MASTER

Developing a health, safety and environment (HSE) management performance index

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Developing a Health, Safety and Environment (HSE) management performance index

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Executive Summary

The attention on the issues pertaining to occupational health, safety and environment has increased rapidly over the last decades due to the catastrophic incidents and increased awareness of green issues. Companies are obliged to manage Health Safety and Environment (HSE) better than ever. The main issue in HSE management is that the costs of it can be established easily, but the benefits are less tangible. The benefits of the HSE management should be measured and monitored because if 'you cannot measure it, you cannot manage it'. HSE performance indicators used in practice are not good enough to measure the performance because they are unreliable, inconsistent across each other, highly volatile, and there is little difference for the environmental indicators. This is mainly because HSE embodies a number of attributes that are both quantitative and qualitative which makes it extremely difficult to measure the benefits gained. Hence, the ambition of this thesis is to develop a model which attempts to quantify the benefits of HSE management.

The author was involved in a project which delivers complete HSE solutions to a client of Shell Global Solutions International, B.V. (SGS), is the consultancy business unit of Royal Dutch Shell BV. SGS used five approaches to show the importance of HSE management and to achieve the "buy-in" of the client.

- Increasing risk awareness
- Showing success stories and best-practices regarding HSE
- Learning from past accidents by showing devastating incidents
- Demonstrating the total cost of an incident
- Carrying out workshops to expose the client to the methodologies used by SGS

Interviews conducted with the people from the client company reveal that the approaches are not sufficiently persuasive. Hence, the primary focus of this study has become to realise a new framework to enable HSE experts to convince management teams by quantifying the benefits of HSE management. For this purpose a solution to the following questions was sought: 'What are the benefits of HSE management?', 'Is there a method to quantify HSE benefits?', 'How is HSE management performance measured?', 'What is the Business Case[1] of HSE?

A literature review has been conducted to find answers to the above-mentioned questions. It is divided into two sections. In the first section, the focus is the evolution of the HSE concept. and its attributes. In the second section, the methodologies used to justify HSE investments are investigated. It is concluded from the literature that there is neither a method that links the HSE performance to financial benefits, nor an indicator that demonstrates the overall HSE management performance. Hence, as an initial step in this domain the author primarily emphasised on *developing a well structured and systematic HSE management performance index* whilst keeping the idea of linking the cost to (the indexed) benefits of HSE management.

The concept of the HSE management can be characterised by means of measurable attributes. Therefore, Multi-attribute theory (MAT) has been utilised to develop the model. MAT is credited

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[1] **Business Case:** Justification of the net profit out of the investment

for an ability to provide a systematic approach and to combine tangible and intangible aspects of performance. Out of different methods of MAT, the Analytic Hierarchy Process (AHP) has been chosen because AHP enables simple comparison of attributes and consistency check. AHP is enhanced in combination with the deliberation technique to overcome the potential pitfalls mentioned in the literature and to yield more accurate results.

Data collection has been performed by using a panel of HSE experts working within SGS. The panel decided on the attributes of the value tree with the guidance of academic advisors associated with this research project. The developed value tree was approved to be valid by being judged against five criteria; completeness, operationality, decomposability, absence of redundancy and minimum size. Expert Choice® has been used in order to calculate the weighting factors, validate the model and conduct sensitivity analysis. Two case studies and sensitivity analyses were conducted so as to demonstrate the practical use of this model and the robustness of the weighting factors. The case studies reveal that the index model generates consistent results in line with the expectation of the experts and with the audit results of the subject plants. Furthermore, the index is more robust and sustainable than the indicators currently in use.

The model developed, provides a broad framework that allows both scholars and experts to quantify the overall HSE management performance of a plant or an organisation by means of an index. The index attempts to fill the intermediary gap that complicates the utilization of Cost – Benefit Analysis for HSE related issues. The index can be further used for practical purposes (1) to benchmark across peer-companies, (2) to track the overall HSE management performance, (3) to determine the most cost-effective way of managing HSE when the required data is collected. It is assumed that there is a link between the index and financial performance. This assumption should be addressed in future studies in order to complete the answer to the initial problem.

On the other hand, it should be noted that the index model has some limitations. It requires participation of more than one person and uses subjective idea. The weights and the attributes of the model are condition dependent. As the conditions change, the model may need revisions. Universal application of the model might be restricted because the weights are elicited with a group of people from Shell. But the approach to develop the model is generic and can be applicable to other cases.

Chapter 1: Introduction

Shell Global Solutions International, B.V. (SGS), is the consultancy business unit of Royal Dutch Shell BV. SGS provides business and operational consultancy, technical services and research and development expertise to the energy and processing industries worldwide. One of the sub-units of SGS is the HSE Consultancy whose aim is to help costumers find cost-effective and value added solutions to health, safety and environmental (HSE) challenges.

The author was involved in a project which delivers complete HSE solutions to a client company located in Turkey. This project consists of four refineries of the client company.

During the project a major challenge of the client engagement has been to justify spending on HSE to a company whose HSE performance and understanding is inferior to Shell's. According to Shell's own benchmarking, the client is a fourth quartile performer at the time of the thesis submission.

SGS considers HSE as the primary enabler to carry out operational excellence programs which cover more technical and operational issues due to the inherent focus on procedure and compliance that a strong HSE performance demands. However, the senior management team of the third party companies usually show interest in quick return benefits rather than projects that require long-term investment, commitment and leadership like HSE.

Hence, the problem was stated: SGS needs a tool or method that can be used to demonstrate the benefits of HSE in an effort to convince the senior (or board level) management to invest in HSE. It is the ambition of this thesis to solve this business problem.

1.1 Background Information (problem definition)

The author attended the SGS project in Turkey as a junior consultant with the HSE workstream. The objective of the team was to improve the HSE performance of the client company by means of implementing new elements or strengthening the existing but weak elements of an integrated HSE program (Health, Safety and Environment program). The initial phase of the project was the investigative Opportunity Confirmation Phase (OCP). The aim of this phase was not only to identify the areas regarding HSE that SGS can help the client improve but also expose the client to the tools and methodologies that SGS would bring in the course of implementation. Thus, SGS exploited this phase as a way to get the client on-board in the early stages of the project. SGS used five approaches to achieve the "buy-in" of the client.

- Risk awareness was the most prevailing methodology that SGS used. Consultants took pictures of the non-compliant (according to the international HSE standards and Shell's internal standards) conditions; explained the potential consequences unless the required precautions were taken; and further asked the client whether they were aware of these risks.
- Showing success stories and best-practices regarding HSE. Consultants presented improvement trends in the HSE related performance indicator, LTIF[2], over years.

[2] **LTIF**: Lost time incident frequency stands for the total number of incidents which result in loss time of more than 1 working day in 1 million working hours.

- Learning from the past accidents by showing devastating incidents that happened in the Shell history and in the industry (such as the Texas Refinery incident of BP) that resulted in major harms on people, asset, environment, and reputation was another way to convey the message of risk exposure. Consultants attempted to emphasize the hard way that Shell learned the importance of HSE.
- Demonstrating that the total cost of an incident in the petrochemical industry is usually underestimated in the practice due to hidden costs. Consultants made use of the empirical studies performed by big companies such as Marsh Risk Consulting [75] etc.
- Carrying out one-day workshops aimed at exposing the client to the methodologies and tools that are used in SGS.

Interviews were conducted with the people from the client company in order to evaluate how persuasive the methodologies used by SGS consultants were to demonstrate the importance of HSE and sustainability of the HSE management.

Despite the consultants having several years experience in the Industry, they found it difficult to convince the client that "(business) processes" and "systems" such as an HSE Management System can actually help improve HSE Performance (reduce incidents) and ultimately benefit the Business. People usually aspired to see and become aware of what kind of benefits the proposed system would bring rather than seek to understand what the current system was missing, Benefits drive the motivation to invest and improve and help stimulate and sustain leadership and commitment to HSE excellence. The conclusion of these interviews is that the disclosure and demonstration of state-of-the-art tools (methods) to be implemented are not sufficient to convince people. This is particularly true because people found it difficult to understand due to the discrepancy between the current system that the people get used to and the system proposed by the consultants. Consequently, showing the client the future way of working was less effective than expected.

Hence, the primary focus of this study has become to realise a new framework to enable HSE experts to convince management teams by quantifying the benefits of HSE management. For this purpose a solution to the following questions was sought: 'What are the benefits of HSE management?', 'Is there a method to quantify HSE benefits?', 'How is HSE management performance measured?', 'What is the Business Case[3] of HSE?

The literature review is divided into two sections. In the first section, the focus is the evolution of the HSE concept. This approach enables an in-depth understanding of HSE phenomenon. In the second section, the methodologies used to justify HSE investments are investigated.

In conclusion the literature failed to provide a precise method to dissolve the stated problems. In order to answer the above stated questions a methodology should be realised to link the HSE performance to financial benefits because typically management is interested in financial results as they are judged against financial performance by the markets. Unfortunately, neither literature nor current practice (to the extent which this study concerns) possesses an indicator that demonstrates the overall HSE performance. Hence, an initial step in this domain the author primarily emphasised on ***developing a well structured and systematic HSE management performance index*** whilst keeping the idea of linking the cost to benefits of HSE management.

The concept of the HSE management can be characterised by means of measurable attributes. Therefore, Multi-attribute theory (MAT) has been utilised to develop the model. MAT is credited in the literature for an ability to provide a systematic approach and to combine tangible and intangible aspects of performance. Out of different methods of MAT, the Analytic Hierarchy

[3] **Business Case:** Justification of the net profit out of the investment

Process (AHP) has been chosen because AHP enables simple comparison of attributes and consistency check. AHP is enhanced in combination with the deliberation technique to overcome the potential pitfalls mentioned in the literature and yield accurate results.

Data collection has been performed by using a panel of HSE consultants working within SGS. The panel decided on the attributes of the value tree with the guidance of academia associated with this research project. Expert Choice® has been used in order to calculate the weighting factors, validate the model and conduct sensitivity analysis. Two case studies and sensitivity analyses were conducted so as to demonstrate the practical use of this model and the robustness of the weighting factors.

Chapter 2: Literature Review

The literature review consists of two sections. The first section explains how the concept of HSE has evolved over the years; the second section focuses on methods used for the justification of HSE investments.

The first section carries a descriptive and a normative perspective that includes a survey of the state of the art in the field of HSE. A three-phase staged approach has been used to explain the current situation; that is, HSE standards, HSE management system and HSE culture.

The second section dwells on the cost and the benefits of HSE management. Current methodologies that are being used to justify HSE interventions are examined in two parts: cost benefit analysis and alternative investment justification. The research question emerges from this part of the literature review.

2.1 Evolution of HSE

HSE is a function within an enterprise that possesses procedures and appropriate measures to ensure that the processes remain contained in the process stream in an aim to prevent undesirable events due to the potential hazards of a hazardous material release or mitigate their impact on people, asset, environment and reputation.

The literature regarding HSE is extensive but fragmented. This is mainly because the attention on HSE has increased rapidly and unexpectedly. The main driver of learning in HSE has not been academic interest but rather a reaction to catastrophic incidents that occurred in real life. The industry has learned the importance of HSE via the hard way by making costly mistakes that resulted in painful accidents. Learning from these mistakes is restricted because the impact of an accident can be realised only in the long run. In addition, sociological and political changes (such as increased awareness of green issues and pressure to increase transparency) have triggered extra attention from the public and government on the issues related to HSE. Meanwhile, academia has contributed responsively to the changes happening in the real life. Since progress with regard to HSE has developed in parallel between academia and real life, the HSE evolution [1] experienced by Shell is used to explain the state of the art regarding HSE.

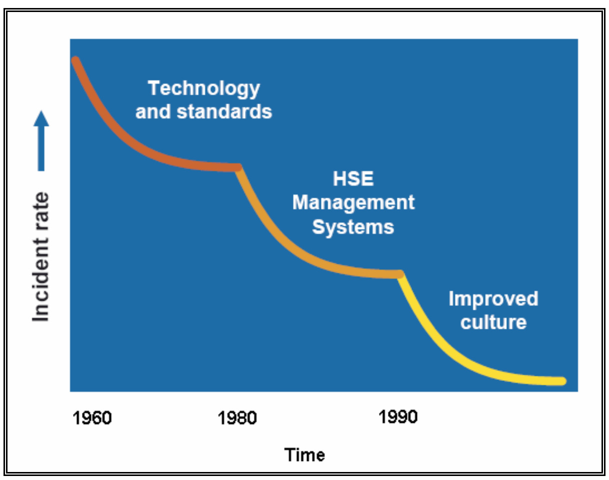

Figure 1: HSE evolution curve (extracted from [1])

HSE has passed through three major eras; namely, compliance with HSE standards, development of HSE management system, and cultivation of an HSE culture on and off the field or site (figure 1). Companies initially considered HSE as a set of mandatory standards imposed by the government. Upon realisation that compliance with standards alone does not provide a sustainable solution to incident prevention, companies developed a structured system to comply effectively and efficiently with HSE standards. Contrary to initial expectations, even after having put the standards in place by means of a structured methodology, the incidents did not stop; although there was a dramatic decrease in the number of incidents. In order to further reduce the number of incidents, the concept of 'HSE Culture' was invoked. 'HSE Culture' lies deeper within the organisation and it is difficult to observe.

2.1.1. HSE standards

HSE standards are examined in three parts; namely, how to form and issue standards, types of HSE standards, comparison of the existing HSE standards.

2.1.1.1. How to form and issue standards?

Before elaborating on the HSE standards the mechanism of standard formation functions should be explained. Three types of entities actively participate in the process of forming and issuing standards: regulatory agencies, trade or profession associations and corporations.

Regulatory HSE agencies are the upper-most level among the three entities. They are organised in one country or under a union. Some examples of regulatory HSE agencies are USA's OSHA, Great Britain's HS&E and Europe's European Agency for Safety and Health [2, 3, and 4]. Detailed information about these agencies can be found in Appendix – 1.

Each of these agencies shares a common mission, albeit distinctly expressed in their mission statements. Their objective is to ensure that the risks to people's health, safety and environment from work activities are properly controlled. To accomplish this mission, they:

- Commission research to provide advice and information
- Propose and enforce new laws and standards
- Licence and approve standards or directives

Trade associations and *profession associations* are the second type of entities. Trade associations are founded and funded by corporations that operate in a specific industry. Profession associations are founded by people who have the same profession and funded by the membership fee and industry related sponsors. Their purpose is generally to promote the industry through public relation (PR) activities such as advertising, education, political donations, lobbying, and publishing. Their main emphasis is collaboration between companies and standardization. Many associations are non-profit organizations governed by laws and directed by officers who are also members. Although there are hundreds of trade and profession associations functioning in different industries all over the world, research is focused on the three largest ones particularly dealing with the petro-chemical industry; namely, API (trade association), AIChE (profession association), CCPS (profession association) [5, 6, 7] (Appendix – 2). They participate in following activities:

- Identify and address HSE needs within the petroleum industries.
- Foster HSE in engineering and science education
- Promote HSE as a key core value in the industry
- Negotiate with regulatory agencies, represent the industry in legal proceedings, participate in coalitions and work in partnership with other associations to protect employees, communities and environment
- Conduct or sponsor research ranging from economic analyses to toxicological testing
- Collect, maintain and publish statistics and data on all aspects of industry operations
- Lead the development of petroleum and petrochemical equipment and operating standards, guidelines and good industry practices

- Organize seminars, workshops, conferences and symposia on public policy issues.

For the scope of this study, *corporations* that operate in the petro-chemical industry are selected. They are held accountable to comply with HSE laws and regulations imposed by regulatory agencies.

The formulation of the standards occurs as follows: trade associations collect information from corporations and transform the most serious ones into standards. These standards are endorsed by governmental agencies and imposed on to the corporations.

2.1.1.2. Types of HSE Standards

HSE standards are divided into two types; namely, prescriptive and performance based [8]. The former points out what measures the companies should take and how to do it based on the prior experiences. The latter attempt to describe what safety level is to be achieved but not in detail how to do it.

Performance based standards are more complete and emphasise the management system of companies. "Management system" refers to the organization's structure for managing its processes - or activities - that transform inputs of resources into a product or service which meet the organization's objectives, such as satisfying the customer's quality requirements, complying with regulations, or meeting environmental objectives [9]. Performance based standards have become superior to prescriptive standards over the last two decades. For the purpose of this study the performance based standards have been reviewed in detail. Namely, COMAH, ISO 14000, IEC 61508, Seveso Directive, RMP, PSM, OHSAS [9 - 15]. Detailed information about these standards can be found in appendix – 3.

2.1.1.3. Comparison of the HSE standards

Main elements of standards can be identified by comparing the processes of different standards in act. Table 1 illustrates the processes of the standards introduced in the previous section. Empty cells mean that the processes are covered under the associated standard.

Table 1: Comparison of the standards (extracted from [8])

Processes of the HSE programs	OSHA PSM	EPA RMP	ANSI/ISA S84.01	IEC 61508	SEVESO Directive
Process Safety Information			PART	PART	
Operating Procedures					
Training					
Mechanical Integrity					
Incident Investigation			NO	NO	
Compliance Audit					
Management of Change					
Pre-startup Review					
Contractor Program			NO	NO	
Employee Participation			NO	NO	
Trade Secrets		NO	NO	NO	
Hot Work Permits			NO	NO	
Emergency Response Program			NO	NO	
Process Hazards Analysis					
Consequence Analysis	NO				
Accident History			NO	NO	
Risk Assessment					
Risk Management					
Management Program			PART		
Life-Cycle Safety (design, installation, operation, maintenance, decommissioning)					PART

The literature [8] emphasizes that a complete and integrated HSE management program should include all of the processes listed on the left in table 1 (For the definition of these processes the reader may refer to appendix – 4.

2.1.2. HSE Management System (HSE-MS)

The importance of HSE-MS is emphasized both in the literature and HSE-MS has also become a widespread practice in all the global petro-chemical companies to the extent this study concerns. There are two major reasons why the HSE-MS has become so widespread:

(1) **The traditional way of compliance is no longer drives improved performance**. Enjoying a top class HSE performance requires a long-term corporate vision and a sustainable investment in HSE [8]. Therefore, companies consider compliance with the safety requirements as the bare minimum and do more than this in order to become the industry leader. In a highly competitive global market with varying economic forces, complying with several international standards is of great importance.

(2) **A structure is required** [16]. When it comes to implementation of the above-mentioned processes of the HSE management programs, corporations find it difficult to comply with several elements, most of which are overlapping and require similar tasks. Hence, a structure that enables a clear framework becomes vitally important.

The research reveals that HSE-MS should possess the elements as shown in the figure 2 [17]. This application is common in the examined global corporations [18 – 23]. (For further information the reader may refer to appendix – 5).

The elements demonstrate a consecutively functioning pattern that ensures continuity. After the vision is set and endorsed in the upper levels of the organisation, an action plan is prepared to identify which processes of HSE management program (table 1) should be implemented. Planning is performed by means of a risk based approach that is at the core of all HSE-MS. Then, the elements of the HSE-MS are implemented in accordance with the plan. The implementation of the elements is regularly monitored at the highest levels of the management. The last part of the continuous cycle is the collection of feedback from the organisation and necessary fine-tuning of the plan. This approach enables corporations to manage HSE as a continuous process rather than a terminated goal in a structured way.

HSEMS Element	Addressing
Leadership and commitment	*Top-down commitment and company culture, essential to the success of the system.*
Policy and strategic objectives	*Corporate intentions, principles of action and aspirations with respect to health, safety and environment.*
Organisation, resources and documentation	*Organisation of people, resources and documentation for sound HSE performance.*
Evaluation and risk management	*Identification and evaluation of HSE risks, for activities, products and services, and development of risk reduction measures.*
Planning	*Planning the conduct of work activities, including planning for changes and emergency response.*
Implementation and monitoring	*Performance and monitoring of activities, and how corrective action is to be taken when necessary.*
Auditing and reviewing	*Periodic assessments of system performance, effectiveness and fundamental suitability.*

Figure 2: The elements of HSE management system (extracted from [17])

The HSE-MS is integrated because environment, occupational health and safety elements are dealt with together. This yields a better efficiency and effectiveness since duplication of the tasks can be eliminated [24]. Moreover, an integrated approach helps to identify business risk issues with a holistic view that will ultimately increase the transparency of the successes and failures of an operation as a whole [25]. Literature supports integration of health, safety and environment aspects [26 – 42].

2.1.3. HSE Culture

HSE culture is explained in three parts; history of the HSE culture, definition of HSE culture and the ways to measure the maturity of HSE culture.

2.1.3.1. History of HSE culture

As a result of completion of hardware and software requirements regarding HSE in the form of technical compliance and management system, companies have realised a significant improvement in the HSE performance [43]. This improvement reached a "plateau" after which HSE performance was not able to continue to improve. The major incidents continued to happen such as Three Mile Island, Chernobyl, Kings Cross and the Herald of Free Enterprise and Clapham. In order to exceed this "low but (seemingly) unassailable" plateau Reason (1998) [44] proposed to address hearts and minds of the management and workforce. This means addressing the behaviours and core values of the employees in an organisation.

2.1.3.2. Definitions and elements of HSE culture

Some of the widely accepted definitions of HSE culture are extracted from the literature.

Safety culture is defined in INSAG-4 [45] as *"Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that as an overriding priority..."*

The Health and Safety Commission of UK [46] describes safety culture as *"Safety culture is the product of individual and group values, attitudes, competencies and patterns of behaviour that determine the commitment to, and the style and proficiency of an organization's health and safety programs. Organizations with a positive safety culture are characterized by communications founded on mutual trust, by shared perceptions of the importance of safety and by confidence in the efficacy of preventive measures."*

The Nuclear Regulatory Commission [45] defines safety culture as *"A good safety culture in a nuclear installation is a reflection of the values, which are shared throughout all levels of the organization and which are based on the belief that safety is important and that it is everyone's responsibility."*

The Confederation of British Industry (CBI) [47] defines HSE culture succinctly *"The way we do things round here"*.

Reason (2000) [48] describes HSE culture as *"… ability of individuals or organisations to deal with risks and hazards so as to avoid damage or losses and yet still achieve their goals."*

Even though a consensus has been reached about the definition of standards and the HSE management systems, the same cannot be said of HSE culture. The number of studies in this particular field is scarce. Therefore, two approaches are introduced to describe the modus operandi of the ethereal HSE culture.

The first approach is a three level model developed by Edgar Schein [49, 50]. The levels of culture in general range from the very visible to the tacit and invisible.

- Level one (Artefacts): The easiest level to observe: it is what one sees, hears and feels. Some examples given by Schein are as follows: safety policy statement; zero lost time accidents; the day the boss broke his ankle; safety award presentations; use of safety equipment.
- Level two (Espoused values): These are adopted and advocated by a person or persons within the organization. Information about espoused values can be obtained by asking questions about the things that one observes or feels. Some examples given by Schein are as follows: safety is the top priority; zero tolerance for safety deficiencies; blame-free work environment; errors are learning opportunities.
- Level three (Basic assumptions): These lie at the deepest level of culture; fundamental beliefs that are so taken for granted that most people in a cultural group subscribe to them but unconsciously. Some examples given by Schein are as follows: accidents are caused by carelessness; some people are accident prone; risks have to be taken to achieve targets; safety can always be improved; accidents are avoidable; properly designed plant is inherently safe.

The second approach has been developed by Reason [51]. He identifies and conceptualises the elements of HSE culture. He states that (a company with a focused) HSE culture:

- Possesses a safety information system that collects, analyses and disseminates information from incidents and near misses, as well as from regular proactive checks on the system;
- Has a reporting culture where people are prepared to report their errors, mistakes and violations;
- Displays a culture of trust where people are encouraged and even rewarded to provide essential safety-related information, but also in which it is clear where the line between acceptable and unacceptable behaviour is drawn;
- Is flexible, in terms of the ability to reconfigure the organisational structure in the face of a dynamic and demanding task environment;
- Has the willingness and competence to draw the right conclusions from its safety system, and is willing to implement reform when it is required.

Literature [51 – 54] states that safety culture deals with every function of an organization. That means, the way how companies manage the HSE is both determined by the safety culture and ultimately determines the maturity of the safety culture. This is consistent with what Clarke (1999) [55] states that safety culture has an influence on all parts of the organization. But there are some units whose HSE performance could be better than the others even within the same organization e.g. geographic differences in road accidents.

2.1.3.3. Measurement of HSE culture

Due to the broadness of HSE culture many indicators need to be used to assess different parts of the system in order to evaluate the overall safety culture maturity [55].
The IAEA [4][50] suggests creating a safety culture index based on the above-mentioned three-level model that could be calculated by the indicators depicted in table 2.

Table 2: Indicators associated with safety culture level (extracted from [50])

Artifacts
Percentage of corrective actions not completed within planned time-scale (a measure of proper resource allocation, top management commitment to safety).
Safety audit scores (a measure of safety performance, self-assessment)
Safety attitude scores (a measure of employee involvement, motivation and job satisfaction).
Percentage of tasks having risk assessment in pre-work planning (a measure of a systematic approach)
Espoused values
Frequency of senior manager plant tours (demonstrates high priority to safety).
Number of safety inspections (demonstrates high priority to safety).
Percentage of managers trained in root cause analysis (organizational learning).
Basic assumptions
Frequency of reporting of near misses (view of mistakes).
Number of safety improvement teams (view of people).
Percentage of employees who have a basic understanding of the safety culture concept and its importance (properly designed plant is inherently safe).

Another attempt to measure the maturity of HSE culture is done by D. Parker et al [56]. They developed a 5-step model (figure 3) that explains the HSE culture of a company in an evolutionary pattern. This model is originally based on the three level approach of Westrum (1993) [57]. It has been further developed following interviews with company executives from the oil and gas industry.

[4] The International Atomic Energy Agency

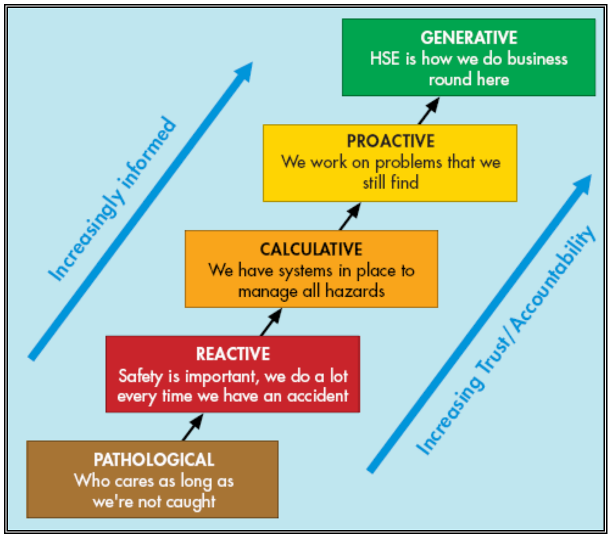

Figure 3: HSE culture ladder (extracted from [56])

The definition of each level is based on the maturity of the processes of the HSE program. The descriptions are collected in a brochure [58] to aid employees at all levels of the organization to locate themselves in terms of safety culture advancement at the work-site. This brochure includes a set of questions (eleven of them are tangible and seven less tangible) referring to the HSE program. It should be noted that the blue lines that are on both sides of the ladder in the figure demonstrate the importance of trust and accountability within the organization. In other words, once the two ways communication between managers and workforce can be achieved by means of increased interdependency, HSE can be improved and generative culture can be reached.

In the next section the justification methods for HSE investments will be elaborated.

2.2. Justification of HSE investments

Selling HSE is an extremely challenging task [59] because HSE management has been viewed as expensive [7, 60] but something to be complied with. HSE professionals have been challenged to prove that these investments can also contribute to business success. [61] argues that companies tend to cut recognition and safety incentive programs at the first blush of revenue slowdown since their added value is difficult to demonstrate. Businessmen or managers usually ask questions to HSE experts like, "What will be the return on our investment?" "What is the payback?" etc. As mentioned in this paper HSE experts have sought to speak the same language as managers to convince them that managing HSE has significantly high return. The language requires words like ROI, payback time, added value, NPV (net present value) cost reduction etc. In other words, the benefits of HSE investments must be made available to management in order to ensure a continuous support and commitment

Managers can be motivated and committed to HSE by different management techniques [59]. Four drivers to implement HSE management programs have been specified:

- **Benchmarking** Industry competitors can be the best practice and the evidence that monetary savings are possible.
- **Compliance** Managers are concerned with complying with the regulations in order to obtain and retain the license to operate.
- **'The Right Thing to do'** Managers are motivated with the ethical and moral reasons with an aim of reducing injuries and illnesses.
- **'What's in it for me?'** Managers are concerned with the benefits that their companies can gain implementing a comprehensive HSE management programs.

There are three prevailing concepts in the literature to justify the expenditures pertaining to HSE management; namely, 1) Return on Investment, 2) Making the Business Case, and 3) Leading and Trailing Metrics [62]. Ernst (2006) [63] claims that many models based on these concepts have been developed to assess the cost effectiveness of the HSE management investments. Many of these models are sophisticated and require data that sought to be gathered from a wide range of units in an organisation.

They serve for the following purposes [63]:

- Convince people that investments in managing HSE are effective
- Evaluate a proposed investment, or to evaluate the decision afterwards
- Benchmark to other companies
- Follow a trend in time
- Sell products, systems

The majority of the studies in the literature deal mainly with the benefits that companies can reap from a sound accident prevention system [64]. Monica B (2005) [65] points to the cost-benefit models whilst persuading decision makers and stakeholders about the significance of benefits from the accident preventive investments. Cost-benefit analysis (CBA) is the most commonly used method. [59] states that *"No matter what level of safety and health program is implemented, a cost-benefit analysis should be completed to justify the benefits to the sceptics in management"*. Many studies have utilised CBA to justify the investments regarding HSE [59, 66, and 67].

2.2.1. Cost-Benefit Analysis (CBA)

There are three significant parts to conduct a CBA for HSE cases [67]; namely, estimating cost of the particular HSE investment, quantifying the associated benefits and discounting the future.

2.2.1.1. Estimating costs of HSE investments

The literature falls short of a complete conceptual model that streamlines all the cost items of HSE management. The existing studies provide insight about:

- Cost estimates for specific items of HSE management e.g. noise protection, asbestos removal etc [68 – 70]
- Program based cost estimates by dividing total cost of an HSE management program into stages e.g. implementing, hiring consultants, etc [71, 72]
- Changes in the life cycle cost of the investments regarding HSE management [73].

Bridges (1994) [72] conducted the most elaborate survey in the cost estimation of implementing Process Safety Management (PSM) of OSHA. In his exploratory study he attempts to quantify the costs and the benefits of international standards' compliance. He carries out several questionnaires among 84 chemical companies exerting effort over a decade to adopt standards. Bridges decomposes and examines the cost of implementation into three stages; that is, develop, implement, and respond.

Develop PSM programs: This stage stands for bringing the HSE program from concept stage to the final design. The cost of this stage is equivalent to labour costs. This stage encompasses leading process hazard analysis (PHA), incident investigations, compliance audits, writing procedures and employee training.

Implement PSM programs: The cost of this stage is in equivalent to labour costs. Tasks generally carried out in this stage are writing operating procedures, updating process safety information, doing initial training of operators and maintenance personnel and documenting/performing PHA.

Respond to Recommendations: The cost in this stage is primarily incurred in terms of capital costs and expenses. Costs are caused by implementing improvements; especially due to the recommendations addressed from PHA, Management of Change, hazard reviews, incident investigations and mechanical integrity deficiency reports.

Bridges' intricate analysis reveals that 50% of the total implementation cost results from (1) training personnel to lead PHAs ; (2) performing and documenting PHAs; (3) responding to PHA recommendations. He displayed the highest cost elements (lowest cost elements are simply ignored) under each category in descending order as designated in the table 3.

Table 3: Highest cost elements of OSHA's PSM (extracted from [72])

Develop	Implement	Respond
Management of Change	Process Safety Information	Process Hazard Analysis
Mechanical Integrity	Mechanical Integrity	Management of Change
Training	Operating procedures & Training	Mechanical Integrity
	Process Hazard Analysis & Management of Change	Incident Investigation

Respondents conceded that MI and MOC are the most difficult elements to carry out since both require groundbreaking culture changes. Bridges estimates the average cost of implementation per facility over a period of 10 years beginning at 40% compliance to be $ 5.8 million. He elaborates further on PSM activities and provides more refined cost estimates for the tasks such as PHA per process and instrumentation drawings (P&ID). Bridges has discovered that government estimates fail to include the part of responding to recommendations. He justifies his argument with the fact that OSHA's cost estimate for refining industry in the US is 22 times lower than API and JBFA estimates. This implies that the OSHA cost estimation model significantly underestimates the total cost of PSM implementation. It should be noted that this study was published in 1994 and no study which has been published since then was found in the literature.

2.2.1.2. Quantifying Benefits

This stage mainly focuses on quantifying the intangible – qualitative – benefits of managing HSE. Improving HSE management can bring a number of qualitative (intangible) business benefits as well as the financial benefits [115]. Many articles can be found in the literature about the latter whereas the former has been overlooked or deliberately not mentioned since it is difficult to keep the records of the intangible items [74].

Literature mostly revolves around the concept of incident costs [8, 74, 75, 76] when it comes to identification of HSE management benefits. The majority of the authors argue that HSE investments help companies avoid a considerable amount of expenses by reducing the number of incidents. These expenses include not only the direct loss resulted from property damage but also long term business losses.

[74] propose that opponents of using incident costs as an indicator of HSE management performance address the difficulties concerning identification of cost figures; namely, (1) scope of costs; (2) timing; (3) commercial sensitivity; (4) exchange differences. Ayers (2006) [59] notes that property damage cannot indicate the real hazard of an incident because business interruption loss is usually ignored. [74] concludes that the number of casualties cannot account for a good indicator of the scale of losses from the accident. Corcoran 2002 [77] claims that the cost of incident is inherently correlated with the compensation costs that change from one country to another. Therefore, he introduces compensation costs as a new factor and states that it is very difficult to find a generic estimation for incident costs, which hold true for every industry and company.

In addition to estimating the cost of an accident, literature includes many other benefits that are both qualitative and quantitative. The benefits articulated in the literature are listed in table 4. This table has been prepared using information retrieved form the academic papers and the studies sponsored by the HSE related agencies [2, 3, 16, 72, 78 – 87]

Table 4: Benefits of Integrated HSE management program

Qualitative Benefits
Comply with the rules and regulations
Increase image/reputation/brand
Engage with employees - morale, loyalty, retention
Build public trust
License to operate: Less regulatory scrutiny, legal complications, lower community discontent, reduction in pollution on environment
Increase business options
Attract and retain high performance staff
Quantitative Benefits
Reduce number of incidents
Save lives and reduce injuries
Reduce property damage costs
Reduce business interruptions
Protect market share
Reduce litigation costs
Reduce environmental hazard
Reduce regulatory penalties from accidents
Reduce regulatory attention
Increase productivity: increase process and equipment reliability, user-friendly accurate operating procedures, improved team effectiveness through employee training, employee ownership of the systems, enhanced troubleshooting capabilities, extended intervals between major turnarounds, decreased turnaround time for minor repairs
Reduce production cost: improvement in yields, lower costs for material rework (quality), lower costs for waste stream disposal, prevention of hazards and operability issues before they occur, more efficient staffing requiring less supervision, engaged employees participating in continuous improvement
Reduce maintenance cost: effective equipment maintenance procedures, contractor safety programs, repairing or replacing critical equipment before it fails, avoiding unplanned shutdowns, lower maintenance turnaround costs, thorough periodic inspection
Reduce capital budget: inherently safer process designs that begin in the conceptual phase, process hazard analyses for new projects and facilities, lower capital expenditures because project teams have

up-to-date process safety information
Reduce insurance cost: effective emergency planning and response, reporting and investigation of near misses to identify potential problems early, thorough incident reporting and investigation programs to prevent incidents from being repeated, lower casualty insurance premiums

The literature review discloses that it is extremely laborious to monitor the quantitative benefits and to quantify the qualitative benefits of HSE management. Due to these difficulties, the utilisation of CBA is scarce in the literature. To compensate this gap, the literature concentrates on best practices from the real life applications. Best practices can be used as a way to convince the management team because most of the above-mentioned benefits have already been realised in these real-life cases. Examples can be accessed from the international agencies' web pages.

HS&E has prepared case studies to post success stories of the companies in its web page [116]. Despite lack of a case study embodying a complete HSE programme implementation, there are facts and figures of benefits gained from specific HSE applications (HSE management programs) such as training, incident reporting, root cause analysis etc. Likewise OSHA has exerted enormous effort to develop alliances to publish success stories from PSM implementation [117]. Accordingly, it has launched an alliance with Abbott [118] and Georgetown University McDonough School of Business in order to develop business case striving to increase the competitive advantage of companies using HSE whilst enhancing the curriculum of the safety education in the university. OSHA has further cultivated alliances with the leading international companies; such as, The Dow Chemical Company and The Steel Group and many other Small and Medium sized Enterprises (SMEs) in order to supply information to this alliance. OSHA runs a program named Voluntary Protection Programs (VPP) in order to improve the workplace safety and health management systems and publishes the outstanding results from implemented activities in its web-page [119]. Moreover, API and CCPS (together with AIChE) [120] held conferences to bring companies in the oil and gas industry together in order for them to make it possible to exchange experiences and learning in terms of HSE management [121]. A selected list of the most outstanding cases has been prepared and can be found in appendix – 6 [16, 88 – 92].

2.2.1.3. Discounting the future

This stage attempts to bring costs and benefits to similar terms so as to make appropriate comparisons. Costs and benefits occur at different times. Often costs are incurred today but the benefits are realized in the future. Discounting is a way to calculate the Net Present Value of the investment so as to allow companies to make decisions comparing the benefits with the costs in similar terms [67].

2.2.2. Alternative justification methodologies

2.2.2.1. Tools developed by international agencies

International agencies are in search of developing a model that provides an in-depth understanding of cost effective HSE investments.

Voluntary Protection Program (VPP) of OSHA

OSHA [123] sponsors scholars to develop decision tools in an effort to help managers determine which elements of HSE program are the most cost effective so that the overhead costs and operating expense can be reduced. [93] use Analytic Hierarchy Process (AHP) to solve this problem in a quantitative way. They addressed six major processes of OSHA's PSM and identified the cost-benefit ratio of these elements through pair-wise comparisons depending on expert judgements. The results of this study allow safety experts and managers to determine which process offers a higher pay-off. Even though AHP is a generic approach, the results are case-sensitive and yet to be generalised [93].

Business Case for HSE: All the examined agencies, regulatory bodies and trade associations have developed business cases for HSE investment. A business case includes significant messages about why companies should invest in HSE and best practices of HSE. Processes implemented as part of an HSE program are linked to the benefits qualitatively. OSHA introduced the concept of leading and trailing indicators that can be used to measure the overall HSE management performance.

$afety Pays Program (SPP) of OSHA

OSHA concedes that the involvement of employers and employees is of great importance to an effective safety performance. This tool helps assist decision makers/managers in assessing the impact of occupational injuries and illnesses in four steps. It uses the profit margin, the average cost of injury/illness and an indirect cost multiplier to estimate the amount of sales that the company has to do in order to compensate the cost. This program [86] fails to provide guidance regarding where HSE investments should be made and in what amount.

NEER Program of WSIB&CME

The workplace Safety and Insurance Board (WSIB) and Canadian Manufacturers and Exporters (CME) Ontario developed this program to enhance safety performance at workplaces [86]. The NEER program encompasses four steps; (1) Determining the maximum potential NEER rebate, (2) Determining actual NEER rebate, (3) Determining average not rebate per claim, (4) Determining gross sales required to recover NEER costs. Its purpose is to motivate companies to make investments in HSE by promising financial incentives.

ROHSEI of ORC Worldwide

This tool has been developed by fifteen ORC Occupational Safety and Health Group to form a task force that allows communicating the value of HSE performance by encouraging better decisions [86]. It has four tools used to complete the program. (1) Understand the Opportunity or Challenge; this tool helps users describe the focus of an opportunity or challenge; that is to identify the addressed question. (2) Identify and Explore Alternative Solutions; cross-functional brainstorming is imperative at this stage. (3) Gather Data and Conduct Analysis; Collecting data of both direct and hidden impacts makes this program semi-quantitative since most of the hidden impacts are qualitative. (4) Make a Recommendation

Spalburg [86] states that ROHSEI approach is the most complete program among the others. This tool helps companies understand opportunities, identify alternative solutions, conduct analysis and make recommendations. Moreover, rather than employing a standardized coefficient the value of qualitative benefits can be computed by survey. Thus, companies should make a significant investment to allocate the required personnel and to eventually complete the program. It should be emphasised that none of these tools provides a framework that will enable us to compare the overall benefits of HSE management.

2.2.2.2. Tools developed in the literature

There are alternative approaches to CBA [65]. [66, 94, 95, 96] introduce three alternative methods:

(1) **Risk assessment** is a method to estimate the consequences of threats and hazards in quantitative terms. Risk assessment does not attach a monetary value to the outcomes it foresees.

(2) **Comparative risk analysis** is a method attempting to minimize the resource utilization whilst decreasing the risk exposure utmost.

(3) **Risk benefit analysis** resembles CBA in which the benefits are the economic advantages and risks are considered to be disadvantages.

Maroo et al. (2006) [97] refer to a list of models [96 – 102] that are based on the above-mentioned analyses as an alternative to CBA to justify the HSE related investments. Lack of competent personnel and the complexity of the models are considered to be the foremost limiting factors against implementing these techniques [97]. The major difference between these methodologies and CBA is that none of them requires the translation of the benefits into monetary terms [66]. Difficulties encountered in the utilization of these methods in justification of HSE investments are mentioned by many scholars as unavoidable limitations [124]. These are summarised as:

- Calculating the true cost of injuries and illnesses, organizational inefficiencies from losses, low employee morale, and compliance exposures are not an easy task to do.

- Measuring the benefits accruing from HSE investments
- Pressure of the safety paradox on the bottom-line makes companies reluctant to implement these methodologies. The safety paradox is an industry recognised phenomenon, summarised succinctly in the phrase coined by [103]: *"The better your safety and health performance, the more difficulty you will have justifying safety and health investments in financial terms.*

Most of the available studies' being recent indicates that the concept of justification of HSE investments is rather new. A list of the tools recently developed in the literature is available in appendix – 7.

The editors of Journal of [99] compared these models with each other based on the criteria of their acceptability, flexibility, complexity, and specificity. It was noted that they lack either one or more important features. Thus, they call for the necessity of methods/tools that will satisfy all these criteria at the same time while considering HSE as a whole.

In their paper, French et al. (2005) [106] concede that multi-attribute theory has become a better candidate for upper level decision-making process such as ALARP because this approach has proven to overcome the aforementioned disadvantages of CBA for HSE applications.

2.2.2.3. Methods used by the global companies

The global companies to the extent that this study entails have similar approaches (and key performance indicators KPIs) when compared to each other. For specific intervention whose costs and benefits are rather easy to estimate, companies utilise straightforward methods similar to CBA. However, Shell does not tend to use CBA because the return of the investment is hard to estimate before the investment is done. Estimating benefits is a more time-consuming and hard to solve problem than estimating costs.

Based on the interviews conducted with people working in various HSE positions in Shell, it is clear that Shell endeavours to justify the investments by estimating the HSE performance indicators such as the expected decrease in the number of fatalities or injuries, the expected reduction in the CO_2 emission etc. These are all KPIs in Shell and managers have associated targets. The research completed reveals that other companies also use similar indicators and publicise them regularly. Companies cannot use CBA easily since the indicators that they use are all quantitative but non financial. These indicators are classified into two main groups; namely, improvements related to occupational health and safety (H&S), and improvements related to environmental aspects. Loss time incident (LTI) or total recordable cases (TRC) are the common indicators used to evaluate the H&S performance. On the other hand the number of spills, leakages and discharges are widely used to monitor the environmental improvements.

As well as these indicators, companies carry out internal and external audits in order to assure that all processes are in place either to prevent incident from happening or to mitigate the impact in case incidents occur. The outcomes of the audits lead to corrective actions to improve the performance. The audit outcomes and findings are mostly visible to upper level management; whereas, the KPIs are usually used to manage HSE in the lower levels. So, different performance indicators appeal to the different levels in the company that might hinder the synergy in terms of HSE application. In addition none of the companies appears to possess any methodology developed to link the HSE expenditures to the performance indicators as an effort to justify the investments. More detailed information about the indicators monitored can be found in the appendix – 8 [107, 108].

2.3. Summary of findings from the literature review

The findings of the literature review can be summarised in four parts: fragmentation in the literature, issue of common language, return of investment, and no relation of available metrics and benefits.

(1) Fragmentation in the literature: The attention on HSE has evolved rapidly and unexpectedly. One reason for this sudden rise might be that sociological and political changes have triggered attention from the public and the government e.g. increased awareness of green issues and pressure to increase transparency about incidents. Secondly, continuing catastrophic incidents in the industry might have played a key role in this evolution. This unexpected increase of the attention might be the prevailing cause of fragmentation in the literature concerning HSE. This argument should be further elaborated and validated.

(2) Issue of common language

- ✓ Current methodologies fail to answer the common managerial questions. Companies tend to cut HSE incentive programs at the first attempt of revenue slowdown due to the difficulties in monitoring their added value. HSE experts sought to speak the same language with managers to persuade them that HSE investments leads to a high return. The common managerial questions cannot be answered with the existing methodologies because neither CBA nor its alternatives can provide sound explanations. Literature suggests using multi-attribute theory rather than CBA.
- ✓ Lack of a common language in order for all the managers at the different levels to speak about HSE performance in an aligned manner. There are 4 main drivers to motivate managers to make investments on HSE. To promote these drivers requires a holistic and well-structured performance indicator. In practice, audit outcomes and findings are solely visible to upper level management; whereas, the quantitative performance indicators are usually used to manage the HSE performance in the lower levels. So, different performance indicators appeal to the different levels in the company, which might hinder the synergy regarding HSE improvement by forcing people to talk different languages for the same target.

(3) Return of investment

- ✓ Companies are seeking for a justification model to track the effectiveness of the HSE interventions. To the author's knowledge none of the companies has managed to develop a methodology to link the expenditures to the benefits gained.
- ✓ Financial measures are not widely used in the practice. This is due to two reasons; (1) Difficulty in collecting data (the money that the company has avoided losing); (2) Difficulty in measuring the financial return of an HSE investment.
- ✓ CBA is inconvenient to be put in practice. Literature [67, 72] points to the following fundamental flaws in the way to use CBA for HSE justification: (1) Literature falls short of studies associated with the total cost of a complete HSE program implementation and the existing cost estimates are found to be unrealistic. (2) Quantitative HSE benefits are difficult to track and estimate. Qualitative HSE benefits are difficult to quantify. (3) Standard economic approaches to valuation are inaccurate and implausible. (4) The use of discounting improperly trivializes future harms and the irreversibility of some environmental problems. (5) The reliance on aggregate monetized benefits excludes questions of fairness and morality. (6) The value-laden and complex cost-benefit process is neither objective nor transparent.
- ✓ Alternative methodologies to CBA are restricted to specific processes. Despite using different approaches, all of the models recently developed in the literature as alternatives to CBA attempt to answer the same question; that is, cost effectiveness of particular interventions pertaining to HSE. Therefore, outcomes of the models cannot be extrapolated to the overall HSE performance of the company. For instance, COS [5][104] is just applicable to particular locations and failure costs are difficult to quantify; similarly, PROCESCO[6] [97] involves only operational safety; not occupational health. Likewise global companies suffer from the lack of a generic methodology to link the expenditures to the performance indicators. Literature calls for the necessity of methods/tools that will consider HSE as a whole.

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[5] COS is a methodology which attempts to estimate the cost of safety. For more information refer to appendix 8.

[6] PROCESCO is a method which attempts to contribute to the development of a more comprehensive safety assessment method by combining the advantages of indices as quantitative tools and the ability of indicators provide indirect measures of safety. For more information refer to appendix 8.

(4) No relation of available metrics and benefits

- ✓ HSE performance indicators used in the best performers are incapable of demonstrating the overall HSE improvement against the investment. Many best performing companies see stagnation in their HSE performance indicators – despite continuous investment (safety paradox). The returns that they can realise are restricted since the performance indicators are based on quantitative but non-financial terms e.g. loss time incidents. Moreover there is no single indicator which allows managers to oversee the entire phenomenon of HSE in one picture. As a result, the return of the investments on companies' overall HSE performance can not be easily monitored and this ultimately results in inefficient and ineffective investments.

Chapter 3: Research question & Methodology

According to the literature survey the current methodologies fail to provide answers to the questions arouse as a result of problem definition (refer to section 1.1). This is mainly because the benefits are realized in various terms; namely, quantitative, qualitative and financial. A prerequisite to the development of a generic CBA model is an indicator capable of encapsulating all the terms within a single value or index.

"Is there a single well structured and systematic HSE management performance indicator?"

The findings summarised in the previous section indicate that there is no single well-structured and systematic HSE performance indicator. So, the next question will be; *"Is it possible to create a single well structured and systematic HSE management performance indicator?"*

The editors of Journal of Safety [99] call for the necessity of methods/tools that consider HSE as a whole. French et al. (2005) [103] concede that multi-attribute theory (MAT) has become a better candidate for the H&S related decision making problems than CBA in the last decade because HSE requires an extensive amount of inputs which are combination of quantitative and qualitative elements.

The author responds to the works of the [99] and [103] and sets an objective of the study to be the development of a framework which will consider all relevant aspects under a single, well-structured and systematically generated value by using MAT. Hence, ***a well-structured and systematic HSE management performance index for the refining industry*** is the primary focus of this study, whilst keeping the development of a generic CBA in mind.

The concept of the HSE management can be characterised by means of attributes. In particular attributes can be further decomposed into measurable scales called performance measures. The Multi-Attribute Theory (MAT), suggested by [103, 109] has been chosen to develop an HSE management performance index. MAT is an appropriate methodology for this study because:

- MAT prescribes a systematic approach to resolve the problem.
- MAT uses a hierarchical approach which allows considering quantitative and qualitative aspects and provides a comprehensive and a structured methodology.
- De-composition of far-reaching questions into small discrete parts yields more accurate estimation.

MAT itself can be adopted using several different methods: (1) Heuristics; (2) SMART; (3) SMARTER; (4) Analytic Hierarchy Process (AHP). Therefore a choice of methodology needs to be made. The resolution of the stated task should meet the requirements depicted in the first column of table 5. This table demonstrates whether a particular method can fulfil the requirement. It is derived that AHP addresses all the requirements to resolve this problem.

Table 5: Comparison of the methods of MAT

Requirements	Heuristics	SMART	SMARTER	AHP
Structured decomposition	NO	YES	YES	YES
Simple comparison of attributes	NO	NO	NO	YES
Simple consistency check	NO	NO	NO	YES
Sensitivity analysis	NO	NO	NO	YES
Sound results in case of preference changes	NO	YES	NO	YES

3.1. Analytic Hierarchy Process (AHP)

AHP has been developed by Saaty [113]. AHP is incorporated in four stages after the attributes are identified.

Stage 1: Weight the attributes

- ✓ Elicit pairwise comparisons of the attributes
- ✓ Transform the comparisons into weights

Stage 2: Convert the weights of the performance measures into utilities

Stage 3: Calculate the index

Stage 4: Validate the model

3.1.1. Weight the attributes

This stage yields the relative importance of the attributes on the index.

Elicit pairwise comparisons of the attributes. The experts make pairwise comparisons of each attribute with every other sibling attribute which is located immediately below the same 'split'. The comparisons are done according to the preference scale that ranges from 1 to 9 (figure 4). Saaty suggests that the comparisons should be initially conducted according to the linguistic scale and then replaced with the corresponding numbers.

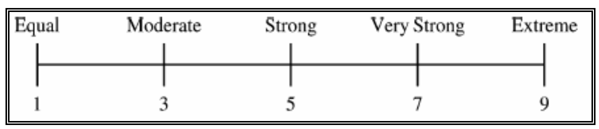

Figure 4: AHP preference scale

As a response to the critics on Saaty's traditional approach, AHP is enhanced by deliberation technique in order to increase the accuracy of the results [110, 111]. Deliberation meetings bring different point of views to the attention of the experts and help to reduce the uncertainty in the final decision. This process has been successfully applied to some real-world problems (112, 113).

The comparisons are employed into the pairwise matrix. If there are three attributes following a split, each attribute should be compared with each other and then a 3x3 matrix is prepared.

Transform the comparisons of the attributes into weights. AHP uses a mathematical approach based on eigenvalues. The eigenvector of the pairwise matrix is solved for in three steps: (1) Raise the pairwise matrix to powers that are successively squared each time. (2) The row sums are then calculated and normalised. (3) Stop when the difference between these sums in two consecutive calculations is smaller than up to four decimals. The computed eigenvector gives the relative importance (weight) of each attribute.

3.1.2. Convert the weights of the performance measures into utilities

Each scale of the performance measures is compared with each other and the relative weights are obtained in the same manner. The performance measures can be transformed into continuous utilities in order for the experts to give intermediary rates. The conversion is done by the linear transformation used in [110, 111]. The reader may refer to appendix – 9 (part I) to get more information.

3.1.3. Calculate the index

The weights and the utilities are used to compute index for the plants (the subject matter in the scope of the thesis). For aggregation of utilities and weights, the formula introduced by [111] is used.

$$\mathrm{PI}_j = \sum_{i}^{Kpm} w_i u_{ij}$$

The performance index for plant j (PIj) is the summation of the weight (w) of each attribute multiplied by the utility (u) of each attribute. The summation is for all performance measures (Kpm).

3.1.4. Validate the model

Validation of the model can be performed in two parts; validation of the value tree and the consistency check of the pairwise comparisons.

Judge the validity of the value tree. Keeney and Raiffa [114] suggested five criteria in order to judge whether the value tree is an accurate and useful representation of experts' opinions:

- Completeness: If the tree is complete, all the attributes which are concern to the objective are included.
- Interdependency: The performance of a plant on one attribute can be judged irrespective of its performance on other attributes.
- Operationality: All the lowest level attributes of the value tree should be comprehensive and specific enough for the experts to evaluate for different plants.
- Absence of redundancy: The lowest level attributes should not duplicate each other. In such a case they represent the same thing which makes one of them redundant.
- Minimum size. The size of the value tree should have a reasonable size to yield meaningful analysis. Rule of thumb is 10 measurable attributes utmost.

Check the consistency of the pairwise comparisons. AHP yields an inconsistency ratio which shows whether the pairwise comparisons are consistent. The 'inconsistency' concept can be explained with the following example. Suppose A is twice as important as B, while B is judged to be three times as important as C. To be perfectly consistent A should be judged six times more important than C. Any other response will lead to an index of greater than zero. A value of zero indicates perfect consistency. Saaty recommends that inconsistency should only be a concern if the index exceeds 0.1. The reader may refer to appendix – 9 (part III) to get more information about how to calculate the consistency ratio.

3.2. Case studies and Sensitivity analysis

Setting up case studies is a generic part of academic studies which aims to test the application of the model. In the context of this thesis case studies are established with a panel of experts who possess breadth knowledge regarding the matter of concern. Expert Choice®, software program, is used to calculate the weighting factors, validate the model and conduct sensitivity analysis. Sensitivity analysis is used to examine how robust the index of a particular plant is to changes in the figures obtained as a result of pair-wise comparisons

3.3. Criticism of the AHP

Even though AHP has been used in several cases, there are criticisms regarding the validity of the AHP. The critics [109] are summarised below:

- Conversion from verbal to numeric scale: The correspondence between the numeric and linguistic scales is an untested assumption.
- Problems of 1 to 9 scale: In case the experts aspire to incorporate very extreme ratios, the restriction of pairwise comparisons to a 1 to 9 scale is bound to create inconsistencies.

- Meaningfulness of responses to questions: AHP questions ask for the relative importance of performance measures (measurable attributes) without reference to their scales.
- Number of comparisons required may be large: While redundant comparison allows for checking consistency of the experts' comparisons, it may also require a large number of judgements from them.

The author was aware of the debate in the literature concerning the validity of AHP. The above-mentioned potential pitfalls were overcome thanks to close interaction (deliberation technique) with the experts and iterative process followed in the model development.

Chapter 4: Development of the model

4.1. Description of the terminology

The terminology that will be used in this section is explained below [114].

Experts are the people who contribute to the practice of pairwise comparisons in order to produce the relative weights of the attributes and utility values of the performance measures.

Objective means an indication of the preferred direction of movement.

Attribute is used to measure performance in relation to an objective.

Utility is the attractiveness of the course of action to the experts that involves risk and uncertainty.

Value tree is a hierarchical representation of attributes that embodies the measurable attributes at the lowest level.

Performance measures are the lowest level measurable attributes.

4.2. General Framework

Four steps were pursued in the application of the method.

Step 1: Setting up decision hierarchy

- Step 1.1: Formation of the panel
- Step 1.2: Identification of the objective
- Step 1.3: Definitions of the attributes and performance measures
- Step 1.4: Judging validity of the value tree

Step 2: Weighting the attributes

Step 3: Eliciting the utilities of the performance measures

Step 4: Checking consistency

4.2.1. Step 1: Setting up decision hierarchy

The intention of the value tree is to arrive at a set of attributes that can be assessed on a numeric scale. The value tree has been developed with input from the literature and the experiences gained in the third party setting on-site in Turkey and in periodic consultation with the panel (figure 5).

The construction was an iterative process. Initially a draft value tree was prepared together with the academic supervisors and presented to the panel. Five workshops were carried out with the panel. The first three workshops had the objective to agree on the value tree and the definitions of the attributes. The panel was then asked to review the draft in the light of the five criteria which ultimately determine the validity of the tree. During each workshop the value tree was challenged against these criteria and the necessary revisions were made accordingly. After each workshop the revision was challenged by an expert outside the panel – the academic advisors in this case.

The process was completed once all the stakeholders confirmed the validity of the model. In the forth workshop the weights of the attributes and the utilities of the performance measures were elicited. The last workshop was dedicated to performing case studies and conducting a SWOT (Strengths, weaknesses, opportunities, threats) analysis of the model.

Stakeholder engagement can be inefficient. By explaining clear objectives and preparing draft versions of the model before each engagement, the workshops ran effectively and efficiently.

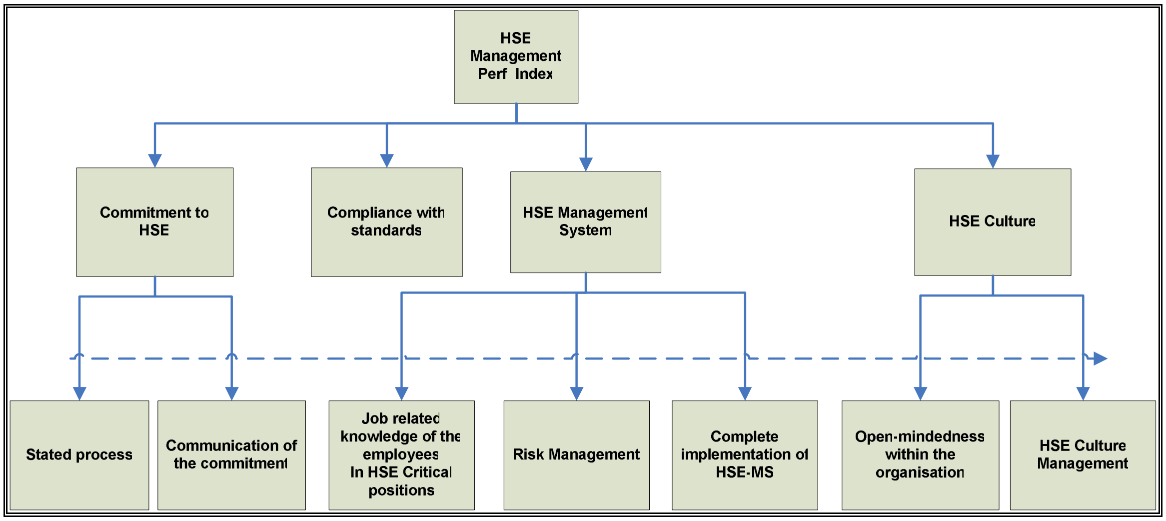

Figure 5: Hierarchical representation of the value tree

4.2.1.1. Formation of the panel team

The panel team was comprised of four HSE consultants working at SGS, hereinafter called "the experts", having breadth of industrial knowledge and expertise regarding HSE. Background information about the experts can be provided upon request.

4.2.1.2. Identification of the objective

While identifying the objective of the value tree, the panel was indecisive between 'HSE performance' and 'HSE management performance'. Even though it seemed to be a matter of semantics at the first glance; one of the experts brought a challenging example up. *"Assume two different enterprises will be assessed on this model; first one is a little office specialized on Internet marketing and the second one is a Formula 1 team. Eventually their HSE performance might be both excellent. Nevertheless, the way how they manage their HSE would differ a lot."* This example led the panel to the following argument; *"HSE performance is a result of HSE management"*. This relationship was assumed to be correct. Then, the experts dwelled around two questions *"Do we like to measure how well has HSE been managed? Or Do we like to measure how well is HSE being managed?"* Most of the indicators currently used are giving answers to the former question; that is, rather lagging and does not tell much about neither today nor future. The panel came to the conclusion that the objective of this model should provide answers to both questions. Accordingly, the objective was defined as follows:

This model attempts to measure HSE management performance by means of an index. HSE management is a long-term process, which is the major determining factor in the overall HSE performance of an organisation. The higher it is, the better the HSE performance within a peer group (within the refining and chemical industry) will ultimately be.

4.2.1.3. Definitions of the attributes and the performance measures

The value tree consists of eleven attributes (as shown in figure 5), eight of which are performance measures and the rest are the non-measurable first level attributes. From hierarchy point of view there are four sets of attributes. Four attributes are the first level attributes (Group I); namely, 'commitment to HSE', 'compliance with standards', 'HSE management system', 'HSE culture'. The attribute 'commitment to HSE' includes two sub attributes; that is, 'stated process' and 'communication of the commitment' (Group II). The attribute 'HSE management system' embodies three sub level attributes (Group III); namely, 'job related knowledge of the employees in the HSE critical positions', 'risk management', 'complete implementation of HSE-MS'. The attribute 'HSE culture' includes two sub level attributes (Group IV); namely, 'open-mindedness within the organisation' and 'HSE culture management'. The definitions of the attributes are given below. Note that the 'utility' column will be explained in section 4.2.3.

Commitment to HSE has to be stated and documented at the highest level of the organisation[7]. The stated commitment should specifically address HSE as a continuous process, which does not have a specific terminal goal or deadline but continues and evolves along with the operations of the organisation. It should be effectively communicated both within the organisation and to external communities[8].

Stated process means that the stated commitment at the highest level of the organisation should specifically address HSE as a continuous process which does not have a specific terminal goal or deadline but continues and evolves along with the operations of the organisation.

Table 6: The level of the stated process

Levels	Definition	Utility
0	**None –** not stated commitment at the highest level of the organisation	**0**
1	**Stated targeted goals –** organisation has operational objectives with targeted short completion times for all three areas of Health, Safety and Environment.	**0,5**
2	**Stated as a long term process** – HSE is treated as a long term process with the aim to continuously improve in all three areas of Health, Safety and Environment.	**1**
	Inconsistency ratio	**0**

Communication of the commitment means that the stated commitment at the highest level of the organisation should be effectively communicated both within the organisation and to external communities.

Table 7: The level of communication of the commitment

The level of communication of the commitment		
Levels	**Definition**	**Utility**
0	**None –** the commitment to HSE is neither documented nor communicated.	**0**
1	**Documented –** the commitment to HSE is documented.	**0,226**
2	**Communicated internally –** level 1 + the commitment to HSE is communicated and the performance shared within the organisation by senior management.	**0,892**
3	**Communicated externally** – level 2 + the commitment to HSE is communicated to and the performance shared with external communities.	**1**
	Inconsistency ratio	**0,01**

Compliance with standards refers to compliance with (1) the law, (2) adopted international and industrial codes and standards, (3) adopted internal company standards and guidance and (4) good industry practices.

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[7] If the highest level of the organisation does not state its commitment to HSE, there is no commitment.

[8] External communities include but are not limited to the communities outside the boundaries of the corporation; neighborhood, local authorities, contractors, state, contributors, stakeholders etc.

Table 8: The level of compliance

Levels	Definition	Utility
0	**None –** non-compliances with legislation	**0**
1	**Legal compliance –** compliance only with legislation (1)	**0,205**
2	**Voluntary compliance –** compliance with (1) the law, (2) adopted international and industrial codes (e.g. World Bank standards)	**0,544**
3	**Create and comply with your own set of internal standards –** compliance with the (1) law, compliance with (2) adopted international and industrial codes and standards, (3) compliance with adopted (or created) internal company standards and guidance	**0,767**
4	**Ensuring the total compliance by reviews and internal audit processes –** compliance with the (1) law, (2) adopted international and industrial codes and standards, (3) adopted internal company standards and guidance and (4) implementation of new standards and good industry practices where applicable	**1**
	Inconsistency ratio	**0,03**

The HSE management system should possess elements to identify hazards pertaining to HSE, assess the associated risk with these hazards and manage the risks accordingly. The HSE MS should be completely implemented. The HSE MS has to ensure that the employees in HSE critical positions possess the required process knowledge to the extent which they avoid inappropriate actions, detect and diagnose abnormal situations and take the appropriate actions.

The attribute **"Job related (functional) knowledge of the employees in HSE critical[9] positions"** encompasses the understanding of the employees in HSE critical positions about the processes not only in the domain of their own function, but also to a broader context such that they are able to detect and diagnose abnormal situations, take the appropriate actions and avoid inappropriate actions.

Table 9: Job related knowledge of employees in HSE critical positions

Levels	Definition	Utility
0	**None –** People in HSE critical positions do not have the basic functional knowledge	**0**
1	**Personal level –** People know their assigned function including identifying and managing abnormal conditions. People know what and why they are doing things and how they are supposed to do them.	**0,347**
2	**Team level –** level 1 + there are people, who are aware of the various functions in their own team to the extent that they actively intervene, contribute or explain when asked.	**0,692**
3	**Unit level –** level 2 + there are people at team level who are aware of the various functions in the unit (business unit) to the extent that they actively intervene, contribute or explain when asked.	**0,842**
4	**Site level –** level 3 + there are people at unit level who are aware of the various functions in the entire site to the extent that they actively intervene and contribute.	**0,962**
5	**Industry (Sector) level –** Level 4 + there are people at site level who keep track of the latest changes regarding the various functions within the industry in an effort to apply them in their own organizations.	**1**
	Inconsistency ratio	**0,07**

[9] HSE critical position is a position that can impact significantly the execution of activities which could directly or indirectly lead to a significant incident.

Risk management is a process that identifies the hazards, assesses the risk associated with the hazard and implements the necessary risk reduction measures (either to reduce the likelihood of an incident or to mitigate the consequences) depending on the severity of the risk. The effectiveness of this process should be regularly monitored.

Table 10: The level of risk management

Levels	Definition	Utility
0	**None –** there is no hazard awareness.	**0**
1	**Identification of the hazards –** the hazards are identified and recorded.	**0,206**
2	**Assessment –** the risks associated with the hazards are assessed by the appropriate risk assessment tools (e.g. an appropriate procedure which determines which type of tool (quantitative vs. qualitative) to be used for which types of risks)	**0,269**
3	**Planning –** control measures are identified based on the risk level and the necessary resources are allocated to put these measures in place and a time schedule to complete the planned actions is set (the required competency is defined).	**0,379**
4	**Coordinating (implementing) –** the predefined projects are completed within the scheduled time frame, the measures (HSE critical tasks) are assigned to competent people and the maintenance of the control measures is performed.	**0,765**
5	**Monitoring –** the risk reduction measures taken are continuously monitored to ensure that they are managing the risks; if not, corrective actions are taken (e.g. reassessment of the risks in an effort to cover the new/changed risks, audits, assurance process, safety reviews, competency assurance etc.)	**1**
	Inconsistency ratio	**0,03**

Complete implementation of HSE Management System means that there is a documented and structured process for implementing the business processes mentioned as a part of written policy. All the elements of this policy are implemented according to conventional management practices which include elements of planning, executing, monitoring and adjusting. The effectiveness of the management system implementation has to be monitored regularly and necessary updates should be done.

Table 11: Complete implementation of HSE-MS

Levels	Definition	Utility
0	**None –** there is no documented procedure or there is a procedure without structure.	**0**
1	**Documented, structured but not implemented –** All elements of the HSE-MS are documented but they are not implemented.	**0,272**
2	**Partially implemented –** level 1 + some but not all of the business processes are implemented.	**0,349**
3	**Full implementation –** level 1 + all of the business processes are implemented.	**0,914**
4	**Full implementation + monitoring –** the effectiveness of the HSE management is regularly monitored and necessary updates (improvements) are done (e.g. audits) leading to continuous improvement of performance as per plan.	**1**
	Inconsistency ratio	**0,02**

HSE culture consists of two building blocks; that is, the prevailing HSE culture in the organization which is evaluated by open-mindedness within the organisation and the structured process in order to improve to a higher level.

HSE culture management should be a systematic process that consists of an assessment of the existing safety culture, identifying deficiencies, determining the priorities and taking corrective actions for change, reviewing progress continuously.

Table 12: The level of HSE Culture Management

Levels	Definition	Utility
0	**None –** company is not aware of the importance of a good HSE culture	**0**
1	**Awareness –** company determines its existing HSE culture	**0,272**
2	**Gaps analysis** - Identify gaps and deficiencies needed to achieve the desired HSE culture level.	**0,349**
3	**Action –** company determines its priorities for change and takes actions accordingly	**0,914**
4	**Continuous improvement –** company reviews its progress regarding HSE culture indefinitely and takes action accordingly.	**1**
	Inconsistency ratio	**0,02**

Open-mindedness within the organisation can be characterized by the extent to which there is sufficient mutual trust between managers and workers enabling them to take "ownership" regarding HSE responsibilities. The way in which bad news is dealt with is used as an indicator.

Table 13: The level of open-mindedness within the organisation

Levels	Definition	Utility
0	**None –** management is unaware of the problems on the shop floor. (Bad news is ignored)	**0**
1	**Informed –** management is aware of most of the problems on the shop floor but only addressing some of them. (Bad news is tolerated but still unwelcome)	**0,25**
2	**Trusted –** management is aware of most of the problems on the shop floor and taking necessary actions to address them accordingly. (Bad news is accepted)	**0,5**
3	**Accountable** – there is sufficient two-way trust between managers and workers to enable the workforce to take "ownership" regarding HSE responsibilities. (Bad news is actively sought)	**1**
	Inconsistency ratio	**0**

4.2.1.4. Judging validity of the value tree

The value tree was revised several times in the course of development. As a part of the iterative process, the panel judged the validity of the tree at the end of each revision. Having completed the final version of the value tree and the definition of the attributes the panel judged the validity of the tree for the final time.

Completeness:

Three analyses were carried out in order to check completeness of the value tree. Note that the completeness should be checked by more people who have sufficient background in the field of HSE.

(1) HSE program: The attributes of the value tree were compared with the processes of management systems examined in this study. Either the attribute itself or the scales of the performance measures comprise the processes (refer to the appendix – 10). Moreover, the

value tree offers the aspect of HSE culture, which has not been mentioned in the examined management systems.

(2) The basic failure types identified by Tripod – BETA: Tripod – BETA is a tool used to link the general failure type (GFT) categories to the latent failures in the organisation after an incident takes place. It was developed by a collaborative work of Manchester University (Reason et al.) and Leiden Universiteit (Hudson et al.), based on research carried out over the past decade regarding the contribution of behavioural factors in accidents [126, 127]. As a result of an exhaustive survey, the researchers identified 11 GFTs. Tripod theory assumes that the root causes of the incident must fall into one of the GFTs. The initial expectation was that the failure types should be accounted for by the attributes of the value tree. It is found that every GFT corresponds to one of the attributes of the model (as shown in the appendix – 11).

(3) Obtain the expert ideas: All of the experts who took part in the panel agreed that the value tree covers all the aspects regarding HSE management. An HSE expert who had not attended any of the development meetings also admitted the completeness of the value tree.

Operationality: The experts admitted that all the lowest-level attributes in the tree are specific and comprehensive enough to evaluate and compare. However, whilst doing the case studies, they mentioned that 'Job related knowledge of employees in the HSE critical positions' is not convenient to assess because one of the experts wanted to give an intermediate rate between two consecutive levels. And he suggested defining the scale as continuous rather than discrete because the required functional knowledge repository might vary from one unit to another in the same plant. Similarly, two of the experts thought that 'open-mindedness within the organisation' and 'complete implementation of HSE-MS' should be treated, as a continuous scale i.e. to give rates in between levels should be allowed. Therefore, all the weights of the performance scales were converted into continuous utilities (refer to section 4.2.3).

Decomposability (interdependency): In the completeness check (appendix – 10 and 11) all the processes of HSE program and the GFTs are addressed by an attribute of the value tree. But none of the attributes contains HSE processes or GFTs that are included in another attribute. This is strong evidence that each attribute is independent from the other attributes. Moreover, the model was revised several times due to interdependency detected between attributes. Finally the experts agreed that an attribute can be judged independent from another in the way it is currently defined.

Absence of redundancy: No double counting is found in the model because the completeness check (appendix – 10) indicates that none of the lowest level attributes contains HSE processes that are included in another attribute. One of the experts endeavoured to take 'HSE Culture' attribute out because he said that *'if there is a proper management system in place, then we can make sure that culture comes along'*. This suggestion was refuted by another expert with the following argument: *'there are many companies that enjoy a top-nudge management system, yet their HSE culture is still poor.'* As a result the panel decided to keep 'HSE Culture' in.

Minimum size: The experts believe that the size of the tree is sufficiently small to work on. Furthermore, the rule of thumb for the maximum number of attributes is ten measurable attributes. The value tree possesses eight performance measures.

An expert who had not attended any of the workshops also confirmed the validity of the model. The value tree, definitions of the attributes and the performance measures were presented to him. He admitted that the model seems to be complete, definitions are comprehensive and the attributes can be assessed independently.

4.2.2. Step 2: Weighting the attributes

AHP uses a mathematical approach based on eigenvalues. The eigenvector of the pairwise matrix is solved for and the computed eigenvector gives the relative importance (weight) of each attribute. The pairwise comparisons of each sibling attribute are obtained from the experts and employed into the pairwise matrix. In the conventional version of his approach, Saaty suggests using geometric average of the preferences after gathering pairwise comparisons from each expert. [111] argues that it is wiser to get the experts to come to a consensus by deliberation meetings because deliberation allows them to exchange their assumptions and premises. Deliberation also allows for a stimulating exchange of insights and experience. Saaty's method may be more appropriate when surveying a large cross-section of opinion. For the purposes of this study, a learning project with a focused community of participants, the appropriate methodology is the same as that used in [111], a combination of AHP and deliberation.

Having judged the validity of the final value tree, the forth workshop was carried out in order to obtain the pairwise comparisons of each sibling attribute. As mentioned in the previous section, the value tree possesses four set of attributes following a 'split'; that is, Group I, Group II, Group III and Group IV. A novel approach is pursued in this thesis to obtain the weights. This approach provides a structure that prevents inconsistency to an extent by bringing the deliberation discussion forward. However, this approach may create bias in the pair-wise comparisons. Thus, it can be an area to work on for future studies, perhaps by surveying a wider community and adopting Saaty's approach.

1. Individual ranking of attributes in each set

The purpose of this step is to compel the experts to ponder on their own experiences and the knowledge before getting biased by each others' opinions per se. The experts were given 10 minutes to rank each set of attributes (Group I, II, III and IV) according to their preferences. As an example, the result for Group I is illustrated in the table 14. Since the other set of attributes did not lead to in-depth discussion, only the ranking of Group I is explained in the next stage.

Table 14: Ranking of the Group I attributes (1 is the most important and 4 is the least)

	Expert 1 (E-1)	Expert 2 (E-2)	Expert 3 (E-3)	Consensus
Commitment to HSE	3	4	3	3
Compliance with standards	2	3	1	2
HSE-MS	1	2	2	1
HSE culture	4	1	4	4

2. Group discussion and deliberation on the individual rankings

The individual rankings indicate that there are two major disagreements. First, E-2 placed 'HSE culture' in a relatively higher position. This disagreement manifested the first discussion. When E-2 explained his reasoning, it became obvious that he had misinterpreted the definition of 'HSE culture' and the definition was revised according to his feedbacks.

The pair-wise comparison between 'compliance with standards' and 'HSE-MS' was the second debate issue. E-3 thought that 'compliance with standards' should be more important than 'HSE-MS' because *"One can comply with standards even without a structured system in place"*. However, others opposed this view and defended their views by the following example:

"If you have got a systematic and structured management system in place, you can ensure that compliance will come along. Five years ago a subsidiary of Shell firmly resisted implementing the company-wise adopted HSE-MS. They believed that as long as they managed to comply with the set of standards, everything would be fine. The experts sent from the main office spent a lot of time to persuade the subsidiary managers that a well structured and effectively implemented management system would be remedy for the compliance problems per se. The management team continued to be reluctant. Thus, the main office decided to force the HSE-MS up on the subsidiary. Within two years they implemented the HSE-MS, a better compliance was achieved i.e. compliance percentage increased from 60% to 90%. The management team now acknowledge the effectiveness of a systematic management system. They admit that a properly structured

system not only enables the company to comply with standards in a more effective manner, but also ensures sustainability of compliance in the long run."

Finally the experts agreed on the following argument; *"compliance with standards without a structured management system is possible (and you can see several examples in the practice); but it will be extremely slow to adopt new standards and probably lead to repetition of similar (unnecessary) jobs over and over again. More severely compliance can not be sustainable unless there is a management system in place."*

Based on the discussions the experts agreed on the ranking showed in the last column of table 14.

The same approach was repeated for the Group II, III and IV. The individual rankings of the experts happened to be very close. So, there was no discussion. 'Job related knowledge of the employees in the HSE critical positions' is slightly more important than the 'risk management' and 'complete implementation of the HSE-MS'. 'Risk management' is equally important as 'complete implementation of the HSE-MS'. 'Open-mindedness within the organisation' is more important than 'HSE culture management'.

3. Group pair-wise comparison of attributes in each set.

Having agreed on the ranking of the attributes for each group, the pair-wise comparisons were carried out according to the preference scale depicted in figure 4. The questions were asked using verbal responses. For instance, *"You decided that 'HSE-MS' is more important than 'compliance with standards'. How much do you think it is more important; weakly (3), strongly (5), very strongly (7), extremely (9)?"* The intermediate responses were also allowed if the experts preferred these.

The previous discussions about ranking prevent disagreements in this stage. The deliberated pairwise comparisons are illustrated in appendix – 12. The numbers in the tables represent how much more important the 'row' attribute is compared to the 'column' attribute. For example, 'HSE-MS' is five times more important than 'HSE Culture'. Fractional values indicate that the 'column' attribute is most important. For example, 'compliance with standards' is only ½ as important as 'HSE MS'.

4. Obtaining weights

After deliberation of the pairwise matrixes AHP converts it into a set of weights that are normalized to 1. AHP uses the mathematical approach based on eigenvalues [113]. There is a computer package called Expert Choice®, which can carry out the computations. The weights calculated are illustrated in tabular format in table 15. 'G' stands for the global weight associated with the particular attribute; and 'L' indicates the local weight of the associated attribute within its set of attributes under 'split'. That means, 'risk management' has an influence of 0.131 on HSE Management performance index; while, its influence on the 'HSE MS' is 0.250.

Table 15: Global (G) and Local (L) weights of the attributes and performance measures

I.	**Commitment to HSE (L: 0.096, G: 0.096)**	
	a.	Stated process (L: 0.833, G: 0.080)
	b.	Communication of the commitment (L: 0.167, G: 0.016)
II.	**Compliance with standards (L: 0.295, G: 0.295)**	
III.	**HSE Management System (L: 0.524, G: 0.524)**	
	a.	Job related knowledge (L: 0.500, G: 0.262)
	b.	Risk management (L: 0.250, G: 0.131)
	c.	Complete implementation of HSE-MS (L: 0.250, G: 0.131)
IV.	**HSE Culture (L: 0.085, G: 0.085)**	
	a.	Open-mindedness within the organisation (L: 0.800, G: 0.068)
	b.	HSE culture management (L: 0.200, G: 0.017)

4.2.3. Step 3: Eliciting the utilities of the performance measures

The lowest level attributes in the value tree are quantitative. To identify how much marginal and preferable one level is compared to another, a workshop with the panel was carried out. The purpose of this workshop was to elicit utilities for each level. The utilities identify the levels for performance measures that account for a progression in the range of 0-1.00 through deliberative methods using AHP in the same manner that the weights were obtained.

There are several techniques available to assess utility functions [111]. AHP has been used once again both for consistency's sake as the same population have input into this section and also because Expert Choice® offers a convenient function in order to evaluate the expert's utility function over a performance measure per se. This is called the 'Ratings' function. Once the pair-wise ratings are populated as the way described in appendix – 13, Expert Choice® automatically produces the utility functions. The final utilities are depicted in the last column of tables from 6 to 13. The 'Ratings' function uses the linear transformation [110, 111]. The reader may refer to appendix – 9 (part II) in order to get more information about the verification of the linear transformation. In cases where the experts prefer a measure of utility between the scales, the graphical format or its mathematical function (refer to appendix – 14) can be used. The second level utility level of the attribute 'complete implementation of the HSE-MS' was redefined as 'between 0,272 and 0,914' so that the experts can give partial credits depending on the number of the business processes that are implemented.

The experts explained reasoning for their individual preferences as follows:

- For 'communication of the commitment to HSE', there must be a relatively small difference between 'none' and 'documented' because there are refineries that have documented the commitment of management to HSE, but people in the lower levels are not even aware of this commitment. The difference between 'documented' and 'communicated internally' should be given the highest credit because the internal communication is vital to align people towards the same target that is set at the highest level of the organisation.
- The difference between each consecutive levels of 'compliance with standards' should be approximately equal. Moreover, legal compliance that is usually set as an ultimate goal by management team is only 20% as important as the total compliance. This result is consistent with the statements made in the literature. That is, compliance with the law should be regarded as a bare minimum and the companies should go beyond it in order to maintain the competitive advantage in the global market.
- For the 'job related knowledge' attribute the highest weights should be given up to unit level and then the increment will be small because most of the incidents occur due to the failures within the boundaries of an operation unit.
- In the 'Risk Assessment' attribute, there should be a big jump between 'planning' and 'coordinating' because coordinating is all about implementation. The experts have been to several refineries that are good at making plans but when it comes to implementation, management seems to be reluctant and tends to find excuses in order not to complete the projects in time. The same line of reasoning applies for the other attributes; namely, 'complete implementation of HSE-MS' and 'HSE culture management'. There is a big gap between 'fragmented' and 'full implementation' because processes are easy to design and difficult to fully implement. Companies usually overlook the structure and repeat the same things over and over again. This leads to unsteadiness in the sense that some processes are fully implemented; whereas others are missing significant parts. Thus, the scale of 'action' is given the highest weight. The experts also agreed on the fact that there must be a big gap between 'trusted' and 'accountable' scales. The trusted level management not only accept the bad news but also they will act up on it. The accountable will delegate the tasks to lower levels.

4.2.4. Step 4: Checking consistency

Along with the weights AHP also yields an inconsistency ratio, which is calculated by Expert Choice® automatically. Saaty recommends that inconsistency should only be a concern if the index exceeds 0.1. The consistency check was performed in two levels; namely, weight of attributes and performance measures. Obviously there can be no inconsistency for Group II and IV since there is only one pairwise comparison. For Group I and III, the inconsistency ratios were 0.01 and 0, respectively. Since the ratios are less than 0.1, the pairwise comparisons are found to be consistent. Similarly, inconsistency ratios for the performance measures are all below 0.1. Thus, the pairwise comparisons of the performance measures are confirmed to be consistent. As expected the novel approach used in this thesis led to consistent pairwise comparisons. It should be emphasized that a consistent evaluation does not necessarily yield the best decision. Further sensitivity analysis should be performed in order to check whether the weights represent the experts' preferences as intended.

4.3. Case Studies

4.3.1. Case Study 1

This application has two main purposes; namely, (1) check the consistency between the expectation of the experts and the final scores, (2) check whether the model is able to demonstrate the improvement in the HSE performance in the same manner and amount as predicted by the experts. Thus, the panel, consisting of three experts, was given two consecutive tasks. In order to avoid biased results, the second task deliberately was not presented before the first task was completed.

Instructions for task 1
Go back ten years from now (to 1997)
Think of a plant (refinery or a chemical plant) that you used to work on (if there is any)
How would you assess its HSE management performance then using the model?

Ten years ago two of the experts (E-1 and E-2) used to work in the same plant, a chemical plant located in the Netherlands. One of them was working as an assistant plant manager and the other one was HSE technologist. The third expert (E-3) was working in a refinery located in the Netherlands as head process operator. E-1 and E-2 assessed the chemical plant whereas; E-3 assessed the refinery.

The experts filled out the form in Appendix – 15 to which the definition of attributes was attached. The resulting HSE management performance scores (out of 100) are depicted in the second column of table 16. The end scores are multiplied by 100 in order for the experts to benchmark the scores with their expectation conveniently.

Table 16: The resulting HSE management performance scores of the task 1 + 2

	1997	2007
Chemicals (E-1)	48	92
Chemicals (E-2)	50	83
Refinery (E-3)	40	60

The results are consistent with what the experts anticipated; that is, the chemical plant has a better HSE management performance. E-2 argued that in reality the HSE performance of the chemical plant was outperforming the HSE performance of the refinery because historically the HSE performance of chemical plants has always been closely monitored. This is because chemical plants use more hazardous materials than a refinery. The other experts affirmed this rationale.

The assessments of E-1 and E-2 happened to be very close to each other (within 10%). As a matter of this fact it can be concluded from this task that this tool yields consistent results when used by different experts. However, this conclusion cannot be over-generalized due to the limited number of examples.

The experts confirmed that the absolute value of the end results reflect the real HSE management performance.
Having completed the first task, the instructions for task 2 were presented to the panel.

Instructions for task 2
Think of the HSE management performance of the same company today.
How much increase would you expect from 1997?
How would you assess the HSE management performance?
Compare the two results
Do you think the comparison is consistent with what you have anticipated?

The result of the assessments was depicted in the last column of table 16. The difference between the assessments of E-1 and E-2 occurs due to the lack of knowledge of E-1 regarding the final situation of the chemical plant. E-2 succeeded in convincing E-1 that the plant has not achieved as good as E-1 thought by giving a number of examples.

The experts approved that the increase in the HSE management performance from 1997 to 2007 can be represented accurately with these results. In the beginning E-3 said that he was expecting a 50% improvement from 1997 to 2007 and this increase is precisely represented with this tool. Likewise, E-1 and E-2 were expecting a 70-90% improvement and the above-mentioned results prove these expectations.

4.3.2. Case Study 2

This application has four purposes; (1) check the consistency between the expectation of the experts and the final scores, (2) check the consistency of the scores between different experts, (3) check whether the model can be used for benchmarking purposes, (4) validate the consistency by means of a crosscheck analysis between the results produced by the index tool and the indicators used by Shell to track the HSE performance of the companies. The panel was given the instructions for Case Study 2 and the following structure was pursued in order to make analysis.

- Collect the individually filled forms by the experts
- Collect benchmarking indicators that are currently used to assess HSE performances of refineries in SGS
- Collect the results of audit reports done by SGS.
- Interpret the results by checking consistency between the indicators that are currently used and the index model
- Present it to the experts to get their comments

Instructions for Case Study 2
Think of 10 refineries (or chemicals plant) that you have sufficient knowledge of HSE management performance.
Pick the refineries both from Shell and third party companies in an aim to broaden the application of this model.
Assess their HSE management performances by using this tool
Benchmark them.
Do you think the benchmarking is consistent with what is believed to be?

The results of the case study 2 are depicted in the table 17. Ten refineries were assessed by four experts using the index tool. The refineries were assigned to the experts who conducted the audit over the last three years. For instance, Ref B was audited by E-1 and E-4 in 2006.

Table 17: HSE management performance index

	E-1	E-2	E-3	E-4
Ref A		71,19		
Ref B	77,90			78,30
Ref C	84,40		87,80	
Ref D		51,50		
Ref E	84,36			
Ref F	88,57		86,80	
Ref G			22,90	27,20
Ref H	27,60			33,33
Ref I		35,52		
Ref J			92,4	

Two set of data from two different sources were collected:

(1) The performances of the HSE indicators of the selected plants between 2001 and 2005 were collected from the 'Benchmarking' department of SGS (refer to appendix – 16). Note that the performances of three plants are missing because they do not report to the Benchmarking arm of SGS. Ref G has recently begun to report to the Benchmarking department.

(2) Audit scores and audit opinions of the selected plants over the time span (2004 – 2007).

The average of the HSE performances was taken over five years in order to simplify the comparison. The results were listed in the tables available in appendix – 17. This data set could not be used for comparison due to four reasons:

- **Unreliable indicators**: These indicators are recorded and reported by companies and their validity is not checked unless it significantly differs. The interviews with people from the Benchmarking team reveal that validity of the data is monitored in the Shell plants during regular reviews or audits as a part of assurance process. However, it is not the case for the third party companies. In particular, indicators that are not imposed by the government can be misleading because most of the third party companies have a blame culture and therefore, do not tend to report incidents unless it is compulsorily required. For example, Ref G has not reported the fires and explosions correctly because reporting these types of incidents is not mandatory in the specific country that Ref G operates.
- **Inconsistency across indicators**: Indicators are not consistent among each other e.g. it can not be concluded that if a company has a higher (lower) LTIF, then it has a higher (lower) TRCF.
- **High volatility in the health and safety indicators**: Once the trend of indicators over the years is monitored, it can be easily realized that they are extremely volatile and heavily depend on external conditions. The volatility might yield to misleading results. For example, a company that has enjoyed excellent LTIF performance over the past years might have a devastating accident with multiple fatalities tomorrow. For instance, before the BP Texas incident that led to 15 fatalities in 2005, the BP Texas refinery had one of the best performances regarding LTIF. On the contrary, a company that has an average LTIF performance might possess a more sustainable HSE performance. This conflict applies for all the indicators.
- **Negligible difference in the environmental indicators:** The discrepancy between the best and the worst performers vary significantly for every H&S indicator. However, this difference disappears when it comes to environmental indicators. This is because environmental indicators are determined by the amount of emissions and discharges, which are usually enforced by governmental bodies as a form of regulation. In other words, companies have to comply with the regulations set by the governmental bodies. Since the

difference of environmental performances across companies is small, it does not yield to proper comparison.

The second set of data is the audit results, obtained from SGS HSE department. In this set there are two types of data; namely, compliance scores and audit opinions.

The Audit Opinion Methodology has been developed by Shell Chemicals. It is based on the maturity of the management system (maturity factor) and the number and seriousness of audit findings (compliance score). Compliance score is calculated by aggregation of the weighted compliance findings. Compliance findings are classified in four categories by a risk assessment tool depending on seriousness; namely, serious, high, medium and low. The weighting factors are 1000 for serious, 100 for high, 10 for medium and 1 for low findings. Each type is multiplied with the associated weighting factor and summed up. The end result gives the compliance score. As an illustration, Ref F (refer to table 18) has 1 high, 11 medium and 7 low findings. This sums up to 217 (1x100 + 11x10 + 7x1. The compliance score is classified as one of four categories; unacceptable, unsatisfactory, fair, or good, based on the pre-specified threshold values.

Maturity factor is determined by assessing the eight elements of the Shell HSE-MS (refer to appendix – 5). The assessed company could get a score ranging from 0 to 8, which is called maturity factor. This factor is converted to four categories; unacceptable, unsatisfactory, fair, or good.

The minimum of the two determines the audit opinion. For instance, a refinery could have a maturity factor of 7.0 i.e. a 'good' opinion but audit score of 1000 which would be a 'fair'. The overall opinion is therefore the minimum of these two i.e. 'fair'.

SGS does not use audit score to give audit opinion because the experts think that it might lead to undesirable results. The majority experts think that the maturity factor should dominate the final audit opinion because the findings regarding HSE-MS should be more important than the compliance findings. The global weights of 'compliance' and 'HSE-MS' in the model (0,295 and 0,524, respectively) show that this conflict has already been addressed in the index.

Table 18: Comparison between Audit results and index

	Compliance Score	Audit Opinion	Index[10]
Ref A	820	Fair	71.19
Ref B	1042	Fair	77.90
Ref C	502	Fair	84.40
Ref D	1020	Unsatisfactory	51.52
Ref E	800	Fair	84.36
Ref F	217	Fair	88.57
Ref I	2700	Unacceptable	35.52

Due to the lack of available data, a statistical analysis cannot be conducted to see the correlation between the audit opinions and the HSE management performance index. Nonetheless, the index appears to be consistent with the audit opinion in the sense that both of them show a similar pattern in case of dramatic changes. For instance, the differences between 'unsatisfactory, unacceptable and fair' happen to reflect as 35.52, 51.50 and values ranging from 71.19 to 88.57.

Similar to case study 1, case study 2 indicates that the results of experts' assessments are consistent with each other (table 17). The experts stated that the difference between individual assessments for the same plant is negligible. Moreover, they stated that the absolute value of the index is a good representation of the current status of HSE performance. Hence, it was concluded

[10] The index figures are extracted from table 17. If a refinery was assessed by two experts, the average was taken.

that this tool could be used to track the performance of HSE of a plant in the refining and chemical industry.

4.2.3. Sensitivity analysis

Sensitivity analysis is used to examine the consistency and robustness of the model based on the feedbacks from the experts and the results of the case studies. Sensitivity analysis offers insight how the end result might be affected by altering the weights. Expert Choice® produces charts that can be used to carry out sensitivity analysis. The sensitivity analysis was carried out in three parts; (1) qualitative check for global weights of the attributes and the performance measures; (2) robustness of the weights; (3) robustness of the individual assessment.

Qualitative check: The global weights of the attributes were presented to the panel. The panel were asked whether they found the numbers consistent with their expectation in the sense that the numbers can represent their preferences. They admitted that 'compliance with standards' should be the highest and will always remain to be high in the future. 0.295 is a relatively reasonable weight because compliance is all about implementation and without implementation nothing else matters. Moreover, most of the major (multiple fatalities) incidents are still happening due to human failures as a result of non-compliances with standards. 'Job related knowledge of the employees in HSE critical positions' is also crucial because 80% of the incidents result mainly from the human failure. Combined weight of HSE-MS and compliance add up to 0.819, which sounds reasonable because they are the foundation ground of HSE management. The rest of the weights are distributed equally between 'commitment to HSE' and 'HSE culture'. All in all, the panel agreed that the weights are consistent with their gut feeling.

The global weights of each level in the performance measures were presented to the experts in order to crosscheck both before and after the case studies. The experts concluded that the weights for levels are consistent. Hence, this question did not yield to any further discussion.

Robustness of the benchmarking results: The data collected from the case study 2 was input into Expert Choice® in order to check robustness of the benchmarking results against change in the weights of the higher level attributes. Sensitivity analysis can be performed only for the higher level attributes because Expert Choice® does not allow conducting a sensitivity analysis in the lowest level attributes. It should be noted that the amount of the available data is not large enough to draw generic or scientific conclusions. One may refer to the appendix – 18 to find the sensitivity graphs extracted from Expert Choice® and the corresponding interpretations. The results demonstrate that the ranking of Ref C and Ref F is very sensitive to the changes in the weights of 'compliance with standards' and 'HSE-MS' because their weights are very close to the breakeven points. For instance, the current weight for HSE management system is 52.4% and the sensitivity analysis reveals that the breakeven point at which the benchmarking results would change is 58%. Since these two figures are very close to each other, this weight needs to be treated carefully.

Robustness of the individual assessment: Case study 1 and 2 provide sound supporting results about robustness of individual assessment. The individual assessments of different experts for the same plants happened to be consistent with each other. However, more data should be collected and analysed for scientific validation. Within the context of this study it is unattainable.

4.4. SWOT Analysis

As a matter of due diligence, a self assessment of the technique adopted should be executed and SWOT analysis (strengths, weaknesses, opportunities and threats) is performed based on an elaborate discussion session with the experts.

4.4.1. Strengths:

- This tool is able to handle the regional differences per se because none of the attributes is sensitive to regional changes.
- HSE management index is more robust and sustainable; whereas, most of the commonly used HSE indicators are volatile because they are very sensitive to disturbances stemming from the external factors such as incidents.
- This tool enables an assessment of the HSE management performance index of a big corporation that includes many plants because it roots its evaluation into the existence and the performance of "systems". It should be noted that the aggregation cannot be performed by means of taking average per se; but, an evaluation that overviews the entire system should be done.

4.4.2. Weaknesses:

- This tool cannot be filled by a single person because it requires subjective assessment, which needs to be enriched with the involvement of diverse views.
- Universal application of this tool might be restricted because the weights are obtained with a panel formed only by the experts from Shell.
- The HSE management index is not as easy as LTIF to understand. One of the experts claimed that LTIF is universally accepted. This argument was refuted by another expert who gave the example of distinction with respect to the definition of LTIF between big corporations.

4.4.3. Opportunities:

- Monitor progress (the improvement in the HSE management performance can be monitored. HSE experts can use it to identify the areas for improvement and to set specific targets).
- Benchmark between companies.
- Benchmark between big organisations and corporations that have many plants (Ref G includes many refineries).
- Convince the senior management about the importance of HSE investments. But the index itself is yet to be sufficient. Considering the fact that managers are interested in financial benefits, the correlation (if there is any) between the financial performance of companies and the HSE management index should be demonstrated.
- This model can be modified to reveal which HSE interventions will generate the highest return in the most cost-effective way in the long run as the required data is collected.
- Measure the overall HSE management performance.
- Audit findings can be used as an input for this tool.

4.4.4. Threats

- Audit cannot be a potential substitute to the index because it feeds information back in order to correct the detected failures that are extremely specific to a plant. Therefore, its results cannot be used for benchmarking. As a part of audit 'maturity factor', which attempts to evaluate the effectiveness of the elements of the management system, is used. The elements are weighted to be equal so it fails to provide a credible result that helps to benchmark.
- This tool relies on subjective judgements. However, the tools used to give strategic decisions should depend on objective and quantitative judgement.
- The index represents the state of the art for the time being. As conditions change the model may need revisions.

Chapter 5: Conclusion

5.1. Conclusion

The author was involved in a project which delivers complete HSE solutions to a client of Shell Global Solutions International, B.V. (SGS), is the consultancy business unit of Royal Dutch Shell BV. SGS used five approaches to show the importance of HSE management and to achieve the "buy-in" of the client.

- Increasing risk awareness
- Showing success stories and best-practices regarding HSE
- Learning from the past accidents by showing devastating incidents
- Demonstrating the total cost of an incident
- Carrying out workshops to expose the client to the methodologies used by SGS

Interviews conducted with the people from the client company reveal that the methodologies are not sufficiently persuasive. Hence, the primary focus of this study has become to realise a new framework to enable HSE experts to convince management teams by quantifying the benefits of HSE management. For this purpose a solution to the following questions was sought: 'What are the benefits of HSE management?', 'Is there a method to quantify HSE benefits?', 'How is HSE management performance measured?', 'What is the Business Case of HSE?

The literature review is conducted to find answers to the above-mentioned questions. It is divided into two sections. In the first section, the focus is the evolution of the HSE concept. This approach enables an in-depth understanding of HSE phenomenon. In the second section, the methodologies used to justify HSE investments are investigated.

The following findings were deduced from the literature:

- Current methodologies fail to answer the managerial questions that require financial figures such as return on investment, etc.
- There is no indicator which helps to align people at the different levels of an organisation.
- HSE performance indicators used in the practice are incapable of linking the overall HSE benefits to the cost.
- Cost – Benefit Analysis is inconvenient to be used for HSE because the HSE benefits need to be quantified.
- Alternative methodologies to CBA are restricted to specific (small size) problems.

There is neither a method that links the HSE performance to financial benefits, nor an indicator that demonstrates the overall HSE management performance. Hence, an initial step in this domain the author primarily emphasised on *developing a well structured and systematic HSE management performance index* whilst keeping the idea of linking the cost to benefits of HSE management.

The concept of the HSE management can be characterised by means of measurable attributes. Therefore, Multi-attribute theory (MAT) has been utilised to develop the model. MAT is credited for an ability to provide a systematic approach and to combine tangible and intangible aspects of performance. Out of different methods of MAT, the Analytic Hierarchy Process (AHP) has been chosen because AHP enables simple comparison of attributes and consistency check. AHP is enhanced in combination with the deliberation technique to overcome the potential pitfalls mentioned in the literature and yield accurate results.

Data collection has been performed by using a panel of HSE experts working within SGS. The panel decided on the attributes of the value tree with the guidance of academic advisors associated with this research project. The value tree was approved to be valid by being judged against five criteria; completeness, operationality, decomposability, absence of redundancy and minimum size. Expert Choice® has been used in order to calculate the weighting factors, validate the model and conduct sensitivity analysis. Two case studies and sensitivity analyses were conducted so as to demonstrate the practical use of this model and the robustness of the weighting factors. Sensitivity analysis reveals the following results:

(1) Qualitative Check: The experts affirmed that the global weights of the attributes are consistent with their expectations and the weights of the scales are also consistent.

(2) Robustness of the benchmarking results: The results of the case study 2 demonstrates that the weights of 'compliance with standards' and 'HSE management system' are sensitive.

(3) Robustness of the individual assessment: The individual assessment of different experts for the same plants happens to be consistent with each other. However, more data should be collected and analysed for scientific validation.

To check the consistency of the index quantitatively, two types of data set from ten refineries were collected; namely, HSE performance indicators and audit results. HSE performance indicators cannot be used due to; (1) Unreliability, (2) Inconsistency across indicators, (3) High volatility in the H&S indicators, (4) Negligible difference in the environmental indicators. On the other hand, there is strong evidence that the index is consistent with the audit opinion in the sense that they both show a similar pattern in case of dramatic changes. More data should be analysed to prove this consistency statistically.

The significant strengths, opportunities, weaknesses and threats identified are summarised below.

Table 19: Strengths, Opportunities, Weaknesses and Threats

Strengths and Opportunities
This index is able to assess the HSE management performance of corporations irrespective of their sizes.
Progress monitoring over the course of project can be done.
Benchmark between companies and big organisations
Once the correlation (if there is any) between the financial performance of companies and the HSE management index is demonstrated, the index can be used to convince the customers and the management about the importance of HSE investments.
The index can be modified to reveal which HSE interventions will generate the highest return in the most cost-effective way in the long run as the sufficient data is collected.
The index allows measuring the overall HSE management performance
Weaknesses and Threats
The index requires participation of more than one person and uses subjective ideas.
Universal application of this tool might be restricted because the weights are elicited with a group of people from Shell. The generic approach in this thesis however should be generally applicable.
As conditions change, the model may need revisions.

To give a complete answer to the initial problem, the link between the index and financial performance needs to be validated.

5.2. Summary of Contributions

The model developed in this thesis provides a broad framework that allows both scholars and experts to quantify the overall HSE management performance of a plant or an organisation by means of an index. The index attempts to fill the intermediary gap that complicates the utilization of CBA for HSE related issues. The index can be further used for practical purposes to benchmark across peer-companies and to track the overall HSE management performance. This thesis also contributes to the fragmented HSE literature by bringing a novel structure that helps to classify the academic studies under four categories that are the first level attributes of the value tree.

5.3. Future Studies

- The index represents the state of the art for the time being. As conditions change the model may need revisions.
- The weights and the utilities elicited in this study can not be over-generalised because it is case specific. In our case the weights are obtained from Shell experts. To generalise it over other petro-chemicals, the opinions of their experts should be taken into account and the weights need to be revised accordingly.
- It is assumed that there is a link between index and financial performance. This assumption should be addressed in future studies.
- Data needs to be collected in order to find out what kind of HSE interventions generates the highest return in the most cost-effective way. The findings of this analysis can be used to demonstrate the return of HSE investments.
- The identified opportunities for HSE improvement can be prioritised by revising the model.
- A novel approach was pursued to obtain the weights. While it provides a structure that prevents inconsistency to an extent by bringing deliberation discussion forward, it may create bias in the pair-wise comparisons. Its impact on the results should be further examined.

5.4. Lessons learned

During the group discussion the disagreements emerged mainly due to:

(1) the lack of information or diverging knowledge or experience regarding a particular concept

(2) misinterpreting the definition of attributes

The deliberation technique is useful and powerful in the sense that it enables experts to exchange information and experience. This technique led to two outcomes in this study, experts either agreed or opponents wanted to maintain their stances. Some of the discussions ended with mutual agreement but there were controversial issues on which both poles had supporting ideas that were conflicting. Thus, experts spent extensive amount of time to compromise. If the size of the value tree is larger, deliberation will be even more time consuming. Taking the geometric average suggested by Saaty might save time in the cases where it becomes extremely difficult to compromise.

The most challenging part of using Multi-attribute theory is preparing the definitions of the attributes. It should meet the aforementioned five criteria. This phase took five months in total and led to many revisions.

The novel approach developed in order to obtain weights, quickens the discussion and ultimately results in better inconsistency ratio.

Glossary

LTIF: Lost time incident frequency stands for the total number of incidents which result in loss time of more than 1 working day in 1 million working hours.

LTI = Lost Time Injuries are the sum of Fatalities, Permanent Total Disabilities and Lost Workday Cases. If, in a single Incident 20 people receive lost time injuries, then it is accounted for corporate reporting purposes as 20 LTI's (not 1 LTI).

TRCF: Total Reportable Case Frequency is the number of Total Reportable Cases per million Exposure Hours worked during the period.

F&E: Fire and explosions

PIPP: Potential incidents (near-misses) per person

VOC: The VOC loss is expressed as a percentage of crude and feedstock processed, i.e. tonnes of VOCs emitted per 100 tonnes of intake.

CO_2: The CO_2 emission is expressed as tonnes of CO_2 emitted per tonne of crude and feedstock processed.

NO_x: The NO_x emission is expressed as a percentage of crude and feedstock processed, i.e. tonnes of NO_x emitted per 100 tonnes of intake.

SO_2: The SO_2 emission is expressed as a percentage of crude and feedstock processed, i.e. tonnes of SO_2 emitted per 100 tonnes of intake.

Oil discharged: The amount of oil discharged is expressed as grams per tonne of crude and feedstock processed. Note that the total quantity of oil discharged at refinery fence may indicate the quantity of lost margin rather than pollution.

Sludge: The amount of sludge generated is expressed as a tonnes per million tonnes of crude and feedstock processed.

Non-sludge waste: The amount of non-sludge waste generated is expressed as tonnes per million tonnes of crude and feedstock processed.

Exposure hours: Exposure Hours represent the total number of hours of employment for work as defined under section 2.1.3 of the guidelines, including overtime and training but excluding leave, sickness and other absences.

Business Case: Justification of the net profit out of the investment

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Appendix

Appendix – 1 [Regulatory agencies]

OSHA (The Occupational Safety & Health Administration)

The following information about OSHA is annotated from OSHA's official web site [2]. OSHA is organised under the Department of Labour (DoL) in the USA. The Department of Labor fosters and promotes the welfare of the job seekers, wage earners, and retirees of the US. OSHA was created by Congress under the Occupational Safety and Health Act, of December 29, 1970. Its mission is essentially to prevent work-related injuries, illnesses, and deaths. There are more than two hundred OSHA offices that monitor workplace safety and health issues located throughout the US. OSHA exerts majority of its effort on workplace inspections in order to improve working conditions. OSHA developed and based new standards for public service on what it has learned from the survey, from meetings with employee and employer groups, and from focus group discussions with workers from many plants and industries across the US. OSHA issues its new standards under the title of The Code of Federal Regulations (CFR), which is a compilation of regulations issued by federal departments. OSHA's public service improvement program will be an ongoing one. It will continue to gather information on the quality of performance in delivering services to enhance the occupational health and safety issues. Since its inception in 1971, OSHA has helped to cut workplace fatalities by more than 60 percent and occupational injury and illness rates by 40 percent. At the same time, U.S. employment has doubled from 58 million workers at 3.5 million worksites to more than 115 million workers at 7.2 million sites.

H&SE (Health and Safety Executive)

The following information about H&SE is annotated from its official web site [3]. The Health and Safety at Work Act established the Health and Safety Commission (HSC) and the Health and Safety Executive (H&SE) in 1974. HSC's primary function is to make arrangements to secure the health, safety and welfare of people at work and the general public. The work includes proposing new laws and standards, conducting research and providing information and advice. H&SE advises and assists HSC and, together with local authorities, has day-to-day responsibility for enforcing health and safety law, investigating accidents, licensing and approving standards in particularly hazardous areas and commissioning research. Their mission is to ensure that risks to people's health and safety from work activities are properly controlled. Their goals are to continue to reduce injury rates; to continue to reduce work-related ill health and consequent days lost from work; to continue to improve the working environment; and to prevent major incidents with catastrophic consequences occurring in high-hazard industries.

European Agency for Safety and Health at work place

The following information about European Agency is annotated from its web site [4]. The Agency is managed by a Director and has a Governing Board made up of representatives of government, employers and workers from the 25 Member States and representatives of the European Commission. Addressing the diversity of occupational safety and health (OSH) issues and the need for increased awareness at workplace level are beyond the resources and expertise of a single Member State. That is why in 1996 the European Agency for Safety and Health at Work was set up to collect, analyse and promote OSH-related information. The Agency's mission is to make Europe's workplaces safer, healthier and more productive, and in particular to promote an effective prevention culture. This agency issues European Directive which is a regulation imposed by the European Union, which supersedes the regulations of the member states. An EU "Notified Body", a testing agency authorized by the EU to verify compliance with (a) specific Directive(s), uses the applicable relevant standards to perform the tests. The consequence of not complying with the EU Directives is denial of product entry into any EU country.

Appendix – 2 [Trade Associations]

API (American Petroleum Institute)

The following information about API is annotated from its web site [5]. API is the national trade association that represents all aspects of America's oil and natural gas industry. 400 corporate members, from the largest major oil company to the smallest of independents, come from all segments of the industry. They can be producers, refiners, suppliers, pipeline operators and marine transporters, as well as service and supply companies that support all segments of the industry. API advocates for the petroleum industry to the public, Congress and the Executive Branch, state governments and the media. API negotiates with regulatory agencies, represent the industry in legal proceedings, participate in coalitions and work in partnership with other associations to achieve members' public policy goals. API conducts or sponsors research ranging from economic analyses to toxicological testing. And it collects, maintains and publishes statistics and data on all aspects of U.S. industry operations. For more than 75 years, API has led the development of petroleum and petrochemical equipment and operating standards. API maintains more than 500 standards and recommended practices. Many have been incorporated into state and federal regulations; and increasingly, they're also being adopted by ISO. API organizes seminars, workshops, conferences and symposia on public policy issues

AIChE (American Institute of Chemical Engineers)

The following information about AIChE is annotated from its web site [6]. AIChE is world's leading organization for chemical engineering professionals, with more than 40,000 members from 93 countries. It has the breadth of resources and expertise pertaining to both core process industries and emerging areas, such as nano-biotechnology. Any member has the right to access information on recognized and promising chemical engineering processes and methods from this global network of intelligent, resourceful colleagues and shared wisdom. AIChE serves as the foremost catalyst in applying chemical engineering expertise in meeting societal needs through stimulating collaborative efforts among industry, universities, government, and professional societies. It advocates public policy that embraces sound technical and economic information and that represents the interest of chemical engineers

CCPS (Centre for Chemical Process Safety)

The following information about CCPS is annotated from its webs site [7]. CCPS is a non-profit, corporate membership organization within AIChE that identifies and addresses process safety needs within the chemical, pharmaceutical, and petroleum industries. CCPS brings together manufacturers, government agencies, consultants, academia and insurers to lead the way in improving industrial process safety. CCPS member companies, working in project subcommittees, define and develop useful, time-tested guidelines that have practical application ranging from human factor issues to qualitative and quantitative risk analysis to security vulnerability to inherently safer design within industry. CCPS and its members are ultimately committed to protecting employees, communities, and the environment by developing engineering and management practices to prevent or mitigate catastrophic releases of chemicals, hydrocarbons, and other hazardous materials. CCPS continues to achieve this mission by advancing state-of-the-art process safety technology and management practices, (2) serving as a premier resource for information on process safety, (3) fostering process safety in engineering and science education, (4) promoting process safety as a key industry value

Appendix – 3 [HSE standards]

COMAH (Control of major accident hazards)

The following information about COMAH is extracted from [10]. It came into force in the United Kingdom on 1 April 1999 and are amended by the Control of Major Accident Hazards (Amendment) Regulations 2005 from 30 June 2005. They implement Council Directive 96/82/EC known as the Seveso II Directive, as amended by Directive 2003/105/EC and replaced the Control of Industrial Major Accident Hazards Regulations 1984 (CIMAH). COMAH applies mainly to the chemical industry, but also to some storage activities, explosives and nuclear sites, and other industries where threshold quantities of dangerous substances identified in the Regulations are kept or used.

ISO 14000

The following information about ISO 14000 is annotated from [9]. ISO 14000 is among ISO's most widely known standards. ISO 14000 is aiming at achieving in enabling organizations to meet their environmental challenges. The ISO 14000 family is primarily concerned minimizing harmful effects on the environment caused by its activities, and continually to improve its environmental performance.http://www.iso.org/iso/en/aboutiso/introduction/index.html - top#top It is accepted as "generic management system standard". "Generic" means that the same standards can be applied to any organization, large or small, whatever its product is and in any sector of activity such as a business enterprise, a public administration, or a government department.

IEC 61508

The following information about IEC standards is annotated from [11]. It provides industry and users with the framework for economies of design, greater product and service quality, more inter-operability, and better production and delivery efficiency. IEC's standards also encourage an improved quality of life by contributing to safety, human health and the protection of the environment. IEC 61508 particularly defines appropriate means for achieving functional safety in the systems it covers. IEC 61508 applies to safety-related systems when one or more of such systems incorporate electrical and/or electronic and/or programmable electronic (E/E/PE) devices. It covers possible hazards caused by failure of the safety functions to be performed by the E/E/PE safety-related systems, as distinct from hazards arising from the E/E/PE equipment itself (for example electric shock etc).

Seveso Directive

The following information about Seveso Directive is extracted from [12]. In Europe, following the Seveso accident in 1976 prompted the adoption of legislation aimed at the prevention and control of such accidents. In 1982, the first EU Directive 82/501/EEC – so-called Seveso Directive – was adopted. On 9 December 1996, the Seveso Directive was replaced by Council Directive 96/82/EC*,* so-called Seveso II Directive. This directive was extended by the Directive 2003/105/EC. The Seveso II Directive applies to some thousands of industrial establishments where dangerous substances are present in quantities exceeding the thresholds in the directive

RMP (Risk Management Program)

The following information about RMP is annotated from [13]. When Congress passed the Clean Air Act Amendments of 1990, it required EPA to publish regulations and guidance for chemical accident prevention at facilities using extremely hazardous substances. The rule, which built upon existing industry codes and standards, requires companies of all sizes that use certain flammable and toxic substances to develop a Risk Management Program which includes

Hazard assessment that details the potential effects of an accidental release, an accident history of the last five years, and an evaluation of worst-case and alternative accidental releases;

Prevention program that includes safety precautions and maintenance, monitoring, and employee training measures; and

Emergency response program that spells out emergency health care, employee training measures and procedures for informing the public and response agencies (e.g the fire department) should an accident occur.

RMP is about reducing chemical risk at the local level. This information helps local fire, police, and emergency response personnel (who must prepare for and respond to chemical accidents), and is useful to citizens in understanding the chemical hazards in communities. EPA anticipates that making the RMPs available to the public stimulates communication between industry and the public to improve accident prevention and emergency response practices at the local level

PSM (Process Safety Management)

The following information is annotated from [14]. Regardless of the industry that uses highly hazardous chemicals, there is a potential for an accidental release any time they are not properly controlled, creating the possibility of disaster. To help ensure safe and healthful workplaces, OSHA has issued the Process Safety Management of Highly Hazardous Chemicals standard (29 CFR 1910.119), which contains requirements for the management of hazards associated with processes using highly hazardous chemicals. Process safety management is addressed in specific standards for construction and general industries. OSHA's standard emphasizes the management of hazards associated with highly hazardous chemicals and establishes a comprehensive management program that integrates technologies, procedures, and management practices. OSHA obtained some standards from ANSI and API during compilation of PSM.

OHSAS (Occupational Health & Safety Assessment Series)

The information about OHSAS 18000 is annotated from [15]. It is an international occupational health and safety management system specification. It comprises two parts, 18001 and 18002 and embraces a number of other publications. OHSAS 18001 is an *Occupation Health and Safety Assessment Series* for health and safety management systems. It is intended to help organizations control occupational health and safety risks. It was developed in response to widespread demand for a recognized standard against which to be certified and assessed. OHSAS 18001 was created via a concerted effort from a number of the worlds leading national standards bodies, certification bodies, and specialist consultancies. A main driver for this was to try to remove confusion in the workplace from the proliferation of certifiable OH&S specifications. Many organisations are now looking at implementing the Occupational Health and Safety Management System (OHSAS 18001). Despite not being a legal requirement, it is a recognised specification that structures the implementation of an effective HSE management system. This overview takes a brief look at the reasons why certification may be appropriate for your company.

Appendix – 4 [Elements of PSM]

This data is extracted from the OSHA's official web site [14].

Employee Participation

Employers are required to have a written plan outlining their employee participation. Employee participation should begin at the inception of PSM implementation. Such participation not only improves employee commitment to PSM, but a facility will end up with a much more viable implementation process. The involvement should include employees at all levels of the organization, from field operators, up through supervision, to operations management. The participation should extend to every element of PSM. NOTE: The safety staff should be a resource for PSM, not the ones in charge of the program.

Process Safety Information (PSI)

Occupational Safety & Health Administration (OSHA) states that PSI is "Complete and accurate written information concerning process chemicals, process technology, and process equipment." It is the information necessary for implementation of all other aspects of PSM. Complete information on every chemical involved in the process, including intermediates, is required. Process technology includes not only Process Flow Diagrams (PFDs) and Piping & Instrumentation Diagrams (P&IDs), but operating and storage conditions as well as operating procedures (see below) and operating history (for existing processes). Process equipment information should include the underlying codes and standards relied upon, in addition to information about the specific equipment used in the process.

Process Hazards Analysis (PHA)

A PHA is a systematic evaluation of the hazards involved in the process. PHAs are required for initiation of a process and at least once every five years after that. The PHA team should be multi-disciplinary, including maintenance, operations, and engineering. There are a variety of methods that can be used to conduct a PHA. The method selected will depend on the maturity of the process and operational experience, in addition to process size and complexity. The facilitator of the PHA must be trained in the methodology being used. For proper conduct of a PHA, the PSI must be as complete as possible.

Operating Procedures

Operating procedures include not only the steps for normal operations, but for upset conditions, temporary operations, start-up, and shutdown. Very important safety information must also be included in operating procedures. Such information includes basic hazards of exceeding operational limits, appropriate response to upset conditions, safety and health information, and emergency operations. The procedures need to be up to date and reliable. They are also a critical element in training of personnel.

Training

Training is required for all employees new to a process before they become involved in that process. Training requirements extend beyond operating personnel to anyone involved in the process. This would normally include at least maintenance personnel and, possibly, contractors. The training must include the hazards of the chemicals and process and what is necessary to protect themselves, their fellow employees, and their surrounding communities. Training should be both written/classroom and hands-on. Employers must evaluate the effectiveness of training and make adjustments to content and frequency of training based on those evaluations.

Contractors

Employers using contractors need to ensure that use of those contractors will not jeopardize the safety of operations. This starts with the selection process, where the employer needs to evaluate the safety performance and capabilities of potential contractors. Once selected, the employer must make sure that contractor employees have the appropriate skills and training to perform their work safely. The employer must also provide contractors with sufficient information/training to perform their jobs safely. Ongoing, the employer should keep a log of contractor injuries and illnesses (in addition to its own employees) and periodically evaluate the safety performance of its contractors. The contractors themselves also have various requirements, including ensuring that all of their employees are appropriately trained or informed to perform all of their responsibilities.

Pre-Startup Safety Review (PSSR)

The Pre-Startup Safety Review is done before startup of a new operation or startup following a change in the process (see Management of Change, below). It is a means for ensuring that all essential action items and recommendations from the PHA have been completed prior to beginning operations. It is also the point at which the design parameters and standards used for construction are verified. If training or modifications to PSI are necessary, completion of these items is also verified during the PSSR. Startup should not be allowed to occur until all safety-critical PSSR items have been completed.

Mechanical Integrity

Employers are required to have a written program to ensure the integrity of processes and equipment. Aspects include listing applicable equipment, training of maintenance personnel, inspection and testing, and maintenance of such systems as controls, vessels, piping, safety systems, and emergency systems. Development and modifications to the mechanical integrity program should be made based on operational experience, relevant codes, and industry standards.

Hot Work Permits

Hot work permits must be issued for any work to be performed on, or near, a PSM-covered process. While the OSHA standard specifically lists Hot Work, permits should be developed for any non-routine work to be performed in or around PSM covered processes. In addition to hot work, this could include line breaking, lockout/tagout, confined space entry, etc. Again, while the standard is titled "permit", it really means an entire procedure covering all hazards of the work to be performed.

Management of Change (MOC)

"Change" includes anything that would require a change in Process Safety Information. This includes changes to equipment, processes, and instrumentation. A proper MOC system requires that any change be evaluated prior to its implementation. The level of evaluation can depend on the degree of change and its criticality to the safety of the operation. In addition to the evaluation and approval of a change, MOC requires that suitable training be conducted (if necessary) and the relevant PSI be updated.

Incident Investigation

Incident Investigation is required for any incident that either did, or could have, resulted in a release of a PSM-covered chemical. There are very specific requirements for the timing of an investigation, the makeup of the investigation team, the resulting report, and the use/dissemination of the information obtained. If done properly, it is one of the primary tools for learning from the operation of a process. It should truly determine the root cause of an incident, not merely find someone or something to blame.

Emergency Planning and Response

Employers are required to develop and implement an emergency action plan for the entire plant, not just the process(es) covered by PSM. It needs to address the actions to be taken in response to the release of any PSM-covered chemical. The plan needs to be comprehensive, including notification to emergency responders, operational responses such as shutdown, and precautions to protect other employees and the public. There is a good probability that requirements for emergency response are also covered by other regulatory standards.

Compliance Audits

Per OSHA, compliance audits must be conducted at least once every three years. The purpose of the audits is to determine whether the practices and procedures developed under the provisions of the PSM standard are being followed and are effective. The auditor(s) must be knowledgeable in PSM and should be impartial to the facility being audited. According to OSHA, selection of appropriate auditors is "critical to the success of the process." An audit report must be developed and the employer must promptly respond to each of the findings. Once deficiencies are corrected, the corrective action must also be documented.

Trade Secrets

The trade secrets provision of PSM requires that the employer provide all information necessary to comply with PSM to all persons who need it. This does not preclude the employer from taking steps necessary to safeguard the integrity of any information disclosed. It merely prohibits the employer from using trade secrets as an excuse not to provide information to either employees or contractors.

Appendix – 5 [Global Companies HSE-MS]

Exxon-Mobil

The information about ExxonMobil HSE MS has been annotated from [18]. ExxonMobil set HSE policies in order to achieve high operational standards and environmental performance. Operations Integrity Management System (OIMS) [19] which provides a robust management framework that addresses HSE requirements has been developed to reach these standards. OIMS (figure 6) consists of 11 elements which should be fulfilled by every ExxonMobil facility.

OIMS allows ExxonMobil to track learnings from incidents and to use those findings to adjust future actions, whilst continually improving HSE performance. The pictorial representation depicted demonstrates three main parts of OIMS; namely, driver, operations and evaluation. Driver is the enabler element which is required to promote the utilization of OIMS in the organization. Operations include the integral elements of OIMS which helps to keep the organization safe. Evaluation enables the organization to assess the current situation of operations and point to the necessary actions if any required to further improve them. This is the common practice of Deming circle for continuous improvement.

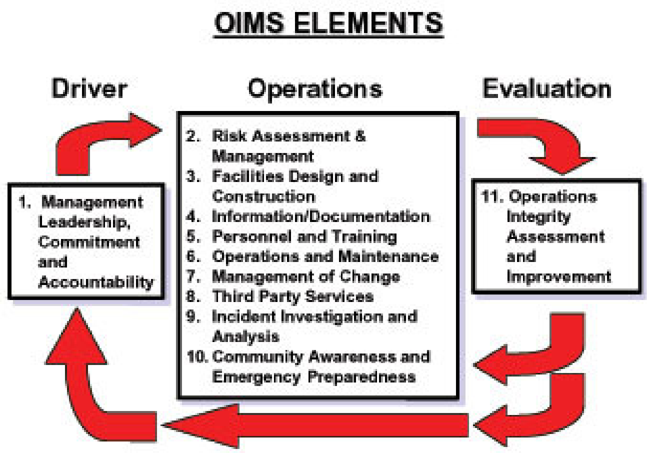


Figure 6: OIMS Elements

BP

The information about BP HSE Management System has been interpreted from [20]. BP HSE MS (figure 7) contains 13 elements that have been structured around the Deming circle of continuous improvement. This framework links to the BP Commitment to Health, Safety and Environmental Performance. In other words, Business Units are held accountable to develop and implement complete MS. Local management systems are organized so as to establish the group HSE performance targets such as reductions in CO2 emissions, ISO 14001 certification requirements etc.

Figure 7: BP HSE Management System

SHELL

The information about Shell HSE MS has been annotated from its web-site [21]. Shell HSE MS contains 8main elements (figure 8). These elements have been structured around a continuous improvement circle. Therefore, strategic targets to improve the HSE performance are set and periodically tracked.

The management system is a systematic approach which is designed to

- Ensure compliance with the law
- Demonstrate that all hazards are adequately managed
- Achieve continuous improvement in HSE performance

The common elements of an integrated HSE MS are involved under standards and guidelines; namely, Incident investigation management, Emergency preparedness, Risk management.

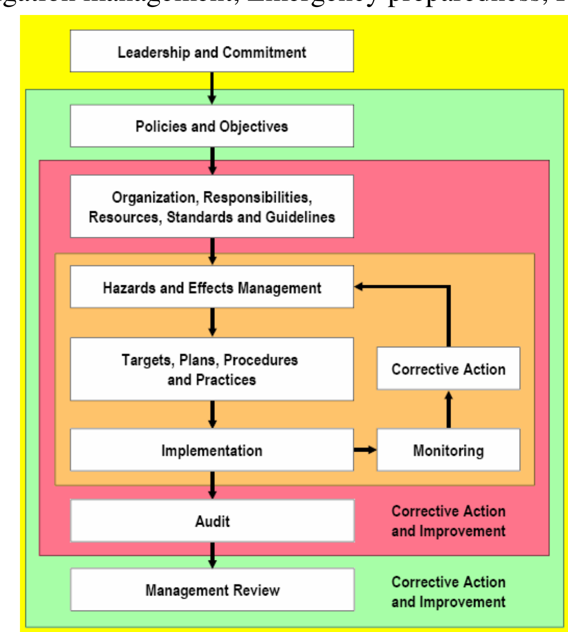


Figure 8: Shell HSE Management System

Dow Chemicals

The information about Dow Chemicals and Responsible Care® were annotated from [22]. Responsible Care® is a voluntary initiative within the global chemical industry to safely cope with the products from developing, through manufacture and distribution, to ultimate disposal. It was launched in Canada in 1987 and has quickly spread to 45 countries. In 1999 Dow declared to devote to Responsible Care® in an effort to continuously improve HSE performance including its affiliates globally.

Responsible Care® is more than a set of principles and declarations. It is implementing management systems, verified through independent auditors; tracking performance through established HSE measures; and extending these best practices to business partners through the industry supply chain.

American Chemistry Council (ACC) [23] adopted a new management system approach for the implementing Responsible Care® in the U.S entitled as The Responsible Care Management System (RCMS). A RCMS offers an integrated, structured approach to yield to results in seven key areas: community awareness and emergency response; security; distribution; employee health and safety; pollution prevention; process safety; and product stewardship.

The basic framework for the RCMS includes:

Policy & Leadership

- Leadership Responsibility
- Commitment

Planning (PLAN)

- Define Risks/Hazards - Objectives & Targets
- Process/Program Development - Communications

Implementation, Operation & Accountability (DO)

- Training - Documentation
- Procedures - Management of Change and Employee Empowerment

Performance Measurement & Corrective Action (CHECK)

- Self-Assessment - Incident Investigations
- Internal Audits - Records Management
- Corrective/Preventative Action - Measurements

Management Systems Review (ACT)

- Management Systems Review

Appendix – 6 [HSE cases from the real life]

The selected case studies from the real life application are depicted in table 20, 21 and 22. Table 20 shows the benefits of HSE program implementation from the case studies published in the literature. Table 21 and 22 show the success stories from the HS&E and OSHA respectively.

Table 20: Benefits of HSE program implementation from Case Studies

Success Story
Alcoa reduced its workplace injury rate by 90% from 1987 to 2000. Alcoa accompanied its safety gains by profit increasing its value to shareholders eightfold [88]
Dow companies reduce injury rates (One achieved a 50% reduction for savings over $8 MM/year). Higher employee morale and loyalty, better attraction and retention of people, higher earnings per share, enhanced corporate image and higher market share and sales. These companies enjoy with a total saving of 150 million $ per year derived from productivity increases, production costs saved, maintenance costs saved, capital budget saved and reduced insurance costs [89].
Samarco implemented an Integrated HSE Management System and gain considerable advantages in terms of competitive Differential, corporate improvement and minimization of risk factors [90].
The Trinidad and Tobago Ltd (Petrotrin) now benefits from improved employee morale, reduced insurance

premiums and fewer legislative liability costs by managing the following waste streams: (1) Basal Sediments from operations and historical pollution; (2) Produced water and drilling fluids from oil recovery; (3) Oil soaked waste from pollution incidents and maintenance activities [91].
As the 1992 report shows, NPS' (Northern States Power Co.) lost workday rate has been reduced almost fivefold since 1982, from 6.22 to 1.35 cases per 100 employees (-78 percent). The total recordable rate dropped 42 percent, from 11.87 to 6.86 Eases per 100 employees [92].

Table 21: HS&E success stories

Astra-Zeneca(UK local branch)
53% reduction in ergonomic-related cases
Downward trend in number of work-related stress cases
Scores for depression in UK staff are 20% to 30% lower.
Health insurance spend is lower than bench marked, saving £200,000 a year
Absence levels are 31% lower than average levels for the UK
Employees note significant improvements in concentration and productivity at work
Ranks in top 10% of Dow Jones Sustainability Performers worldwide, in the top 20% in Europe, and recently listed in the FTSE4Good series
Taylor Woodrow(UK local branch)
Analysis of productivity and safety benchmarks within Taylor Woodrow shows that the sites with the best safety performance also tend to be the most productive, predictable and profitable
St Regis Paper Company(UK local branch)
61% drop in injuries from 4.9 to 1.9 per 100 employees
64% reduction in the overall accident rate from 2.37 to 0.85 per 100,000 hours worked
73% reduction in employee insurance claims from 833 to 222 per 100,000 employees
Reduction in rate of increase of Employers Liability Insurance premiums
18% reduction in numbers of days lost to injuries
Royal Mail Group plc(UK local branch)
40% reduction in reportable injuries per 1000 employees
More than 30% reduction in 'all accidents' per 1000 employees since 1997
More effective accident investigation, monitoring of safety improvements as a result of investigations, and better records
Better audit data enabling benchmarking and continuous improvements
40% reduction in days lost per employee through accidents and ill health
Reduction in days lost over five years equivalent to around £700,000 savings
50% reduction in the yearly number of civil claims from around 25-30 per year, to 17 in 2002
The Associated Octel Company Ltd(UK local branch)
Effective 40% reduction in production unit costs and improvements in equipment reliability
Reduction in lost time incidents from 35 in 1996 to zero in 2002 and 2003
Improved trust and reputation in local Community
Reduction in insurance claims, from over 50 in 1997 to zero in 2002
Improved staff morale – absenteeism down from 10% to 2.5% of staff
50% reduction in injuries compared to hours worked
Improved housekeeping procedures
Greater accountability in internal projects, particularly in capital investments

<u>GlaxoSmithKline </u>(UK local branch)
First GSK site with joint accreditation under ISO 14001 and OHSAS 18001
Better stress management
First GSK site to achieve 4 million hours worked without any Lost Time Injury or Incident
Lost Time Accident rate per 100,000 hours worked reduced from 1.43 to zero
Establishment of a positive organisational culture ensuring good industrial relations
Around 40% reduction in employers liability claims since 2000
Improved relationships with local community

Table 22: OSHA success stories

On August 29, 2001, Liberty Mutual Insurance Company released a report titled: *A Majority of U.S. Businesses Report Workplace Safety Delivers a Return on Investment.* The Liberty Mutual survey shows 61 percent of executives say $3 or more is saved for each $1 invested in workplace safety.
An HSE director for an environmental services company in Massachusetts reported that its tracking data indicated $8 saved for each dollar spent on a quality HSE program.
A coal mining company in Charleston West Virginia has attained a competitive advantage through investment in HSE programs. The company claims its worker compensation rate is $1.28 per $100 in payroll as opposed to its competitor's rate of $13.78.
Fall protection program implementation reduced one employer's accident costs by 96 percent - from $4.25 to $ 0.18 per person-hour.
Implementation of an OSHA consultation program reduced losses at a forklift manufacturing operation from $70,000 to $7,000 per year.
Participation in OSHA's Voluntary Protection Program has saved one company $930,000 per year and the company had 450 fewer lost-time injuries than its industry average A SHARP (Safety & Health Assessment & Research for Prevention Program) participant reduced its lost workday incidence rate from 28.5 to 8.3 and reduced insurance claims from $50,000 to $4,000 through decreases in both direct and indirect losses through a reduction its number of back and shoulder injuries.
Implementation of an improved safety and health program reduced Servicemaster's worker's compensation costs by $2.4 million over a two-year period
A manufacturer using a state consultation program reduced its worker's compensation modification rate from 1.7 to .999, and saved $61,000 on its worker's compensation insurance premiums.
OSHA's Office of Regulatory Analysis has stated: …*our evidence suggests that companies that implement effective safety and health cans expect reductions of 20% or greater in their injury and illness rates and a return of $4 to $6 for every $1 invested...* In their 9/2001 article titled: *Measuring Safety's Return on Investment*, Susan Jervis and Terry R. Collins, make the argument that there is a direct correlation between a company's performance in safety and its subsequent performance in productivity and financial results. They pointed out that in the Forbes 1999 Financial Rankings, among those listed ten of the most-successful U.S. businesses were participants in the OSHA VPP program

Appendix – 7 [Tools developed in the literature]

Table 23 depicts the evaluation methods recently developed in the literature.

Table 23: Evaluation methods recently developed in the literature

[100] Net-cost model for workplace interventions	Introduces a methodology to examine the costs and benefits of ergonomic interventions applicable to a variety of economic sectors and settings comprehensively.
[101] CERSSO	is a tool kit that can be used as a self-evaluation instrument and be comprehensive

	enough so that any user can collect the data from scratch and come up with sound results which help them underpin the underlying logic to make decisions. It has 6 steps. **1** Definition of the Magnitude of the Problem according to causes and effects **2** Risk Estimation **3** Definition of the preventive measures to be undertaken. **4** Graphing the relationship between the preventive measures and their positive impact. **5** Evaluating the cost of prevention and its effects **6** Analysis of the Costs-Benefits
[102] Productivity Assessment Tool	is a specific cost benefit analysis tool helping to estimate the cost effectiveness of employees after an intervention pertaining to occupational health and safety. It indicates important financial role that safe and efficient workplaces can play. This tool takes the hidden costs into account as well as the direct costs of injuries and job related illnesses in an attempt to justify the preventive investments. There are four parts to the analysis in this tool. 1. Data concerning the employees i.e. the number of employees, their working time and wages, overtime and productivity 2. Data concerning the workplace i.e. supervisory costs, recruitment, insurance, overheads, maintenance, waste, energy use costs. 3. Intervention costs 4. Cost-benefit analysis calculations
[97] PROCESCO	This method attempts to contribute to the development of a more comprehensive safety assessment method by combining the advantages of indices as quantitative tools and the ability of indicators provide indirect measures of safety. It takes into account 25 areas in the review of the plant safety in order to measure specific aspects of safety. The index model involves just operational safety; not occupational safety. Therefore, this index can not be an appropriate representative for a complete HSE programme.
[104] Cost of Safety, COS	presents a cost analysis model that can help HSE professionals measure, analyze, and communicate safety strategies in business terms. Authors use cost of quality, COQ, model from total quality management and tailor it to the safety in an effort to justify the HSE investments. By using prevention, detection, internal failure and external failure concepts of COQ, they end up with an optimal equilibrium point for safety level. It is not a perfect model because it can not be generalized to the entire company; i.e. it is just applicable to particular locations and failure costs are difficult to quantify.
[105] An Integrated Safety	A semi-quantitative safety assessment technique which is LOPA (Layer of Protection Analysis) attempts to justify the investment. It is an operational safety tool which contributes to the technical and organizational aspects of safety whose results can be used for input in recommendations regarding investment decisions for development of safety performance indicators. This technique considers the impacts in both organizational and technical level. Organizational aspects can be measured by safety culture quick scans based on the OSHAS 18001 audit method. Then Tripod delta, a model developed by University Leiden and Manchester used to identify latent failures which may result in human error, is used and scenarios, which might unleash these latent failures, are developed. Based on these scenarios safety ratings, safety quality factor and safety gap are estimated. Finally a value called cost effectiveness ratio, CE, is calculated simply dividing the increase in the safety rate by the expected difference between cost and savings from the investment. The higher CE, the more cost-effective investment is. Hence companies can assess the safety level of a site or installation to justify these safety measures. Even tough this model helps to explain which element of an HSE programme will lead to the highest return; it fails to provide insight about the overall HSE performance of the company.

Appendix – 8 [HSE indicators used by the global petrochemical companies]

This appendix explains the HSE indicators tracked by the global petrochemical companies.

ExxonMobil

Exxon Mobil keeps record of the following items.

1. ExxonMobil records all incidents and near misses, conduct thorough incident investigation and use the lessons learned.
2. ExxonMobil benchmarks 'occupational injuries and illnesses rate' of each unit against its own global standards and relevant external indicators.
3. ExxonMobil monitors and measures its environmental performance through a range of consistently defined Environmental Performance Indicators such as:
    - Energy efficiency
    - Greenhouse gas and other air emissions
    - Spills to water and land
    - Waste
    - Operating permit compliance

To obtain further information about the methodologies being used to track the HSE performance in Exxon-Mobil, refer to its web-site [107].

BP

BP sets both short and long term targets. HSE targets are included in the performance contracts of all levels within BP. These targets not only serve as progress measures, but also encourage sound behaviors and demonstrate commitment. There are two main types of targets:

- outcomes - tangible results indicating improved performance, e.g. fewer injuries, spills, or near misses
- Inputs - activities expected to cause or affect the desired outcomes, eg audits, training, or risk assessments completed

Input targets tend to be used in individual performance contracts and at the facility level. Outcome targets can better demonstrate commitment and work best with groups and at higher levels within the organization. A combination of outcome and input targets is essential to focus effort and drive behaviour changes.

Some BP affiliations have publicized their HSE performance data from [108]. These data appear to be type of outcomes. The input types of data are held confidential since they include facility specific information.

1. Fatality Rate
2. LTIF
3. RI: Recordable incident
4. Air Emissions
5. Discharges to water
6. Waste disposal
7. Spills

Shell

The HSE plan includes formal audits, regular monitoring and measurement, and structured management reviews to ensure the continuing suitability, adequacy and effectiveness of the management systems. Shell keeps track of the following set of HSE indicators.

- Loss time injury (LTI) and Loss time injury frequency (LTIF)
- Number of Near-misses
- Total Recordable incident case (TRIC)
- Number of fires and explosions
- Number of leaks and spills
- Emissions (CO_2, SO_2, NOX, VOX)
- Oil discharged to the water/effluent

Dow Chemicals

Below are the HSE performance indicators being used to set targets and track the performance in Dow.

- Injuries and illnesses (Recordable incidents) per 200,000 work hours
- Number of Fatalities – Dow Employees and Contractors
- Loss of primary containment incidents (leaks, breaks, and spills)
- Transportation incidents per 10,000 shipments
- Process safety incidents (fires, explosions, and chemical releases)
- Motor vehicle incidents per one million miles
- Repeat incidents with Dow product at customer facilities
- Capital expenditures for HSE projects OR Percentage of Total Capital Spending

Different from the other companies Dow Chemicals attempts to justify the HSE expenditures. Dow Chemicals began to record HSE expenditures in 1999 and since then facility managers are expected to allocate budget for HSE. Nonetheless, there does not appear to be any methodology developed to link the expenditures to the performance indicators unless carried out statistics manually.

Appendix – 9 [Verification of the Linear Transformation and calculation of the inconsistency ratio]

Part I: Conversion of the weights of the performance measures into utilities:

$$u = a + b * w$$

$$a = -b * worst$$

$$b = \frac{1}{(best - worst)}$$

where u is the utility, and best and worst refer to the largest and smallest weights.

Part II: Verification of the linear transformation:

Let us take the scales of 'open-mindedness within the organisation'. Expert Choice® produces the utility values depicted in the last column of the table 13. The weights of the levels are calculated as 0, 0.143, 0.286, 0.571, from level 0 to 3, respectively. If one solves the above-introduced transformation for u for each level, then one will numerate the same values produced by Expert Choice®.

b = 1 / (0.571 – 0)

a = 0

u (for level 2) = 0 + 0.286*[1/0.571]

u (for level 2) = 0.5

Part III: Calculating the inconsistency ratio:

It has been shown that for any matrix small perturbations in the entries imply similar perturbations in the eigenvalues; thus the eigenvalue problem for the inconsistent case is:

$$A\ w = \lambda_{max}\ w,$$

since it represents the average of the remaining eigenvalues. To find lambdamax,

$\det[A - \lambda_{max} I] = 0$

should be solved.

where λ_{max} will be close to n (actually greater than or equal to n) and the other lambdas will be close to zero. The estimates of the weights for the activities can be found by normalizing the eigenvector corresponding to the largest eigenvalue in the above matrix equation.

The closer λ_{max} is to n, the more consistent the judgments. Thus the difference, λ_{max} - n, can be used as a measure of inconsistency (this difference will be zero for perfect consistency). Instead of using this difference directly, Saaty defined a consistency index as:

$$(\lambda_{max} - n) / (n-1)$$

In order to derive an accurate interpretation of either the difference or the consistency index, Saaty simulated a very large number of random pairwise comparisons for different size matrices, calculating the consistency indices and arriving at an average consistency index for random judgments for each size matrix. He then defined the consistency ratio as the ratio of the consistency index for a particular set of judgments to the average consistency index for random comparisons for a matrix of the same size.

Since a set of perfectly consistent judgments produces a consistency index of 0, the consistency ratio will also be zero. A consistency ratio of 1 indicates consistency akin to that which would be achieved if judgments were made at random rather than intelligently. This ratio is called the inconsistency ratio in Expert Choice, since the larger the value, the more inconsistent the judgments.

Appendix – 10 [Comparison of the value tree and management systems]

The red coloured items are the attributes of the value tree. And the bold written items below stand for the process that the attribute corresponds to.

Table 24: Comparison of the value tree and management systems

Commitment to HSE: **Commitment of the senior management** to HSE stands at the core of all the management systems examined in this study.
Compliance with standards: **Compliance Audit** **Life Cycle Safety** (design, installation, operation, maintenance, decommissioning)
Job related knowledge of the employees working in the HSE critical positions: **Background education** determines whether the employee is sufficiently qualified for his particular job in terms of process knowledge and capacity. **Operating procedures** are the procedures for all processes (initial start-up, normal operations, temporary operations, emergency shutdowns, normal shutdowns, start-ups following a turnaround or emergency shutdown) exist in the system. **Training** is a way to provide the required information, skills and abilities to the people involved in operating a process.
Risk Management: **Level 1 – Identification of the hazards:** **Process Safety Information** (PSI) provides the essential knowledge about the hazard prior to an elaborate hazard analysis including information pertaining to the hazards of hazardous chemicals used or produced, technology of the process and equipment used in the process**.** **Pre-Startup Safety Review** is a review of PSI in case of a major modification or renewal of the facilities or introduction of the new chemicals. **Management of Change** is the process of addressing any change having an impact on a covered process (e.g. changes to process, chemicals, technology, equipment, procedures and/or facilities). Its main purpose is to increase the awareness of the new hazards as a result of a change in the system. **Incident Investigation** requires investigating the incidents which resulted in, or could reasonably have resulted in a release of highly hazardous chemicals in the workplace. **Accident History** **Process hazard analysis** begins with identification of the hazards. **Work planning** and **permit to work** are the activities to help organisations become aware of the potential hazards in the outset of the task. **Level 2 – Assessment:** **Risk assessment** is done by using the appropriate methodology. **Level 3, 4, 5 – Managing the risks:** **Contractor Management** **Mechanical integrity** **Emergency response planning** **Leadership to HSE**
Complete implementation of the management system: **Management Program** ensures that a structured approach is used to put the entire HSE program in place.

Appendix – 11 [Comparison of the value tree and GFTs of Tripod – BETA]

Definition of the general failure types (GFT):

There are 11 failure types identified by Reason [125]. The definitions of the failure types are as follows:

Table 25: Definition of the general failure types

Hardware (HW) - where the failures are due to inadequate quality of materials or construction, non-availability of hardware and failures due to ageing (position in life cycle)
Design (DE) – where the deficiencies are in layout or design of facilities, plant, equipment or tools that lead to misuse or unsafe acts, which increase the chances of particular types of errors and violations
Organisation (OR) - where there are deficiencies in either the structure of a company or the way it conducts its business that allow safety responsibilities to become ill-defined and warning signs to be overlooked.
Procedures (PR) – where procedures are unclear, unavailable, incorrect or otherwise unusable standardised task information that has been established to achieve a desired result
Training (TR) - where there are deficiencies in the system for providing the necessary awareness, knowledge or skill to an individual or individuals in the organisation. In this context, training includes on-the-job coaching mentors and supervisors as well as formal courses. Awareness refers to the process of understanding the hazardous conditions present at the worksite.
Maintenance management (MM) - where there are failures in the systems for ensuring technical integrity of facilities, plant equipment and tools
Housekeeping (HK) - where tolerance of deficiencies in conditions of untidiness and cleanliness of facilities and work spaces or in the provision of adequate resources for cleaning and waste removal increase the chances of unsafe acts
Defences (DR) - are failures in the systems, facilities and equipment for control or containment of hazards or for the mitigation of the consequences of either human or component failures. These comprise: detection/alarm; control and interim recovery; protection/containment and escape.
Error-enforcing conditions (EE) - where factors such as time pressures, changes in work patterns, physical working conditions acting on the individual or in the workplace encourage the performance of unsafe acts (errors or violations)
Incompatible goals (IG) - where there is a failure to manage conflict: between organisational goals (such as safety and production); between formal rules (such as company written procedures and the rules generated informally by a work group); between the demands of individuals, tasks and their personal preoccupation or distractions.
Communication (CO) – where there are failures in transmitting information that is necessary for the safe and effective functioning of the organisation to the appropriate recipients in a clear and unambiguous or intelligible form. Transmission failures indicate that the necessary communication channels do not exist or the necessary information is not transmitted.

Table 26: Comparison of the attributes and the GFT

Attributes of the model	GFT
Commitment to HSE	OR
Compliance with standards	HW, DE
HSE management system	PR, TR, MM, HK, DR
HSE culture	EE, IG, CO

Appendix – 12 [The pairwise comparison of the sibling attributes]

The experts agreed that 'general HSE knowledge of the employees' is significantly more important than 'risk management' and 'effectiveness of HSE MS' because any deficiency in the employees' HSE knowledge would potentially trigger incidents per se. On the other hand, management systems are not linked to incidents as direct as the HSE knowledge of the employees. 'Risk management' and 'effectiveness of the HSE MS' is rated to be equal.

Table 27: Comparing the importance of first level attributes (Group I)

	Commitment to HSE	Compliance with standards	HSE Management	HSE Culture
Commitment to HSE		**1/3**	**1/5**	**1**
Compliance with standards			**1/2**	**4**
HSE Management System				**5**
HSE Culture				
Inconsistency ratio: 0.01				

The experts thought that 'open-mindedness within the organisation' is strongly more important than the 'HSE culture management'.

Table 28: Comparing the importance commitment attributes (Group II)

	Stated process	Communication of the commitment
Stated process		**5**
Communication of the commitment		

Table 29: Comparing the importance of 'HSE Management System' attributes (Group III)

	Job related knowledge	Risk Management	Complete implementation of HSE-MS
Job related knowledge		**2**	**2**
Risk Management			**1**
Complete implementation of HSE-MS			
Inconsistency ratio: 0			

Table 30: Comparing the importance of 'HSE Culture' attributes (Group IV)

	Open-mindedness within the organisation	HSE culture management
Open-mindedness within the organisation		**4**
HSE culture management		

Appendix – 13 [Instructions how to use priority function]

Figure 9 is extracted from the Help of the Expert Choice®. It explains how to use the priority function.

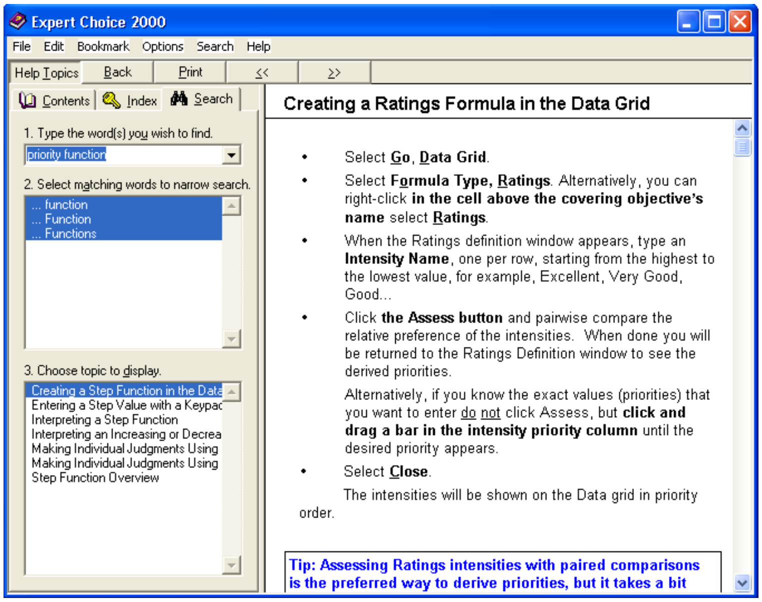
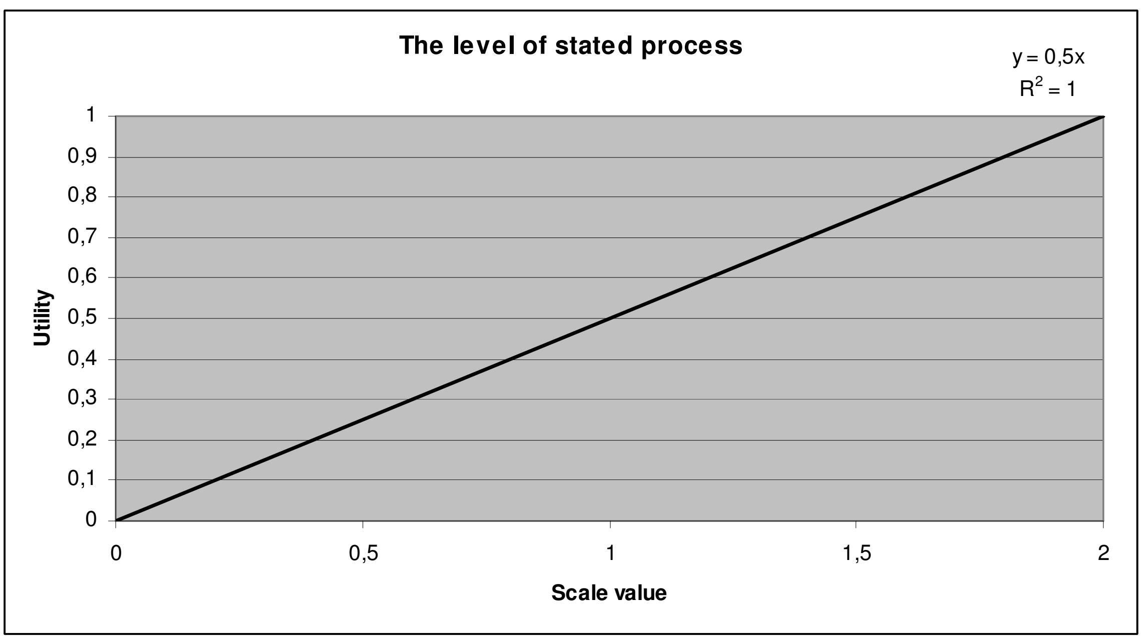
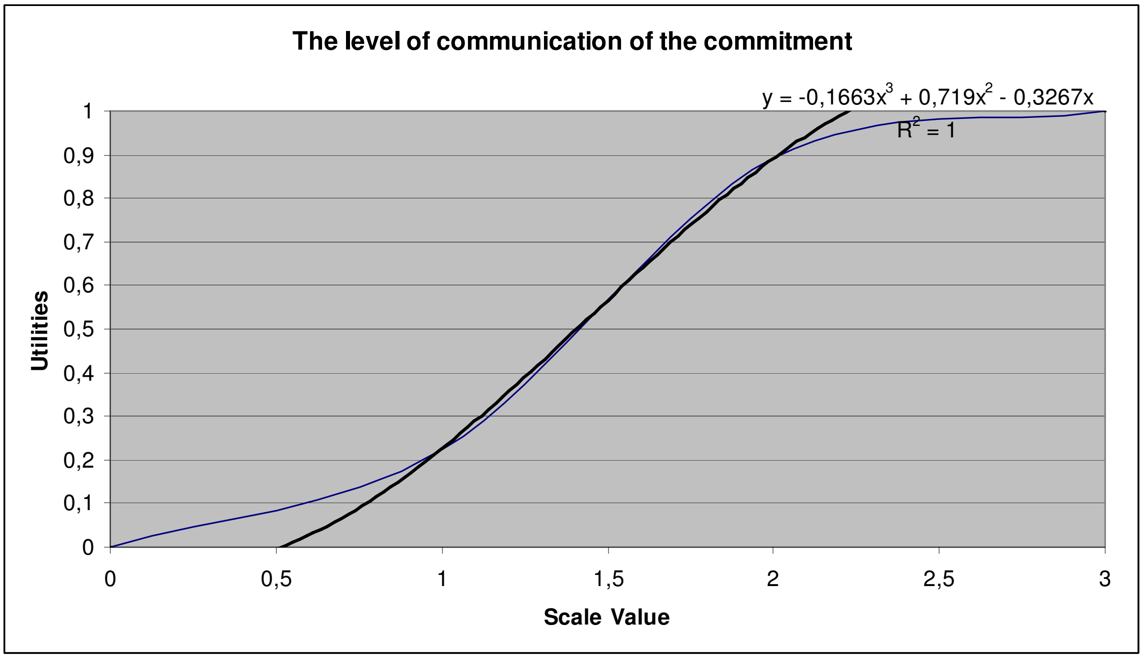
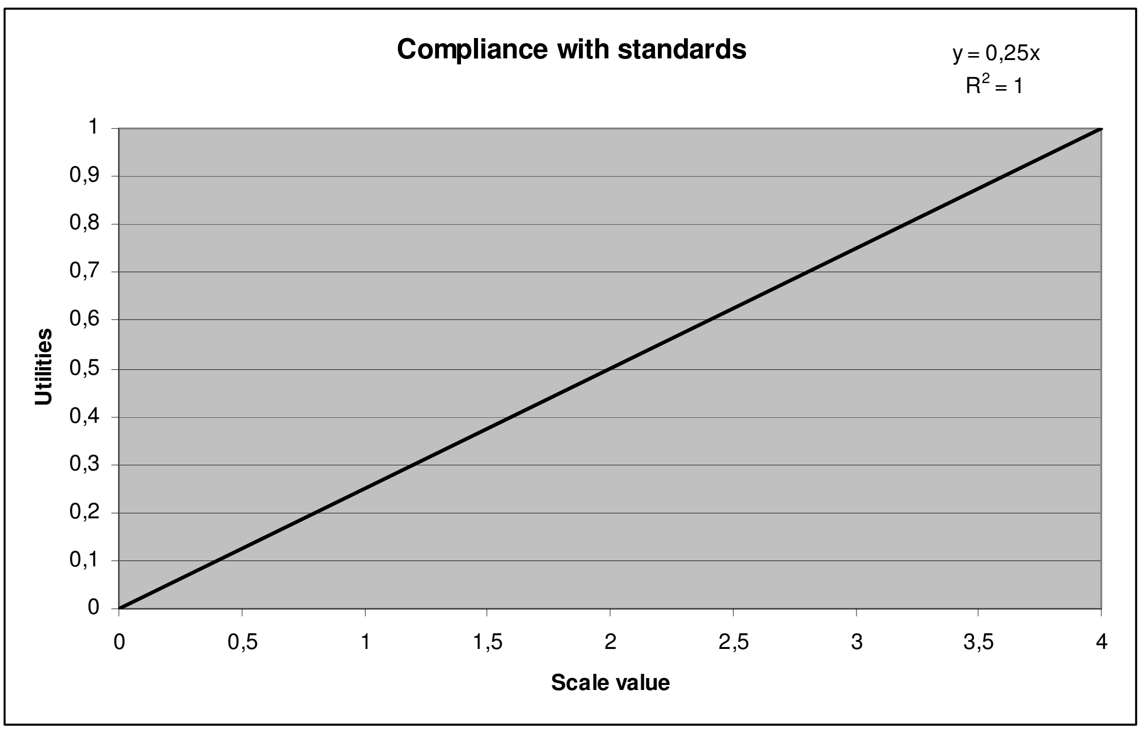


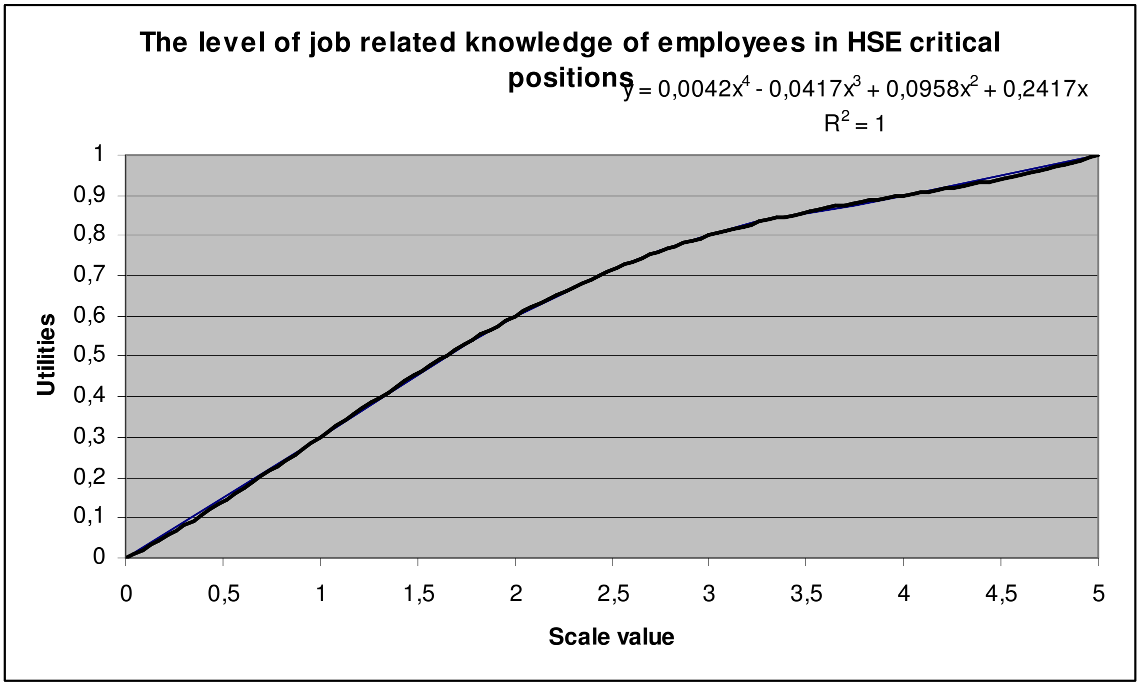
Figure 9: instructions how to use priority function in Expert Choice®

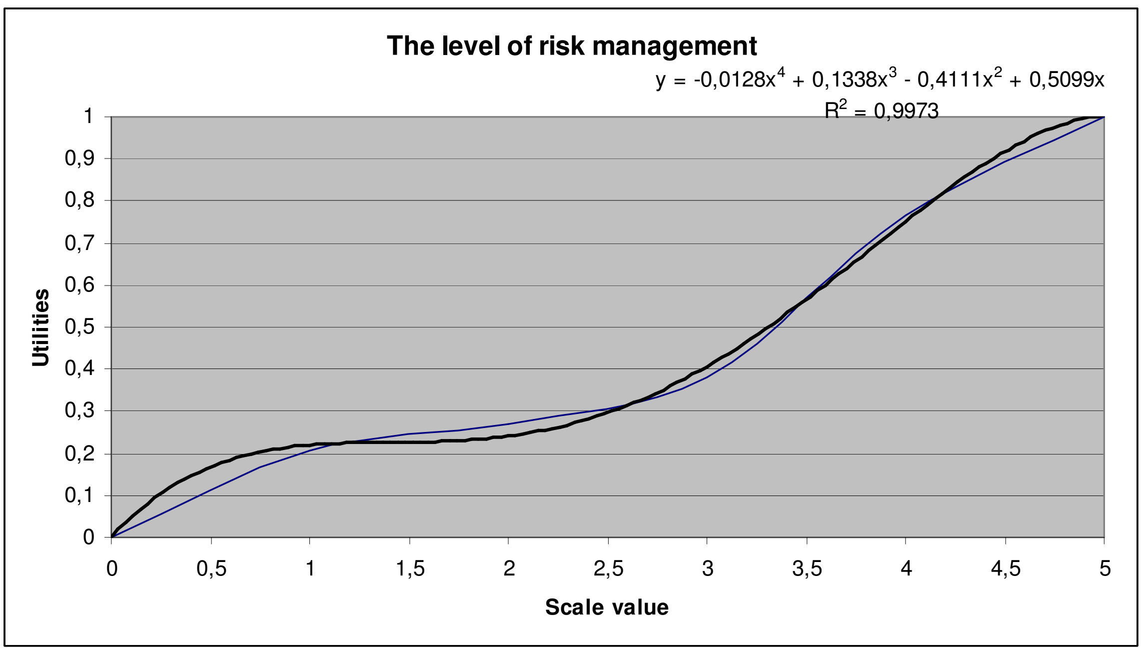
Appendix – 14 [Graphical representation and mathematical function of the utility functions of the performance measures]

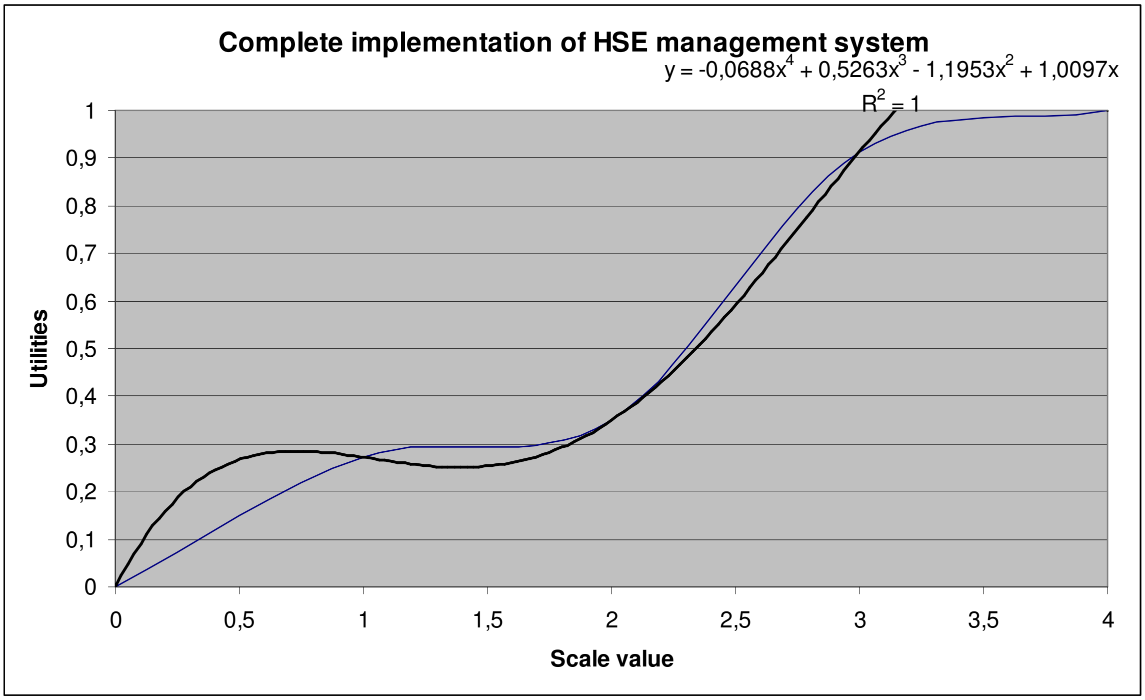


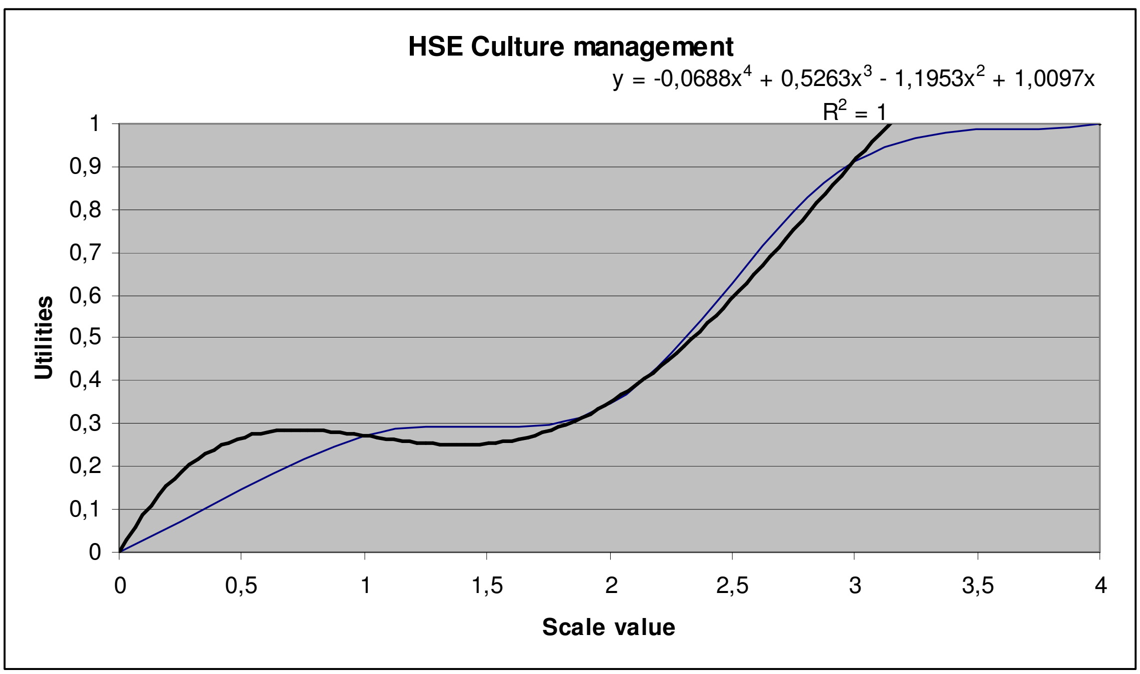

The level of communication of the commitment
y = -0,1663x3 + 0,719x2 - 0,3267x
R2 = 1
Utilities
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,5
1
1,5
2
2,5
3
Scale Value


Compliance with standards
y = 0,25x
R2 = 1
Utilities
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,5
1
1,5
2
2,5
3
3,5
4
Scale value


The level of job related knowledge of employees in HSE critical positions
y = 0,0042x4 - 0,0417x3 + 0,0958x2 + 0,2417x
R2 = 1
Utilities
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Scale value


The level of risk management
y = -0,0128x4 + 0,1338x3 - 0,4111x2 + 0,5099x
R2 = 0,9973
Utilities
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5
5
Scale value


Complete implementation of HSE management system
y = -0,0688x4 + 0,5263x3 - 1,1953x2 + 1,0097x
R2 = 1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Utilities
0
0,5
1
1,5
2
2,5
3
3,5
4
Scale value


HSE Culture management
y = -0,0688x4 + 0,5263x3 - 1,1953x2 + 1,0097x
R2 = 1
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
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0
Utilities
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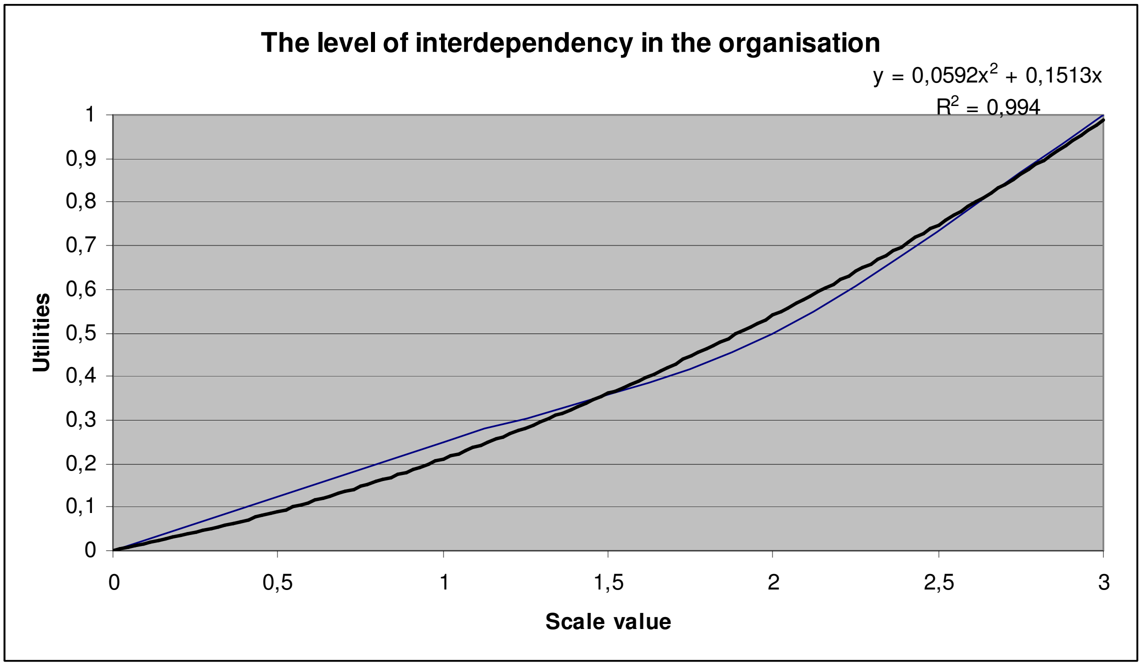
2,5
3
3,5
4
Scale value



Appendix – 15 [Model matrix for practical uses]

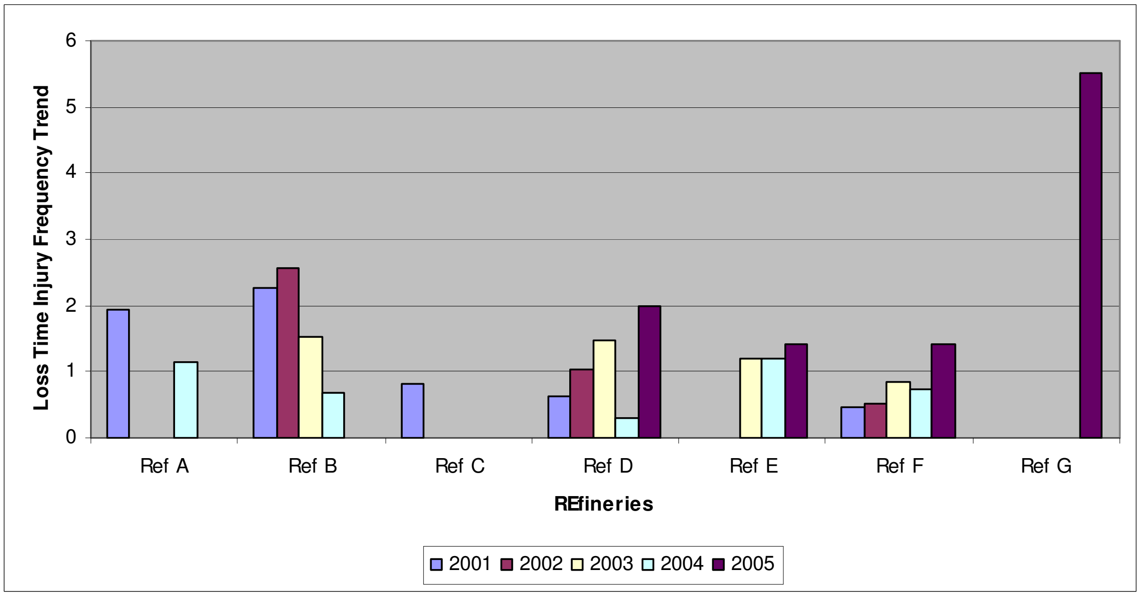
Experts crossed the associated circle for a specific attribute and level.

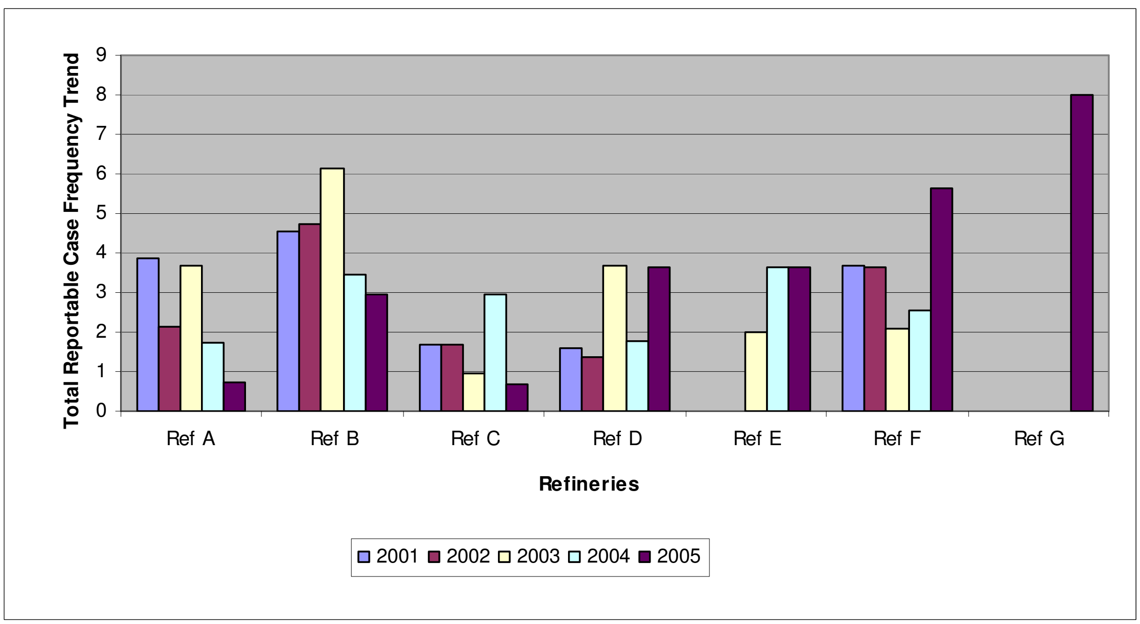
Table 31: Model matrix for practical use

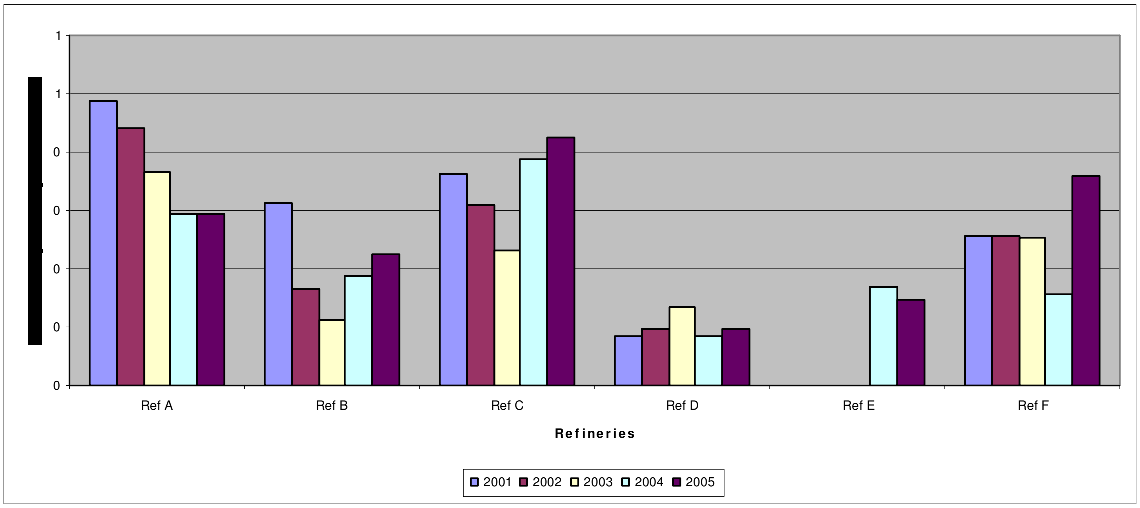
Attributes	LEVELS					
The level of stated process	none 0	stated targeted goals 0	stated as long term process 0			
The level of communication of the commitment	none 0	documented 0	communicated internally 0	communicated externally 0		
Compliance with standards	none 0	legal compliance 0	voluntary compliance 0	create and comply 0	ensuring the total compliance 0	
The level of job related knowledge of employees in HSE critical positions	none 0	personel level 0	team level 0	unit level 0	site level 0	industry level 0
The level of Risk management	none 0	identification of the hazards 0	Assessment 0	Planning 0	Coordinating 0	Monitoring 0
The effective implementation of HSE management system	none 0	Defined and documented 0	fragmented 0	full implementation 0	full imp. + monitoring 0	
HSE Culture Management	none 0	awareness 0	gaps analysis 0	action 0	continuous improvement 0	
The level of Open-mindedness in the organisation	none 0	informed 0	trusted 0	accountable 0		

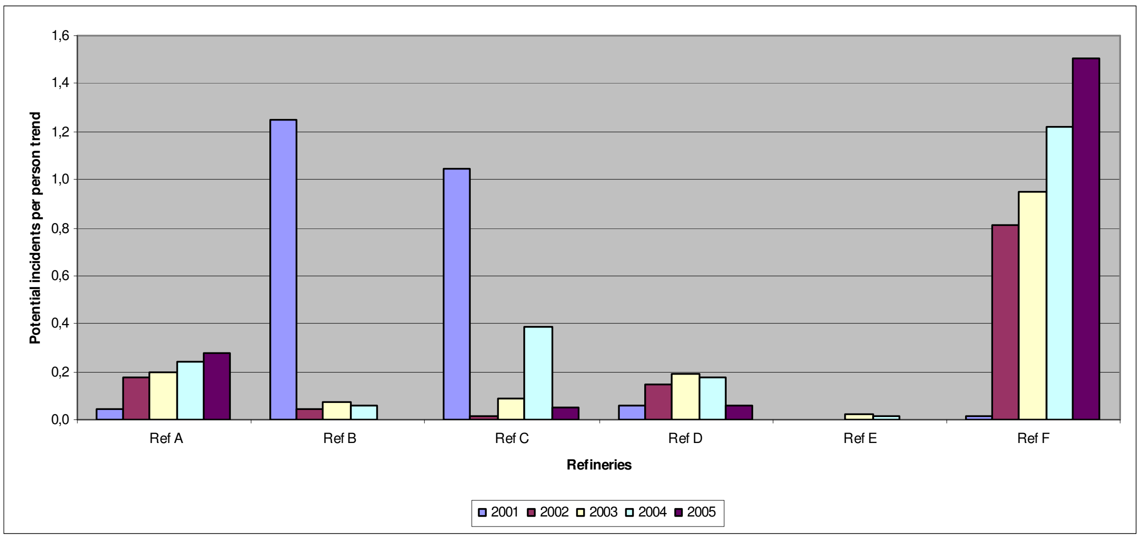
Appendix – 16 [HSE Refinery Benchmarking Results]

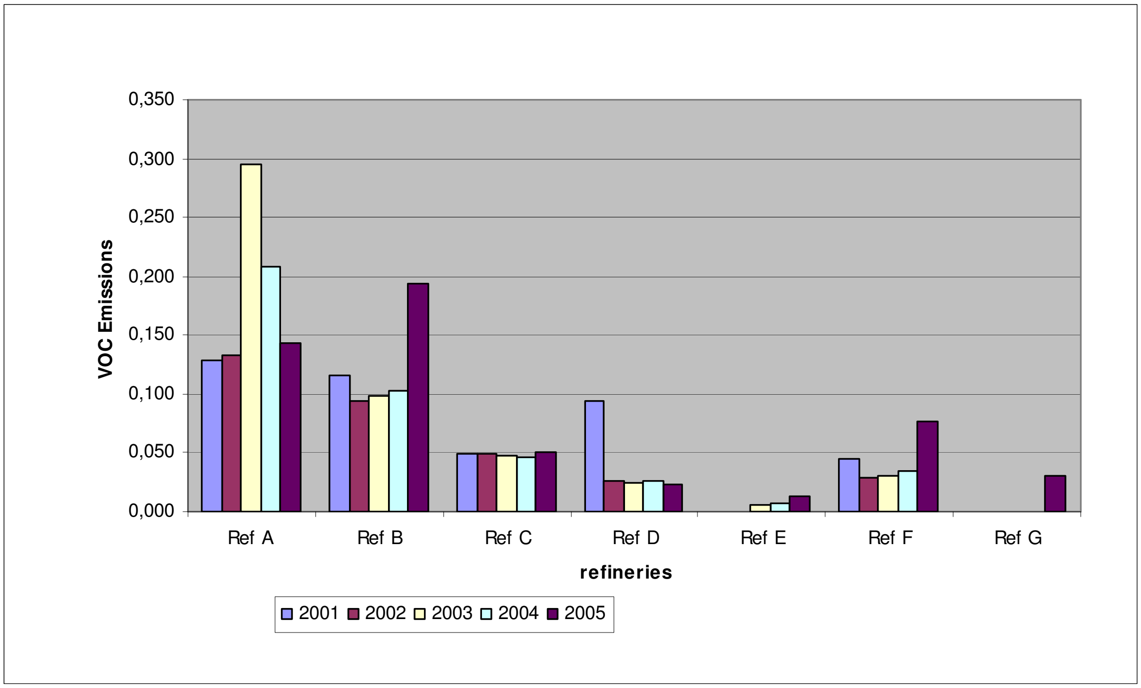
In this appendix the performance of the HSE indicators collected from the Benchmarking department is depicted. The figures show the particular performance of the refineries for the years between 2000 and 2005.

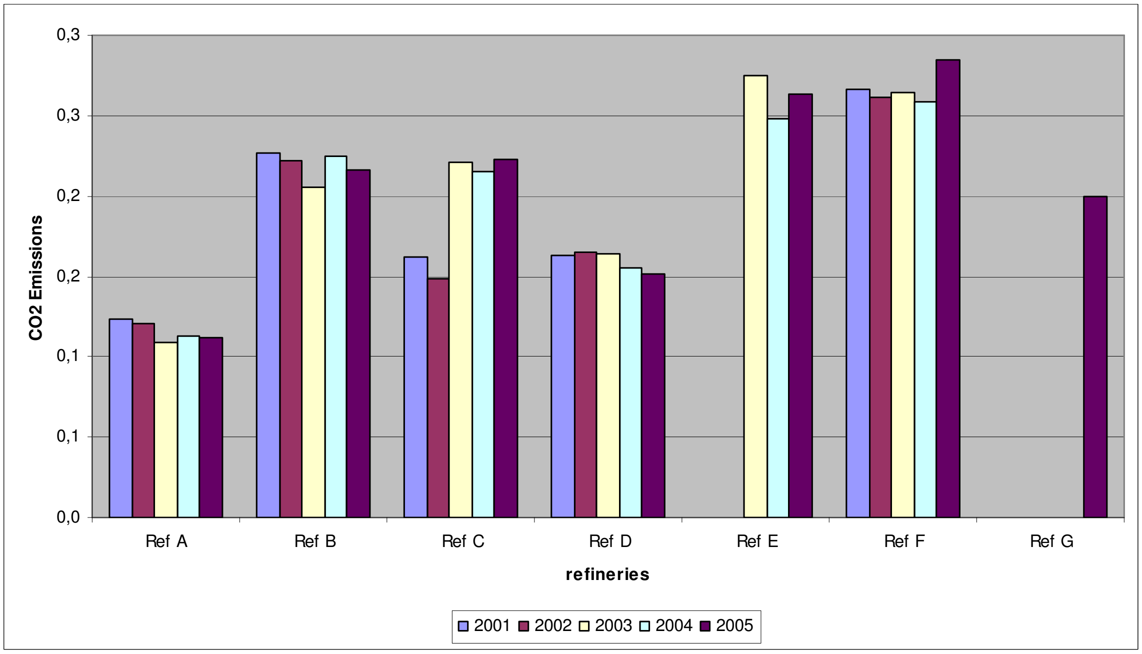


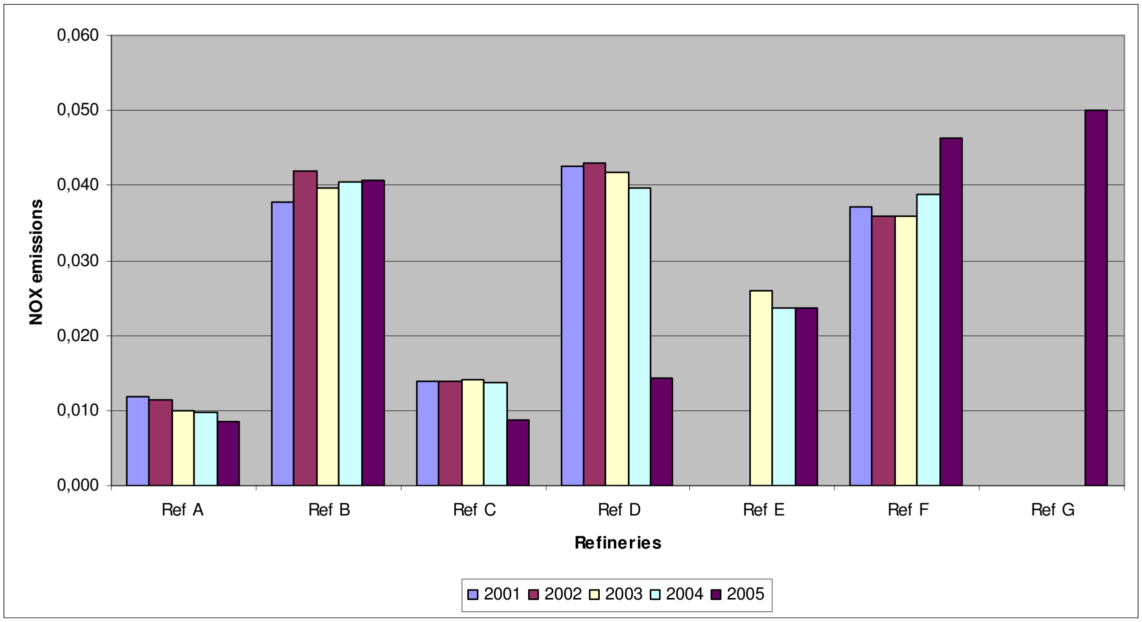


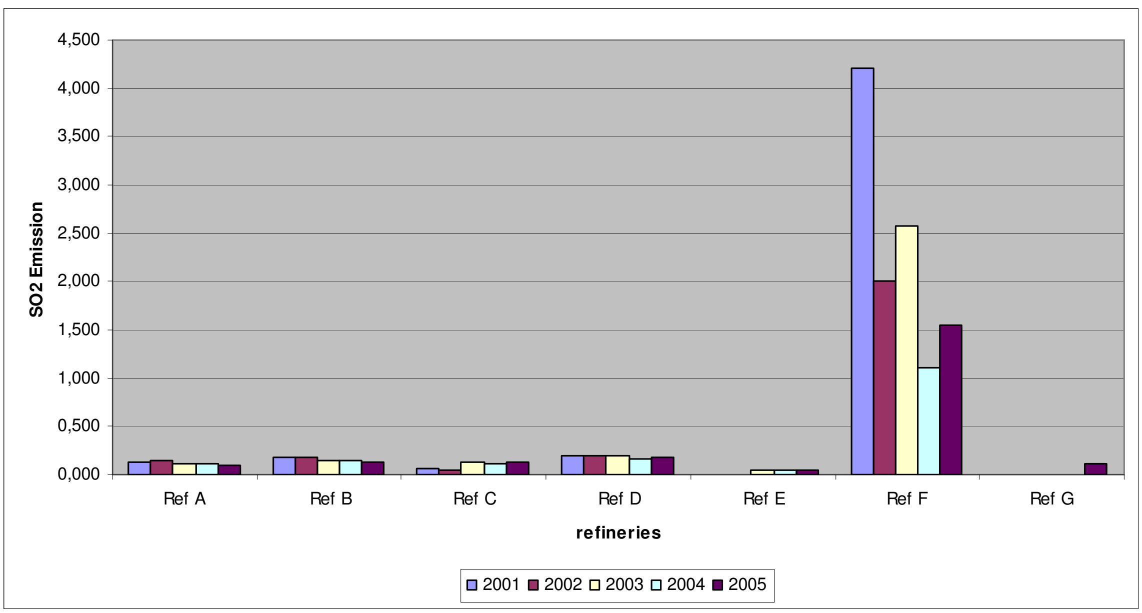

[redacted]
1
1
0
0
0
0
0
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Refineries
2001 2002 2003 2004 2005

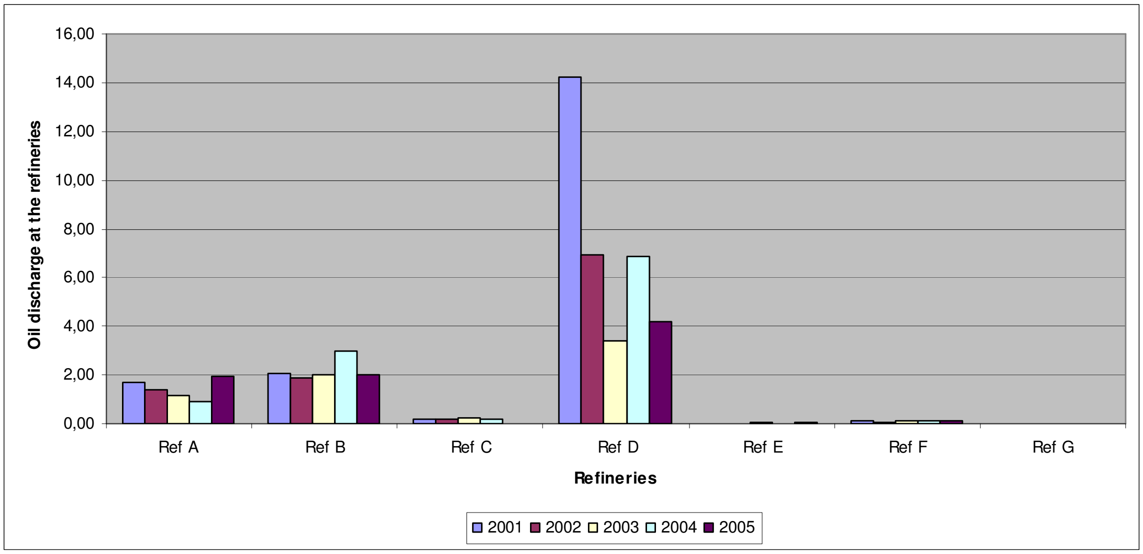

Potential incidents per person trend
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Refineries
2001 2002 2003 2004 2005

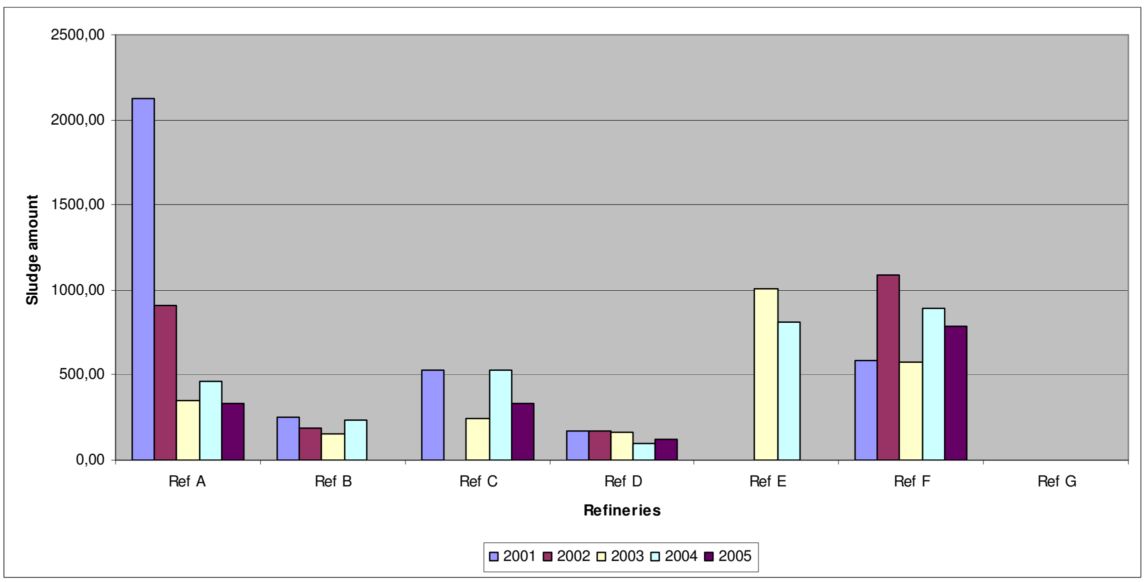

0,350
0,300
0,250
0,200
0,150
0,100
0,050
0,000
VOC Emissions
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
refineries
2001 2002 2003 2004 2005

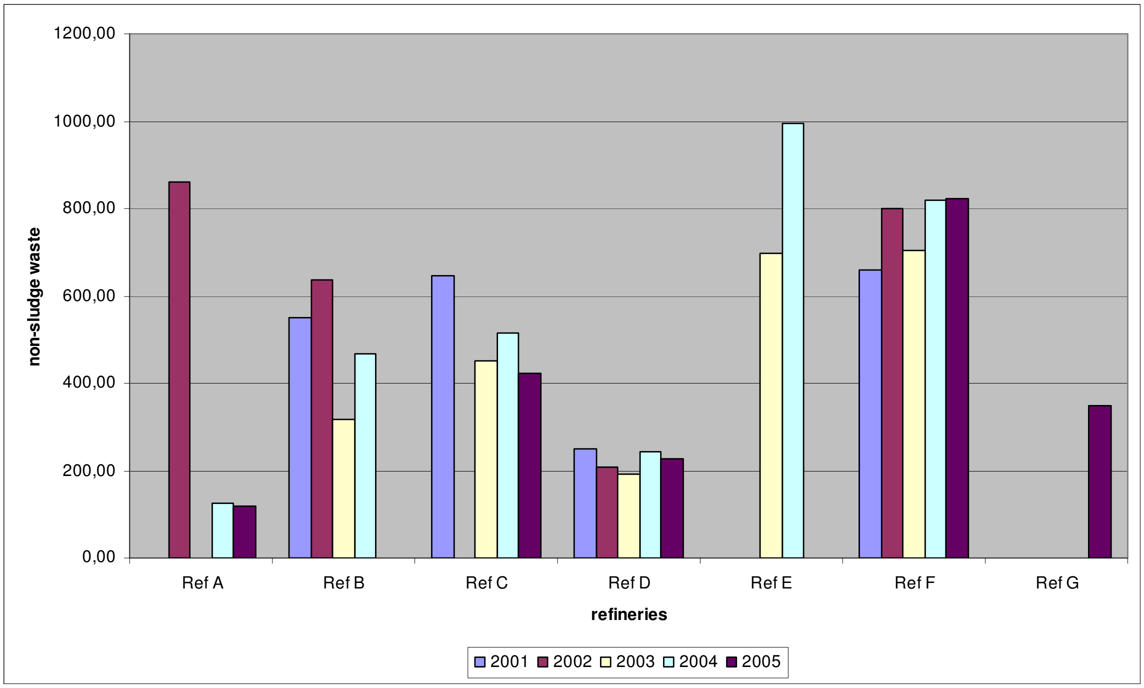

0,3
0,3
0,2
0,2
0,1
0,1
0,0
CO2 Emissions
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
refineries
2001 2002 2003 2004 2005


NOX emissions
0,060
0,050
0,040
0,030
0,020
0,010
0,000
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
Refineries
2001
2002
2003
2004
2005


SO2 Emission
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
0,500
0,000
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
refineries
2001
2002
2003
2004
2005


16,00
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
Oil discharge at the refineries
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
Refineries
2001
2002
2003
2004
2005


2500,00
2000,00
1500,00
1000,00
500,00
0,00
Sludge amount
Ref A
Ref B
Ref C
Ref D
Ref E
Ref F
Ref G
Refineries
2001
2002
2003
2004
2005



Appendix – 17 [Benchmarking performances]

The tables demonstrate the performances of the plants selected as a part of the case study. Definition of the indicators can be found in the Glossary.

Table 32: Performances of H&S indicators

	LTIF	TRCF	F & E	PIPP
Ref A	0,62	2,42	0,38	0,19
Ref B	1,41	4,37	0,20	0,29
Ref C	0,17	1,58	0,34	0,32
Ref D	1,09	2,42	0,10	0,13
Ref E	1,28	3,09	0,11	0,01
Ref F	0,79	3,52	0,26	0,90
Ref G	7,00	8,00	0,02	0

Table 33: Performances of Environmental indicators

	VOC	CO2	NOX	SO2	Oil discharged	Sludge	Nonsludge
Ref A	0,18	0,12	0,01	0,12	1,42	836,13	277,05
Ref B	0,12	0,22	0,04	0,15	2,18	206,69	492,85
Ref C	0,05	0,19	0,01	0,10	0,16	326,33	406,87
Ref D	0,04	0,16	0,04	0,19	7,12	144,44	223,33
Ref E	0,01	0,26	0,02	0,05	0,06	909,67	846,56
Ref F	0,04	0,27	0,04	2,29	0,10	784,33	761,68
Ref G	0,03	0,20	0,05	0,120	NA	2,000	350

Appendix – 18 [Sensitivity Graphs]

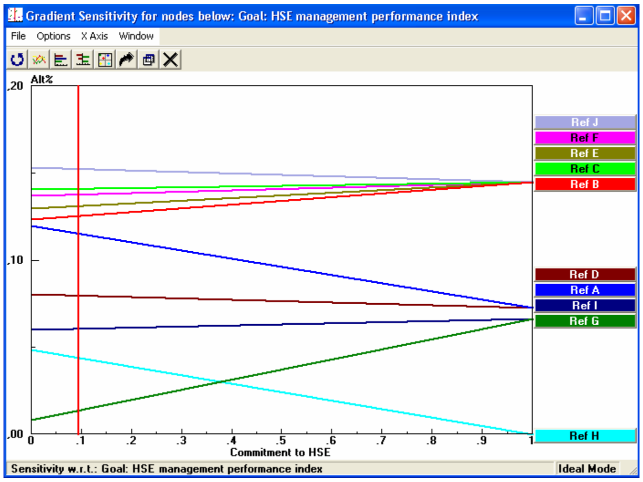


Figure 10: The sensitivity of the end result versus change in the weights of commitment to HSE

If the weight of 'commitment to HSE' < 38%, ref H has a higher performance index than ref G.

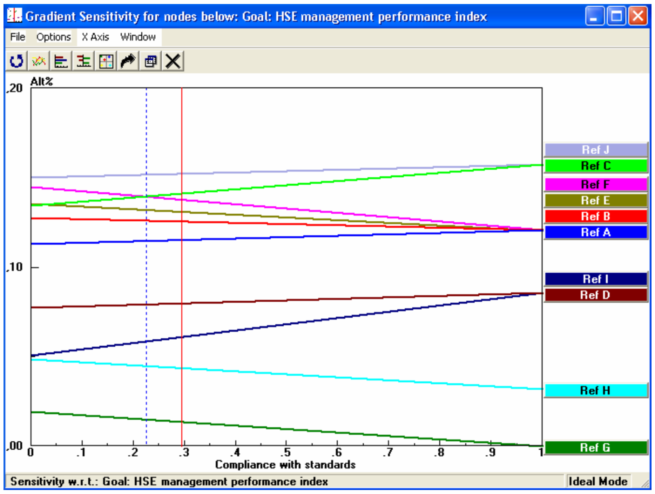


Figure 11*:* The sensitivity of the end result versus change in the weights of compliance with standards.

If the weight of 'compliance with standards' < 23%, ref F has a higher performance index than ref C.

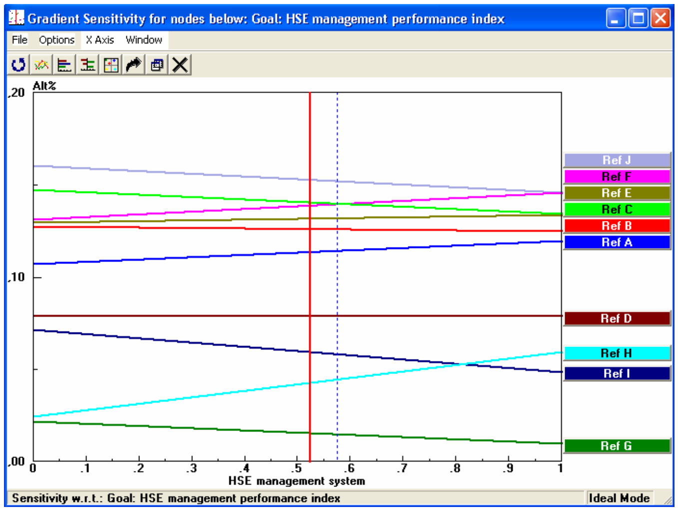


Figure 12: The sensitivity of the end result versus change in the weights of HSE management system.

If the weight of 'HSE management system' < 58%, Ref C has a higher performance index than Ref F. If the weight of 'HSE management system' < 84%, Ref I has a higher performance index than Ref H.

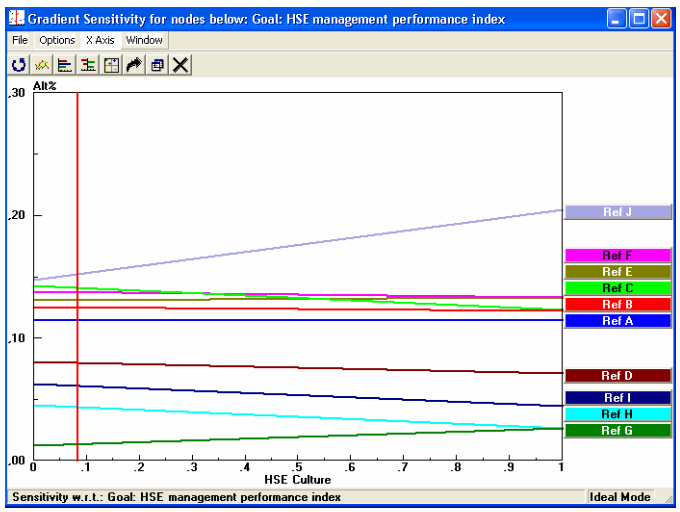


Figure 13: The sensitivity of the end result versus change in the weights of HSE culture

Current ranking is robust to changes in the weight of HSE culture.