety analysis model developed by using multiple regression analysis process was tested by developing severity equations for the year 2009. The unstandized and standardized co-efficient for the year 2009 was used and equations for the four seasons of the year was developed. The equations were;

S_{S1} = 6.902 + (-0.811) (S3) + (0.338) (S4) + (1.34) (S2) (4.1)

S_{S2} = 0.023 + (0.533) (S3) + (0.017) (S4) + (0.506) (S1) (4.2)

S_{S3} = 2.089 + (-0.607) (S1) + (1.055) (S2) + (0.455) (S4) (4.3)

S_{S4} = (-4.747) + (0.351) (S1) + (0.048) (S2) + (0.619) (S3) (4.4)

4.14.1. Validation of Risk and Safety Analysis Model with Reference to the Year 2010

The data for the year 2010 was analyzed by using equation 4.1, 4.2, 4.3 and 4.4. A severity value for respective seasons for the year 2010 was calculated as below;

S_{S1} = 6.902 + (-0.811) (46) + (0.338) (70) + (1.34) (116)

S_{S1} = 148.696

R_{S1} = (187/419)*148.696 = 66.363

S_{S2} = 0.023 + (0.533) (46) + (0.017) (70) + (0.506) (187)

S_{S2} = 120.353

R_{S2} = (116/419)*120.353 = 33.319

S_{S3} = 2.089 + (-0.607) (187) + (1.055) (116) + (0.455) (70)

S_{S3} = 42.81

R_{S3} = (46/419)*42.81 = 4.699

S_{S4} = (-4.747) + (0.351) (187) + (0.048) (116) + (0.619) (46)

S_{S4} = 94.932

R_{S4} = (70/419)*94.932 = 15.859

Table 4.37: Comparison of Risk Score for the Year 2010 by using Generalized Model Equations and Actual Regression Equations

Rank No	Year 2010 Actual Risk Flow Pattern	Year 2010 predicted risk flow pattern by using generalized model equations
1	R_{S1}	R_{S1}
2	R_{S2}	R_{S2}
3	R_{S3}	R_{S4}
4	R_{S4}	R_{S3}

A similar risk score results with reference to year 2010 by using generalized severity equations and actual multiple regression equations can be observed from

Table 4.37. It shows successful application of four models that developed by using year 2009 data on year 2010 data.

4.14.2. Validation of Risk and Safety Analysis Model with Reference to the Year 2008

The further validation of generalized model equations was carried out by using year 2008 data. In generalized model equations 4.1, 4.2, 4.3 and 4.4 as described above, the year 2008 data was tested and compared with the actual results. The application of generalized model equations is described below;

$S_{S1} = 6.902 + (-0.811)\ (S3) + (0.338)\ (S4) + (1.34)\ (S2)$

$S_{S1} = 6.902 + (-0.811)\ (305) + (0.338)\ (297) + (1.34)\ (153)$

$S_{S1} = 64.953$

$R_{S1} = (448/1203)*64.953 = 24.188$

$S_{S2} = 0.023 + (0.533)\ (S3) + (0.017)\ (S4) + (0.506)\ (S1)$

$S_{S2} = 0.023 + (0.533)\ (305) + (0.017)\ (297) + (0.506)\ (448)$

$S_{S2} = 394.32$

$R_{S2} = (153/1203)*394.32 = 50.158$

$S_{S3} = 2.089 + (-0.607)\ (S1) + (1.055)\ (S2) + (0.455)\ (S4)$

$S_{S3} = 2.089 + (-0.607)\ (448) + (1.055)\ (153) + (0.455)\ (297)$

$S_{S3} = 26.703$

$R_{S3} = (305/1203)*26.703 = 6.77$

$S_{S4} = (-4.747) + (0.351)\ (S1) + (0.048)\ (S2) + (0.619)\ (S3)$

$S_{S4} = (-4.747) + (0.351)\ (448) + (0.048)\ (153) + (0.619)\ (305)$

$S_{S4} = 348.64$

$R_{S4} = (297/1203)*384.64 = 86.073$

Table 4.38: Comparison of Risk Score for the Year 2008 by using Generalized Model Equations and Actual Regression Equations

Rank No	Year 2008 Actual Risk Flow Pattern	Year 2008 predicted risk flow pattern by using generalized model equations
1	R_{S3}	R_{S4}
2	R_{S1}	R_{S1}
3	R_{S2}	R_{S2}
4	R_{S4}	R_{S3}

A Table 4.38 shows the comparison of risk score for the year 2008 and calculated risk flow pattern by using generalized model equations. Similar results in each season of the year can be observed. It shows the validation of generalized model equations on year 2008 data. Therefore, for calculation of severity of respective season in any season of the year the proposed severity equations 4.1, 4.2, 4.3 and 4.4 as mentioned above can be used successfully.

4.15. Mitigation Strategies Results and Discussion

Mitigation strategies are a set of training programs, refresher courses, safety talks, safety alerts and lessons learned. During the application of checking and review process, the mitigation strategies prepared were communicated to the employees through emails, publications, brochures and posters. The titles of the mitigation strategies that were prepared and implemented during the operation and maintenance of the PFS's are tabulated in Table 4.39.

Table 4.39: Mitigation Strategies Applied during Operation and Maintenance of PFS

No	Title	No	Title	No	Title
1	Seat Belts	19	Driver and Vehicle Safety	37	Hard Hat Maintenance (Safety Helmet)
2	During an Earthquake	20	Motorcycle Safety	38	HSE at Home
3	Noise Pollution	21	Tips for Better Driving	39	Microwave Ovens (Safe Use)
4	Use of Drinking Water	22	Fuel Conserving Tips	40	Slips and Trips (floor cleaning)
5	Health Hazards of Osteoarthritis	23	Fire Safety at Workplace	41	Swine Flu
6	Hazards of Carbon Monoxide gas	24	Tips to Prevent Food Poisoning	42	Be-Aware: LPG Decanting
7	CNG Safety	25	Tips to Understand Safety Signs	43	Cell Phone Hazards
8	Global Warming	26	Electrical Safety	44	Portable Generator- Storage & Shifting
9	Safety for CNG Vehicles	27	Water and Soil Pollution	45	Computer Fire Safety
10	Bird Flu	28	Prevention of Back Strain	46	Safety Measures in Fog
11	Road Safety	29	Diesel Engine Emission	47	Safety Tips for Driving
12	Workplace Safety Rules	30	Heat Stress	48	Road Safety Tips
13	Need for Water Conservation	31	Workplace Eye Safety	49	Snakebite
14	Fire Extinguisher use & Safety Tips	32	Dengue Fever	50	Hazards of Water Pollution
15	Legionnaires Disease	33	Safe Lifting Techniques	51	Ten "Steps" to Stairway Safety
16	Mobile Manners	34	Basic Energy Saving Tips	52	Sun Safety
17	Stress Management	35	Ladder Safety Tips	53	Chemical Handling
18	Driving in the Rain	36	Seating Ergonomics	54	Heart Attack

Table 4.39: (Cont'd) Mitigation Strategies Applied during Operation and Maintenance of PFS

No	Title	No	Title	No	Title
55	Staying Safe at the Pump	68	Smoking is a Serious Health Hazard	81	Psychological Health
56	Safety Tips for Computer Uses	69	Blind Spot	82	Housekeeping
57	Hazards of Chemical Products	70	Cough	83	Fossil Fuel & Environmental Impacts
58	Prevention of Cold Flue at Workplace	71	Global Warming	84	Tips for Preventing Back Injuries
59	Extra Care in Ramadan	72	Dehydration	85	Tips of Reducing Paper Waste at work
60	Healthy Brain	73	Driving in Fog		
61	Swine Influenza	74	Cell Phone can be Deadly		
62	Hand Hygiene	75	Prevention from Cold		
63	Using Gas Heater Safely	76	Asthama and Air Pollution		
64	Hazards Identification	77	Kitchen Safety		
65	Controlling Stress	78	Tips for good Foot Health		
66	Keep the Geyser's Thermostat at WARM	79	Safety Tips from (CO) during Travelling		
67	Electricity Breakdown & Generator Safety	80	How to detect Mosquito Spreading Dengue Viral Hemorrhagic Fever		

The reduction in HSE non-compliances were noticed with application of mitigation strategies. Table 4.40 illustrated the results of reduction in HSE non-compliances with application of mitigation strategies. During year 2009, in July, August and September, 226 HSE non-compliances were recorded. After application of mitigation strategies the reported HSE non-compliance cases were 163 cases.

Table 4.40: Reduction in HSE Non-Compliances with Application of Mitigation Strategies

No	Classification	HSE non-compliances before application of Mitigation Strategies	HSE non-compliances after application of Mitigation Strategies
1-	Maintenance	26	12
2-	House Keeping	7	2
3-	Mechanical Fault	4	0
4-	Electrical Fault	4	4
5-	Carelessness	183	143
6-	Miscellaneous	2	2
Total		226	163

Safety conscious companies make a near miss a big deal. Near misses are not funny; they are often deadly. Reporting of near misses may be encouraged in organizations. In the initial stage, for similar near miss cases, immediate action needs to be taken to prevent recurrences. Near misses can be considered as warnings that something or someone is not performing the job correctly. Those involved should not let near misses repeat themselves or they may find themselves or a co-worker being treated for an injury that could have been avoided.

4.16. Evaluation of Checking and Review Process for Petrol Filling Stations

The data collected from July 2007 to December 2008 was used for the development of checking and review process for petrol filling stations. The data collected for the years 2009 and 2010 was analyzed by using the developed checking and review process. A significant reduction in the occurrences of HCFs was noticed in each year.

Table 4.41shows the reduction in the occurrences of the HCFs in the years 2009 and 2010.

Table 4.41**:** Yearly Reductions in Occurrences of HCFs

Summary of Hazard Contributing Factors					
No	Classification	HSE Non-Compliances before application of Checking and Review Process		HSE Non-Compliances after application of Checking and Review Process	
		2007	2008	2009	2010
1	Housekeeping	54	55	42	5
2	Transportation Hazard	128	255	191	165
3	Slips, trips and falls	137	215	202	49
4	Carelessness	87	224	97	41
5	Fire Risks	7	17	16	39
6	Electrical Fault	34	97	69	18
7	Miscellaneous Cases	158	279	198	81
8	Medical Treatment Cases	69	61	87	39
	Total	674	1203	902	437

In the year 2007 during the 6 month data collection period, 674 HCFs were recorded. The number of HCFs recorded in the year 2008 was 1,203. With the application of the Checking and Review Process a noticeable reduction in the HCFs was recorded in the year 2009 and 2010. The number of HCFs recorded in the year 2009 was 902. For the year 2010, the reported HCFs were further reduced to 437.

The HSE non-compliances recorded during the 3.5 year data collection period were categorized on the basis to cause fatality, accident, incident and near miss cases. The proposed Checking and Review Process was applied during the years 2009 and 2010. Table 4.42 shows the results of the recorded fatality, accident, incident and near miss cases before and after application of Checking and Review Process for the years 2007, 2008, 2009 and 2010.

Table 4.42**:** Yearly Reduction in Occurrences of F, A, I and NM Cases

No	Summary of F, A, I and NM Cases				
	Classification	HSE Non-Compliances before application of Checking and Review Process		HSE Non-Compliances after application of Checking and Review Process	
		2007	2008	2009	2010
1-	Fatality	1	5	1	7
2-	Accident	47	90	101	188
3-	Incident	239	352	238	146
4-	Near Miss	387	756	562	99
	Total	674	1203	902	440

Overall, a significant reduction in the occurrences of unsafe acts and unsafe conditions can be observed in Table 4.42. The number of fatality cases increased to 4 in the year 2008 and decreased to 1 in the year 2009. However, in the year 2010, the number of fatality cases increased back to 4 cases. During the 3.5 year data collection period 14 fatality cases were reported. The noticeable increment pattern of accident occurrences can be viewed in Table 4.42. In the years 2007, 2008, 2009 and 2010, the accident cases recorded were 48, 91, 101 and 188, respectively. A significant incident and near miss reduction pattern can be observed in Table 4.42 during the years 2008, 2009 and 2010.

4.17. Safety Triangle for Petrol Filling Stations

A safety triangle for PFS's was developed by using the occurrences of fatality, accident, incident and near miss cases.

Table 4.43: Fatality, Accident, Incident & Near Miss Cases Occurrences and Weights for the Year 2007, 2008, 2009 and 2010

No	Description	2007	2008	2009	2010	Total
1	Fatality	1	5	1	7	14
2	Accident	47	90	101	188	426
3	Incident	239	352	238	146	975
4	Near Miss	387	756	562	99	1804
	Total	674	1203	902	440	3219
	Weight	20.94	37.37	28.02	13.67	

Table 4.43 shows the yearly number of fatality, accident, incident and near miss cases flow pattern. The weighted average of each variable, .i.e., fatality, accident, incident and near miss cases was calculated and a safety triangle for the PFS's was prepared.

The weight of each variable was calculated by dividing the respective year's column total value by the aggregate total. The calculation for each weight was carried out as described below:

Weight for the year 2007 = (674/3219)*100 = 20.93

Weight for the year 2008 = (1203/3219)*100 = 37.37

Weight for the year 2009 = (902/3219)*100 = 28.02

Weight for the year 2010 = (440/3219)*100 = 13.66

Calculated weights were assigned to each variable for that particular year and summed up to get the final result.

Table 4.44: Development of Safety Triangle for PFS

No	Description	2007	2008	2009	2010	Total	Approximate
1	Fatality	0.05	0.13	0.04	0.51	0.73	1
2	Accident	2.24	2.41	3.60	13.75	22	22
3	Incident	11.41	9.42	8.49	10.68	40	40
4	Near Miss	18.48	20.23	20.06	7.24	66	66

A Table 4.44 illustrating the calculated values after assigning associate weight to the variables. The variables values were calculated as follows,

Fatality year 2007 =	(1/20.94)	=	0.05	
Fatality year 2008 =	(5/37.37)	=	0.13	
Fatality year 2009 =	(1/28.02)	=	0.04	
Fatality year 2010 =	(7/13.67)	=	0.51	
Accident year 2007	=	(47/20.94)	=	0.05
Accident year 2008	=	(90/37.37)	=	2.41
Accident year 2009	=	(101/28.02)	=	3.60
Accident year 2010	=	(188/13.67)	=	13.75
Incident year 2007	=	(239/20.94)	=	11.41
Incident year 2008	=	(352/37.37)	=	9.41
Incident year 2009	=	(238/28.02)	=	8.49
Incident year 2010	=	(146/13.67)	=	10.68
Near Miss year 2007	=	(387/20.94)	=	18.48
Near Miss year 2008	=	(756/37.37)	=	20.23
Near Miss year 2009	=	(562/28.02)	=	20.05
Near Miss year 2010	=	(99/13.67)	=	7.24

In Table 4.44, it can be concluded that during the operation and maintenance of the PFS's, the occurrence of 1 fatality case is followed by 22 accidents, 40 incidents and 66 near miss cases. Figure 4.29 shows the pictorial representation of the safety triangle for the PFS's.

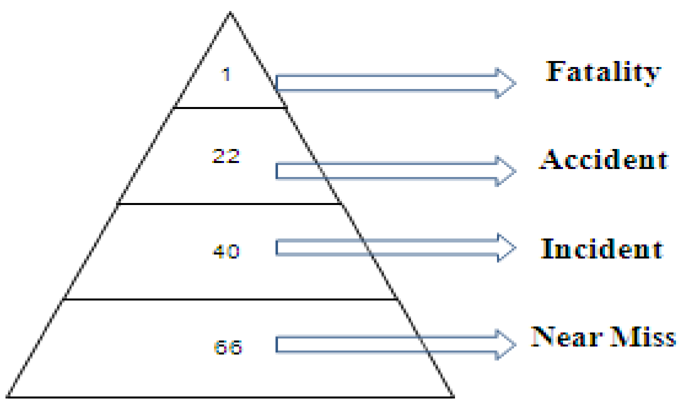

Figure 4.29: Safety Triangle for PFS

Figure 4.29 can be read in a reverse way. The numbers of near miss cases at the base of the triangle were of more significance. Each set of 66 near miss cases would result in the occurrence of 1 fatality case. Therefore, to minimize the occurrences of fatality, accident and near miss cases, consideration should be given to near miss cases reporting. Moreover, if these near miss cases can be controlled by the safety triangle, the situation will improve by itself. The flow pattern of the fatality, accident, incident and near miss cases with reference to the safety triangle for the PFS's was also in line with the studies conducted by [27, 59, 60]. Heinrich in 1995 proposed a relationship among major or lost time injury, minor injury and no injury accident cases as 1:29:300. Bird in 1969 developed a relationship among the serious or disabling injury, minor injury, proper damage accidents and incidents with no visible injury or damage as 1:10:30 and 600. The Tye & Pearson study in 1974 introduced a ratio among fatality or serious injury, lost time injury, injury requiring first aid, property damage/accidents and near misses as 1:3:50:80:400. In all the three proposed theories and the safety triangle for the PFS's, near miss got the base position. These near misses are considered less important but, actually, they have a noticeable value. If the reporting of near misses cases is encouraged, the pyramid flow would be improved significantly.

4.18. Analytical Hierarchy Process (AHP) Evaluation Results

An AHP (analytical hierarchy process) was designed to solve decision making problems. It is a tool that combines qualitative and quantitative analysis and successfully implementation in many fields of health and safety [120]. The AHP application was described by [118] in detail. It was also highlighted by [121] that AHP developed by Saaty has become a popular approach and has been used in a broad variety of situations by various researchers. Furthermore, apart from the occupational health and safety discipline, the successful application of the AHP have been reported in marketing, economics, finance, public policy, education, medicine and sports. Moreover, AHP applications have been proven to be well tested and supportive in many other decision situations concerning evaluation and selection processes [122]. The AHP approach is helpful to address selection, evaluation, resource allocation, benchmarking, quality management, health care and strategic planning as well. The AHP provides an environment that creates simplicity and easiness in decision making process.

Table 4.45 illustrates the cumulative data related to the HSE non-compliances during the 3.5 years study period. The HSE non-compliances during the study period were categorized into eight variables. The first column contained the eight variables. These eight variables were Housekeeping (HK), Transportation Hazard (TH), Slips, trips and falls (STF), Carelessness (C), Fire Risks (FR), Electrical Fault (EF), Miscellaneous Cases (MC), and Medical Treatment Cases (MTC). The rest of the columns represents the duration in months from January to December. The data Table 4.45 consisted of a 6 month duration of data for the year 2007 from July to December and a three year duration covering the years 2008, 2009 and 2010.

By using the measurement scales in Table 3.1 and comparing each HCF to another, the original criteria matrix was composed. Table 4.46 gives a glimpse of the decision maker's judgment and preference of the criteria with pairwise comparisons.

Generally, for any pairwise comparison matrix, 1s have been placed down the diagonal from the upper left hand corner to the lower right hand corner then a comparison of the respective criteria is made. Considering Table 4.46, HK has a moderate importance with TH, therefore 3 has been placed in the intersection cell. STF has an extreme importance with HK, therefore 9 has been placed in the intersection of HK in the first row. By applying the same method all the rest of the cells were filled. Since comparing row 1, the other can similarly be compared. On the flip side of the diagonal, when TH was compared with HK it was 1/3 and so on.

Table 4.45: Cumulative Data Related to HSE Non-Compliances during 3.5 Years Study Period

No	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	HK	11	2	4	14	8	9	17	35	16	10	17	13	156
2	TH	68	43	57	54	47	39	84	85	74	70	50	68	739
3	STF	53	66	91	19	28	33	46	74	66	29	45	53	603
4	C	36	25	30	38	15	25	34	52	58	40	62	34	449
5	FR	8	8	5	18	3	3	4	8	4	9	4	5	79
6	EF	26	8	25	11	8	18	23	17	24	21	22	15	218
7	MC	45	63	51	48	32	40	83	72	87	56	83	56	716
8	MTC	18	10	33	13	9	10	29	27	19	28	30	30	256
	Total	265	225	296	215	150	177	320	370	348	263	313	274	3216

Table 4.46: Original Criteria Matrix

	HK	TH	STF	C	FR	EF	MC	MTC
HK	1.00	3.00	9.00	7.00	9.00	3.00	5.00	3.00
TH	0.33	1.00	3.00	5.00	5.00	3.00	5.00	7.00
STF	0.11	0.33	1.00	7.00	3.00	3.00	5.00	7.00
C	0.14	0.20	0.14	1.00	5.00	3.00	5.00	7.00
FR	0.11	0.20	0.33	0.20	1.00	7.00	5.00	5.00
EF	0.33	0.33	0.33	0.33	0.14	1.00	3.00	7.00
MC	0.20	0.20	0.20	0.20	0.20	0.33	1.00	5.00
MTC	0.33	0.14	0.14	0.14	0.20	0.14	0.20	1.00
Total	2.57	5.41	14.15	20.88	23.54	20.48	29.20	42.00

Once these comparisons had been made, the data were used to determine the weights of the criteria; the process, as was summarized before, was in three steps: calculating the total of each column, dividing each value obtained by its column total, and calculating the averages of the rows. Table 4.47 depicts the final results and it illustrates the weights for each HCF.

The last column in Table 4.47 includes the weights of all the eight involved HCFs in this process. It shows that the final weights of Housekeeping (HK), Transportation Hazard (TH), Slips, trips and falls (STF), Carelessness (C), Fire Risks (FR), Electrical Faults (EF), Miscellaneous Cases (MC), and Medical Treatment Cases (MTC) were 0.34, 0.18, 0.14, 0.11, 0.10, 0.07, 0.04 and 0.03.

Table 4.47: Normalized Criteria Matrix

	HK	TH	STF	C	FR	EF	MC	MTC	**Weights**
HK	0.39	0.55	0.64	0.34	0.38	0.15	0.17	0.07	0.34
TH	0.13	0.18	0.21	0.24	0.21	0.15	0.17	0.17	0.18
STF	0.04	0.06	0.07	0.34	0.13	0.15	0.17	0.17	0.14
C	0.06	0.04	0.01	0.05	0.21	0.15	0.17	0.17	0.11
FR	0.04	0.04	0.02	0.01	0.04	0.34	0.17	0.12	0.10
EF	0.13	0.06	0.02	0.02	0.01	0.05	0.10	0.17	0.07
MC	0.08	0.04	0.01	0.01	0.01	0.02	0.03	0.12	0.04
MTC	0.13	0.03	0.01	0.01	0.01	0.01	0.01	0.02	0.03
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

4.19. Forecasting of Hazards for the Years 2011, 2012 and 2013

Forecasting is an important aspect to predict the HSE non-compliances that may occur in the future. Normally, past years' data are used to predict the future hazard occurrences. In a similar way to predict the upcoming HSE non-compliances during the operation and maintenance of the petrol filling stations, the 3.5 year study data was used. The occurrences of fatality, accident, incident and near miss cases were predicted.

Table 4.48: Summary of Actual Fatality, Accident, Incident and Near Miss Cases Occurrences during 3.5 Years Study Period

No	Period	Fatality	Accident	Incident	Near Miss
1	2007	1	47	239	387
2	2008	5	90	352	756
3	2009	1	101	238	562
4	2010	7	188	146	99

Table 4.48 illustrates the number of fatality, accident, incident and near miss cases that was reported during the data collection period. An exponential smoothing method was used and the number of fatality, accident, incident and near miss cases for the years 2011, 2012 and 2013 was forecasted. The values were forecasted by using

equation 3.20 described in section 3.12. The exponential smoothing constant (α) values were used as 0.6 and 0.4 with the forecasted and actual values, respectively. The forecasted values for each year from 2007 to 2013 were calculated and compared. The forecasted value for the year 2007 was calculated by taking the average of the number of fatality cases reported in the years 2007, 2008 and 2009. Therefore, the forecasted numbers of the fatality cases for the year 2007 were:

$$F_{(2007)} = (1+5+1)/3 = 2.33$$

The calculation for forecasted values for fatality cases was determined as;

$$F_{(2008)} = 0.4\ F_{(2007)} + 0.6\ A_{(2007)}$$

$$F_{(2008)} = 0.4\ (1) + 0.6\ (2.33)$$

$$F_{(2008)} = 1.798$$

The forecasted values for each HCF was determined in a similar way as described above and are presented in Tabular form in Table 4.49.

Table 4.49: Summary of Forecasted Values for Fatality, Accident, Incident and Near Miss Cases for the Year 2011, 2012 and 2013

No	Period	Fatality	Accident	Incident	Near Miss
1	2011	5	127	223	391
2	2012	4	127	224	414
3	2013	4	136	212	367

Table 4.49 depicts the predicting values for fatality, accident, incident and near miss cases for the years 2011, 2012 and 2013. It can be observed in Table 4.49, that similar to past years the frequency for occurrences of near miss cases were still higher as compared to accident and incident cases. The chances for occurrences of fatalities still exist. Therefore, HSE professionals with the management committee should take preventive measures and closely monitor the HSE management system at all PFS's. Accident and incident case prediction is also noticed to be higher. Therefore, close monitoring is also required to reduce occurrences of accident and incident cases.

4.19.1. Comparison between Forecasted and Actual Values for Fatality, Accident, Incident and Near Miss Cases

The actual data for the year 2011 was requested from the Company. Reported fatality cases were 6, accident cases were 160, incident cases were 210 and near miss cases were 350. Percentage variation between actual and forecasted values was calculated. The results of %age variation are presented in Table 4.50.

Table 4.50: %age Variation of Fatality Cases Occurrences

S. No	Period	Actual	Forecasted	%age Variation
1	2007	1		
2-	2008	5	2	+60.0%
3-	2009	1	3	-66.67%
4-	2010	7	3	+57.14%
5-	2011	6	5	+16.66%

Table 4.51 shows the %age variation of fatality cases occurrences. It can be observed from Table 4.51 that during the year 2008 its 60.0% higher as compared to actual values. Whereas, as for the year 2009 the forecasted values were 66.67% higher as compared to actual values. During the year 2011, the forecasted fatality cases were 5, whereas the actual cases reported were 6. The variation of only 16.66% can be noticed among actual and forecasted values.

The Table 4.51,

Table 4.52 and Table 4.53 shows the %age variation of accident, incident and near miss cases.

Table 4.51: %age Variation of Accident Cases Occurrences

S. No	Period	Actual	Forecasted	%age Variation
1	2007	47		
2-	2008	90	67	+25.55%
3-	2009	101	76	+24.75%
4-	2010	188	86	+54.25%
5-	2011	160	127	+20.62%

Table 4.52: %age Variation of Incident Cases Occurrences

S. No	Period	Actual	Forecasted	%age Variation
1	2007	239		
2-	2008	352	262	+25.58%
3-	2009	238	298	-25.21%
4-	2010	146	274	-87.67%
5-	2011	210	223	-6.19%

Table 4.53: %age Variation of Near Miss Cases Occurrences

S. No	Period	Actual	Forecasted	%age Variation
1	2007	387		
2-	2008	756	496	+34.39%
3-	2009	562	600	-6.76%
4-	2010	99	585	+490.25%
5-	2011	350	391	+20.62%

Minor %age variations in actual values and forecasted values can be observed among accident, incident and near miss cases in Table 4.51, Table 4.52 and Table 4.53. It shows the successful application of forecasting approach to predict the occurrences of upcoming fatality, accident, incident and near miss cases. It is helpful to the safety professionals to have an idea that how many upcoming hazards can be occurred in the future so that they can take preventive and corrective action to avoid their occurrences.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1. Introduction

This chapter presents and discusses the major concepts and progress that this research intends to achieve. Moreover, some recommendations that might be done as expected works for further improvement and better results are explained.

5.2. Conclusion

The HSE non-compliances were recorded during the operation and maintenance of petrol filling stations (PFS). 3.5 years data related to HSE non-compliances was recorded. The HSE non-compliances were categorized into two main classifications. These were, those based upon hazard contributing factors (HCFs) and occurrences of incidents [fatalities, accidents, incidents and near miss cases]. HCFs were identified as the root causes for occurrences of fatalities, accidents, incidents and near miss cases. With reference to first classification, HSE non-compliances were categorized further into eight HCFs; these were housekeeping (HK), transportation hazards (TH), slips, trips and falls (STF), carelessness (C), fire risks (FR), electrical faults (EF), miscellaneous cases (MC) (Oil spillages, water leakages, snakebite cases, minor damages, maintenance issues, robbery, theft, natural disasters/wind storms, law and order situations) and medical treatment cases (MTC). These two classification systems introduce a new systematic approach for HSE non-compliance categorization.

Both classification systems were further extended to monthly, quarterly and seasonal distribution of hazards. The monthly and quarterly form of classification was chosen by keeping in consideration that normally in organizations, HSE committee meetings organized on a monthly and quarterly basis. By showing the results of the classifications to management committee, the safety professionals can highlight the potential accident causes and discuss the preventive actions that can be taken. With reference to the seasonal distribution of the hazards, the long term safety measures can be taken. The three ways of the classification system are viably important to achieve HSE objectives and targets at every PFS. The seasonal way of classification is also helpful to implement a study on a large scale in any country. It was found that normally the HSE department in any industrial sector has a lot of data and it may difficult for the HSE professional to extract useful information. By using the seasonal way of classification, the HSE professionals focus on particular hazards during that specific season and come up with remedial measures. The same approach can be adopted for the monthly and quarterly classification systems.

The potential accident root causes were identified as HCFs and were discussed in detail. It was felt that if the occurrences of HCFs can be minimized, then the occurrences of fatalities, accidents, incidents and near miss cases may be reduced significantly. The PFS business requires an extensive use of tank lorries and road network systems. Most of the accidents that were reported, occurred during the transportation of fuel through tank lorries from oil storage depots to the PFS. The accidents happened due to three main factors. These were the negligence of the driver, inappropriate maintenance of the tank lorries and unsatisfactory conditions of road/highway. The negligence of the drivers could be minimized by organizing defensive driving training programs and awareness sessions. Refresher courses for tank lorry drivers after every six month period were felt to be necessary. Past accident/incident findings should be discussed to avoid re-occurrences. Detailed investigations to find the root causes of road/highway accidents and record keeping will also lead to accident reduction in the future. A scheduled inspection and maintenance of tank lorries by designated and certified dealers enhance the conditions of tank lorries and would be highly effective in minimizing accidents. Improving the road/highway conditions is beyond the control of the company but the accidents related to this aspect can be reduced by describing to drivers about the road/highway configurations, conditions and dangers related to that particular section. In that way, drivers can take extra safety measures and drive carefully during fuel transportation along that portion of the road/highway. The training of the contractor's staff members should be carried out if the fuel transportation network is being taking care of by the contractors as well. It was also noticed that with tank lorries monitoring during fuel transportation was also helpful to avoid accidents; therefore, tank lorries satellite tracking monitoring can be used. Other contributing factors such as housekeeping (HK), slips, trips and falls (STF), carelessness (C), fire risks (FR), electrical faults (EF), miscellaneous cases (MC), and medical treatment cases (MTC) can be minimized by organizing worker's training and awareness sessions and PFS facility infrastructure improvement.

The risk and safety analysis models were prepared by using two proposed classification systems. The risk and safety analysis model prepared by using monthly classification of hazard contributing factors and occurrences of fatality, accident, incident and near miss cases. The results compared and some variations were recorded. It was due to noticeable fluctuations in occurrences of HSE non-compliances on monthly basis. To overcome this difficulty a seasonal classification of hazards contributing factors was used and new risk and safety analysis model was prepared and validated. It was found very successful to evaluate and prioritize the hazards associated during operation and maintenance of PFS. The models were developed by using multiple regression analysis (MRA) method. The MRA was performed by using statistical package of social sciences version (18.0). The proposed risk analysis model reduce the chances of errors that normally occur during risk evaluation process and may leads to wrong judgment and hazard ranking. The risk analysis by using proposed risk and safety analysis model incorporates all hazards during risk assessment and come up with accurate risk ranking of hazards pertaining to the workplace.

A simplified checking and review process framework based upon HSE non-compliances was developed and proposed for implementation during this study period. It can be seen from the results that implementation of the checking and review process was found to be successful in reducing the occurrences of HSE non-compliances during the operation and maintenance of PFS. It consisted of seven steps that can be performed within an organizational set up without additional resources.

Different statistical tools such as the analytical hierarchy process (AHP) and exponential smoothing methods were used to predict the HSE non-compliances that could occur in future. It provides guidance and helps to HSE professionals to take preventive necessary measures to protect the workplace. It will lead to a noticeable reduction in occurrences of fatalities, accidents, incidents and near miss cases and helps to improve the overall safety statistics.

There were a few problems faced during the data collection phase from the PFS. As the PFS's monitored were located in different areas, the data was collected with the help of different people. Some of them were responsible for other work assignments in addition to data collection pertaining to HSE non-compliances at PFss. A briefing and detailed description of the project study was provided to all the focal persons. But still, due to the performance of other duties by the focal persons, the data collection frequency was affected. More data could be collected if the focal persons were only responsible to perform tasks related to safety duties at PFS. It may lead to taking more comprehensive safety management measures to raise the safety standards at PFS's.

5.3. Recommendations for Future Research

This research work has several future directions that might be followed. The following points address a few future directions for further related research work:

- The proposed system for the HSE non-compliance classification, risk and safety analysis model development, analytical hierarchy process and exponential smoothing may be employed in other industrial sectors.
- With the availability of data from other industrial sectors a safety triangle can be developed with the use of the proposed methodology for PFS. It enables safety professionals to see the flow of fatalities, accidents, incidents and near miss occurrences.
- For future work, the possible construction of facilities such as shopping arcades, office buildings and multilevel car parking areas with a change in the roof design is recommended. Normally flat roof is designed for PFS. With the elimination of hazards associated with PFS's and roof design modifications, the multilevel construction can be performed. As PFS's are located within urban areas and the property value in urban areas is normally high, if a multilevel construction can be made than the space can be utilized in a better way with revenue generation.

- Underground storage tanks (UGSTs) are considered to be the main source of hazard at PFS's. If they can be shifted away from the PFS's and connected to the retail outlet via piping than it would be very helpful to reduce the major source of hazards as well as it encourage the utilization of space in a better way. It is also possible that UGSTs could be mutually shared by other PFS located in the close vicinity as a fuel supply source. A further research work in the future could be carried out to address the appropriate location of UGSTs and the possibility mutual sharing.
- The close monitoring of outside vehicles that are arriving for taking fuel at PFS was felt. It has the possibility that vehicle may contains hazardous/flammable material. With minor negligence any catastrophic event may occur.

5.4. Limitations of Research

There are 3 main stages of work in which hazardous events may occur at PFSs. These are the preliminary stage, the development and construction stage and the operation & maintenance stage. The probability and severity of hazards at every stage are unique. This study focuses on occurrences of hazardous events during the operation and maintenance stage at the PFS. The data for the study was collected from one the biggest Petrol Filling Station's operating Company in Pakistan. The company is operating various PFS's around the country. The data was collected from more than 2500 PFS's. The data was consisted of 3.5 years of duration (from July 2007 to December 2010). HSE representatives at PFS's were trained to collect data. At those PFS's where dedicated HSE representative was not available, focal persons were assigned to record observations pertaining to HSE Non-Compliances.

5.5. Summary of Research Contribution

The main contributions of this research are illustrated in the following points;

- The proposed study highlights the HSE non-compliances that occurred during operation and maintenance of petrol filling stations. These HSE non-compliances may results in occurrences of catastrophic events. With application of this study the HSE non-compliances can be reduced and helpful to make petrol filling stations safer.

- Different ways of HSE non-compliances classifications proposed in this study. It includes monthly, quarterly and seasonal classifications. It is helpful to view collected data from different perspectives and target the most hazardous period so that remedial measures can be taken to avoid future recurrences.
- Statistical tools such as test of correlation, multiple regression analysis, analytical hierarchy process (AHP) and exponential smoothing method that is seldom being used by the safety professionals introduces a new approach in analysis of data. The use of these methods plays vital role in the analysis of specific hazard, period of occurrences and the needed appropriate control measures. Ultimately, it leads to improve in safety records and reduction in occurrences of HSE non-compliances.
- Gaps identified in existing risk assessment methods. A new risk and safety analysis model was developed by using 3.5 year study data. The use of inappropriate risk assessment process just merely shifts the hazard. By using a proposed risk assessment model accurate risk assessment can be performed, hazards prioritized and control measures can be taken timely. It helps to eliminate hazard from the system and make work place safer.
- The development of safety triangle for petrol filling stations provides guidance about the flow pattern of occurrences of fatalities, accident, incident and near miss cases.
- The fatality, accident, incident and near miss cases forecasting approach highlighted in this study provide guidance to the safety professionals to use past years data and forecast the upcoming hazards that may arise at the facility. It helps safety professionals to plan future safety objectives and targets and significantly reduce the occurrences of fatality, accident, incident and near miss cases.