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Doctoral Dissertation

Occupational Health Risk Assessment on Benzene Exposure at Gasoline Storage and Distribution Facility in Developing Countries

発展途上国のガソリン貯蔵・流通施設におけるベンゼン曝露に関する
労働衛生リスクアセスメント

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February 2019

Osaka University

Graduate School of Engineering

Division of Sustainable Energy and Environmental Engineering

Preface

This research work titled, ''*Occupational Health Risk Assessment on Benzene Exposure at Gasoline Storage and Distribution Facility in Developing Countries*'' was initiated in Osaka University at the Engineering Department to the Division of Sustainable Energy and Environmental Management of Japan. The research took place under the supervision of Professor Akihiro TOKAI, from the period April 2016 to January 2019.

This PhD dissertation is composed of three manuscripts submitted to be published to International scientific journals with a profile related to Engineering and Environmental issues. Two of the manuscripts out of the 3 are already published and the last one is still in process.

The list of publications and submitted papers from this PhD thesis is as follow:

1. A. Francis Obame Nguema, A. Tokai, I. Susanto, N. Kojima. Occupational Exposure Estimate of Benzene and the Effectiveness of Control Measure in Gabon's Gasoline Storage and Distribution Facility. Asian journal of applied science Vol 6, No 6 (2018): December 2018

2. A. Francis Obame Nguema, A. Tokai, H. Nguyen, N. Kojima. Occupational Health Risk Assessment for Benzene Exposure in Gasoline Storage and Distribution Facility: comparison between developing and industrialized countries for the period of 1986-2001. Asian journal of applied science Vol 10, No 01 in (2019): January 2019.

3. A. Francis Obame Nguema, A. Tokai, H. Nguyen. Analyzing factors influencing occupational benzene exposure concentration in loading operations at gasoline storage and distribution facility in developing countries. Asian journal of applied science Vol 7, No 1 (2019): February 2019

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This Doctoral thesis was made possible through the assistance, help, guidance and support of a couple of persons and institutions. I would like to take this opportunity to sincerely express my gratitude to them.

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Special thanks to my family. To my mother for her endless love even in challenging situation. To my Japanese host family Mr. and Mrs. KONNO for their truly care during my stay in Japan.

Finally, I would never have been able to undertake a PhD program without the opportunity that the Japanese government offers to international students around the world, through its Ministry of Education, Culture, Sports, Science and Technology. My entirely thanks and appreciation goes to the financial contribution from Japanese government through the MONBUKAGAKUSHO, MEXT scholarship to enable me to complete my program.

Abstract

In order to convey refined petroleum products from the refinery to the end users, gasoline storage and distribution facility (GSDF) is considered as a critical step to successfully achieve this operation. According to Verma, GSDF is considered has the highest exposure occupation in downstream petroleum industry. Loading operations constitute intermittent and higher exposure tasks. The processing of petroleum products in GSDF for loading operation has caused the generation of vapor emissions sources.

Benzene is one of those vapor emissions that workers are likely to be exposed at high exposure level during conducting out specific tasks such as loading gasoline to various petroleum storage transport modes. This results in many problems on human health such as cancer and non-cancer diseases. However, if we consider that, there is a priority for developing countries towards economic benefits to sponsor other urgent social needs compare to investing in occupational health and safety; the main remaining concerns is to which extent health risk can be assessed for benzene exposure at GSDF in developing countries. This presents a problem of attempting to evaluate occupational health risk at GSDF with developing countries' challenges. Therefore, there is a need to develop a framework to assess health risk at GSDF for developing countries; where there is a lack of measurement data; high benzene contains in gasoline; lack of engineering control such as vapour recovery system; poor regulations and weak working practice as challenges.

This research is structured around three main objectives to assess health risk of benzene exposure at GSDF for developing countries: (1) to analyse factors influencing occupational benzene exposure concentration in loading operations at GSDF in developing countries; (2) to estimate occupational benzene exposure and effectiveness of control measure at the GSDF and finally (3) to assess occupational health risk for benzene exposure at GSDF and compare between developing and industrialized countries.

The chapter 1 presents the introduction; problem statement; the research objectives; the scope of the research and the research structure. This chapter also gives an overview of the all research content.

The chapter 2 tackles the first specific objective, analyse the factors that influence occupational benzene exposure concentration in loading operations at GSDF in developing countries. Through active literature review, 23 sub-factors influencing benzene exposure during loading operations at GSDF from previous studies were identified. Then, 6 mains factors were identified and represented the 23 sub-factors into 6 groups of factors. Theses 6 mains factors were used as questionnaire survey with the aims to be ranked. The interpretive structural model (ISM) was applied to understand the interactions of factors that influence benzene exposure concentration during loading operations at GSDF in developing country and would help management to conduct a more comprehensive and accurate chemical risk assessment. The results of this study reveals that the identified factors such as: ''product'', ''regulation'', ''working practices'' and ''installation'' are the most influential for benzene exposure concentration level at gasoline storage and distribution facility in developing countries. Based on those results, management should tackle first these factors before others and emphasize on strategy to improve these factors with the view of providing a safe working place through a benzene exposure concentration level lower than the occupational exposure limit.

The chapter 3 covers the second specific objective of the research. This chapter aims to estimates occupational benzene exposure and assess the effectiveness of control measures at GSDF in Gabon. In this study, the occupational exposure estimate of benzene in Gabon's gasoline storage and distribution facility was investigated by using a quantitative and predictive exposure inhalation model; to estimate benzene concentration before and after applying control measures. The results indicate that the benzene concentrations varied between 9.46 mg/m³ and 187 mg/m³ for short term and have the value of 187 mg/m³ for long term. The implementation of control measures including using vapor recovery system, chemical filter mask and improving worker's behavior might contribute to significantly reduce benzene concentration to the range of 4.52 – 29.08 mg/m³ for short term and down to 4.55 mg/m³ for long term. This almost meets the Agency Governmental Industrial Hygienists standard, in which occupational exposure limit for short term and long term exposure are 8.1 mg/m³ and 3.16 mg/m³, respectively.

The chapter 4 addresses the final objective of the research. This chapter aims to assess occupational health risk for benzene exposure at GSDF in developing countries. By collecting occupational benzene data from loading operations and using a cumulative probabilistic distribution (CPD), to visualize the exposure concentrations trends and compare to the occupational exposure limits guidelines. Then, characterized the non-cancer and cancer risk through Hazard Quotient and Cancer risk for Lifetime Adverse Daly Dose at the 50% and 95% exposure concentration level; respectively the main exposure population and the highest exposed population for the task being performed. Finally, through the overall risk probability (ORP) technique, a quantitative description of uncertainty and variability in evaluating the risk of adverse health effects at GSDF for developing countries is given. The results indicate a significant health risk for workers in GSDF in developing countries, compared to the workers in industrialized countries. The above results were translated by the presence of high volume level of benzene contain in petroleum products and the lack of implemented engineering controls measures such as vapor recovery system for countries with the highest health risk.

Finally, the chapter 5 presents the conclusion and recommendations that have been derived and formulated from this research work. The conclusion of this research contributes to assess occupational health risk of benzene exposure at GSDF in developing countries, where exposures assessment challenges occur. Recommendations are provided in how to improve exposure assessment which constitutes the first step to conduct a more accurate health assessment, to stakeholders and policy makers.

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Chapter 1

Introduction

1.1. Background

The increase consumption in developing countries of petroleum products last decade as energy source in many industries [1], for urban development and transportation, has led to an important volume of petroleum product to be handled in gasoline storage and distribution facilities (GSDF). The GSDF is the major occupational sources for benzene exposure, through the inhalation of gasoline vapors, in the supply industry [2]. Benzene is classified and confirmed as carcinogenic for human health [3]. In the GSDF, workers are exposed at high risk to adverse health effects associated with inhalation of benzene released from loading operations [4].

Gasoline loading operations had been studies at GSDF in various industrialized countries from Parkinson [4] to Pandya [5]. With Parkinson the benzene concentration during loading truck tank was higher up to 9ppm at GSDF, with a 33% of benzene volume. For Sherwood [6], the mean concentration during 5h loading operation the concentration ranged between 1.6 to 2.5 ppm. Phillips and Jones [7] at various marketing terminals reported up to 3 ppm. Holmberg and Lundberg [8] reported a range of 0.3 to 3ppm also for loading truck tank. Runion and Scott [9] summarized benzene measures from marketing terminals in the period of 1978 to 1983, with a low level of exposure. Then, Irving and Grumbles [10] reported benzene exposure up to 2.29 ppm for top loading truck tank. However, these results led to conduct a health risk assessment in this occupational setting with a view of protecting workers. Furthermore, the results contributed to the various improvement made by industrialized countries in occupational health and safety at GSDF for loading operations.

The importance of occupational health is often overlooked and people tend to equate occupational illness with industrialization. This narrow view hampered the development of occupational health in developing countries [11]. This is because, the level of occupational safety and health in Africa is low compared with the rest of the world [11]. According to the African Refinery Association through the ‘’AFRI-4 specifications’’ the target of 1% benzene volume contain in gasoline is set for 2020, and the 5% volume are currently authorized [12]. Loading operation in developing countries, the scenario may be worse where management of such exposure-health problems is typically not well-implemented and workers may not be well-protected about such health risk. Although, contamination with benzene is mostly due to uncontrolled industrial activity and lack of the awareness of workers, the magnitude of the problem is said to be grave for developing countries [13]. Moreover, health risk of benzene exposure is assessed in refinery and distribution facility with standard checklist, material safety data sheet and structured interviews of staff concerning the health hazard at workplace in developing countries [13]. This approach to health risk assessment presents a high degree of uncertainty and variability, which can be harmful to workers’ health. Therefore, it is vital to conduct health risk assessment for benzene exposure at GSDF in developing countries taking into consideration uncertainty and variability.

1.2. Problem statement

The benzene exposure had been studied throughout decades from various industries, such as petroleum downstream industry. According to Verma [14] the gasoline storage and distribution facility (GSDF). In past, high exposure concentrations of benzene were recorded in GSDF from several studies (kawai et al.,1991). A tremendous improvement on strategy to reduce benzene exposure in GSDF was achieved throughout the past decades. However, gasoline loading operations remains an excessive exposure source of emission in GSDF.

The increase consumption in developing countries of petroleum products last decade as energy source in many industries [1], for urban development and transportation has increased the volume of petroleum products to be handled in GSDF. This presents a potential problem on human health such as non-cancer and cancer diseases. Therefore, exposure variability and exposure uncertainty are needed to be taken into consideration when undertaking a health risk. Thus, in order to conduct a more accurate estimation of occupational health risk assessment to benzene in developing country, with the view of protecting workers at GSDF; a methodology addressing health risk at different exposure levels is required.

1.3. Research Objectives

Although, significant improvement in benzene exposure reduction in GSDF has been achieved, but loading operations remain the main excessive benzene exposure emission source in the GSDF. This research aims to assess health risk of exposure to benzene at various exposure levels in developing countries, where there is lack of measurement data; vapor recovery system; poor regulations and weak working practice. This leads the following research question to be addressed:

How occupational health risk to benzene exposure at GSDF in developing countries can be assessed at different exposure levels?

From the above research question, 3 objectives are derived to address the research study as follow:

Identify and Analyze factors influencing Occupational exposure of benzene concentration in loading operation at Gasoline Storage and Distribution Facility in developing countries
-*what are the factors that influence benzene exposure concentration in developing country for gasoline loading operation in gasoline storage and distribution facility*?

Estimate the Occupational exposure of benzene and the effectiveness of control measure at gasoline storage and distribution facility
-*what are the estimates of benzene concentration at the task level and their appropriate control measure for loading operations?*

Assess Occupational Health Risk for Benzene Exposure in Gasoline Storage and Distribution Facility: comparison between developing and industrialized countries for the period 1986 to 2001
-*what are the health risk of workers at the task level and site level for industrialized and developing countries?*

1.4. Research Scope

This research is restricted to gasoline storage and distribution facility in industrialized countries and developing countries; with a focus on three modes of loading operation such as, loading truck tank, loading barges and loading storage tank. The framework and methodology used can be transferred and applied to other developing countries for benzene exposure during loading operations in GSDF.

1.5. Thesis structure

The Fig.1.1. of the research shows the thesis structure with its different chapters and flows. The Table 1.1. presents the study research points.

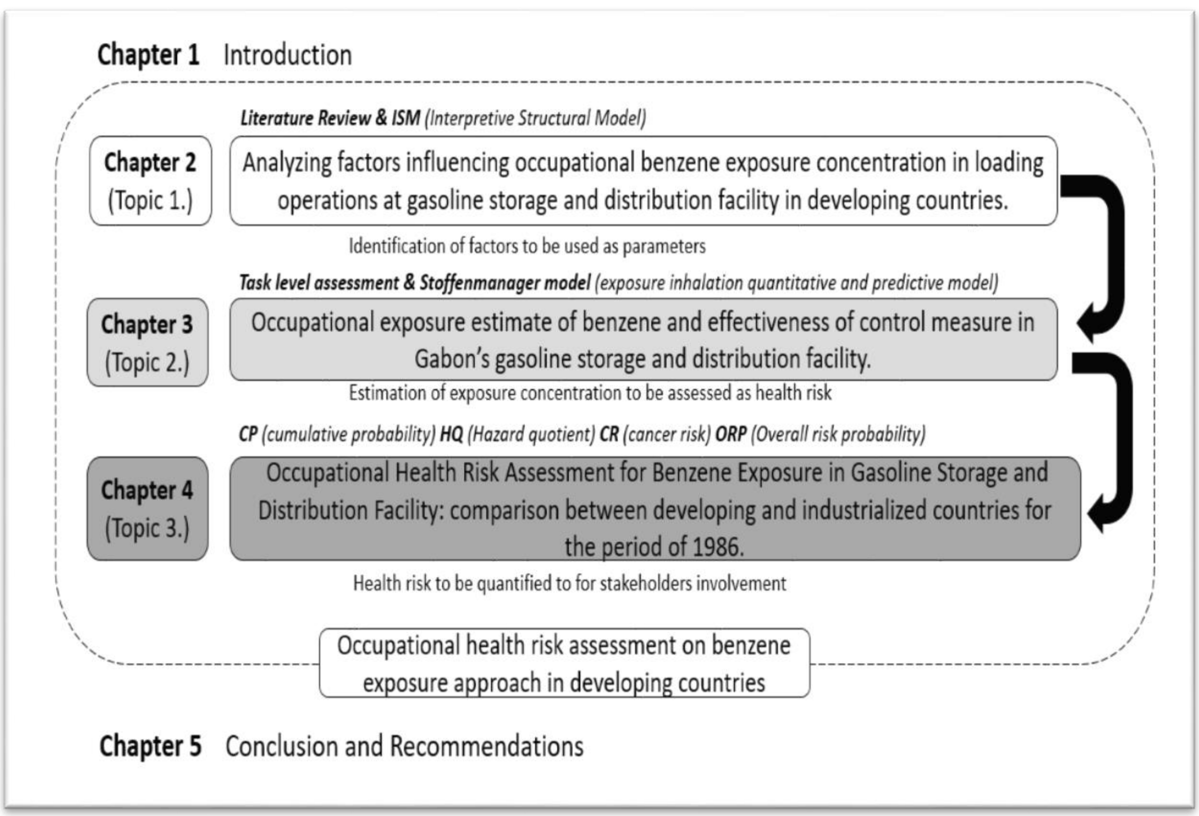

Fig.1.1. Thesis structure

Table 1.1. Study research overview

No	Chapter	Areas	Objectives	Tools	**Outcome**
2	Topic1. Analyzing factors influencing occupational benzene exposure concentration in loading operations at gasoline storage and distribution facility in developing countries	Developing countries	Identify the main factors influencing benzene exposure	-Literature review -ISM Model	Factors influencing benzene occupational exposure in developing countries
3	Topic2. Occupational exposure estimate of benzene and effectiveness of control measure in Gabon's gasoline storage and distribution facility.	Developing country (Gabon)	Estimating benzene exposure and evaluate the effectiveness of control measures	-Task level assessment -Stoffenmanager Model	estimates of benzene occupational exposure in gasoline storage facility
4	Topic3: Occupational Health Risk Assessment for Benzene Exposure in Gasoline Storage and Distribution Facility: comparison between developing and industrialized countries for the period of 1986-2005.	Comparison between Industrialized countries and developing countries	Health risk assessment	-cumulative probability - Hazard quotient - cancer risk - Overall risk probability	Health risk estimate for industrialized and developing countries

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Chapter 2

Analysing factors influencing occupational benzene exposure concentration in loading operations at gasoline storage and distribution facility in developing countries

2.1. Introduction

In order to convey refined petroleum products from the refinery to the end users, gasoline storage and distribution facility (GSDF) is considered as a critical step to successfully achieve this operation. GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, rail tank, truck tank) [1]. GSDF is as the same time an useful tool for a nation's economic growth and health issue to its working population; through economic gain from loading operations activities and health damage such as cancer risk from workers' exposure to petroleum products respectively

Loading operation is the process of transferring petroleum refined products from bulk storage tank to operating tank [2]. It is also the transfer of petroleum refined products from storage tank to various petroleum storage transport mode such as; barge tank; rail tank; truck tank, through pipelines, hoses, flexible joint arms [1]. Loading operation is the main activity in GSDF and required well trained working force and functional equipment to be run properly [2]. These requirements act as a guaranty for a safe working environment freed from any economic loss and occupational injure. However, during loading operations and storage of petroleum refined products, such as gasoline, benzene vapors escape into the atmosphere [3]. Air toxics are released from the GSDF during gasoline loading truck tank; rail tank; storage tank; barge tank and from other sources like the vapor leaks at loading pumps, valves and other equipment in the facility [4]. In several articles, occupational benzene exposure concentration during loading operations are discussed and the benzene concentration in these various studies exceeded the different occupational exposure limit set throughout each period [1, 3, 5, 6, 7, 8, 9, 10, 11, 12]. Thus, GSDF's workers are exposed to high level of benzene concentration during loading operations [13].

Benzene is one of the volatile components of petroleum products, like gasoline and is an established carcinogenic chemical for human health by the International Agency of Research on Cancer [14]. Short term human exposures to benzene can give rise to various adverse effects such as headaches, dizziness, inability to concentrate, impaired short term memory and tremors [15] and is considered as acute exposure effects. While long term human exposure can give rise to more complex health effects including haematotoxicity, genetoxicity, immunological and reproductive effects as well as various cancers [16] and is considered as chronic exposure effects. In general, acute exposure effects are considered to be reversible, while chronic exposure effects are probably irreversible [17].

Although, contamination with benzene is mostly due to uncontrolled industrial activity and lack of the awareness of workers [18], the magnitude of the problem is said to be grave for developing countries [19]. In most oil exporting developing countries, a comprehensive and harmonious data collecting systems is unavailable. A standard checklist, a material safety data sheet and structured interviews of staff concerning health hazard in petroleum loading operations are used as chemical assessment method [19, 20]. This approach remains unsatisfactory to perform a more accurate chemical risk assessment at GSDF in developing country.

The literature review suggests that no study has been taken that investigate explicitly the interactions among the factors that impact benzene exposure concentration during loading operations and proposes an interpretive structural modelling (ISM) based model for these factors. This study attempts to identify the factors that influence benzene exposure concentration through literature review and; experts' opinions and then develops a contextual relationship among these identified factors using ISM method. Furthermore, it also proposes a hierarchy of benzene exposure concentration factors that would help the management to understand and to be aware of the identified factors for a more accuracy in performing a chemical assessment at gasoline storage and distribution facility in developing countries. The Fig.2.1. shows the study framework of this study.
The main objectives of this study are as below mentioned:

- To identify and rank the factors influencing benzene exposure concentration at GSDF in developing countries during loading operations.

- To find out the interaction among identified factors using ISM

- To discuss managerial implication of this study and suggest directions for future studies.

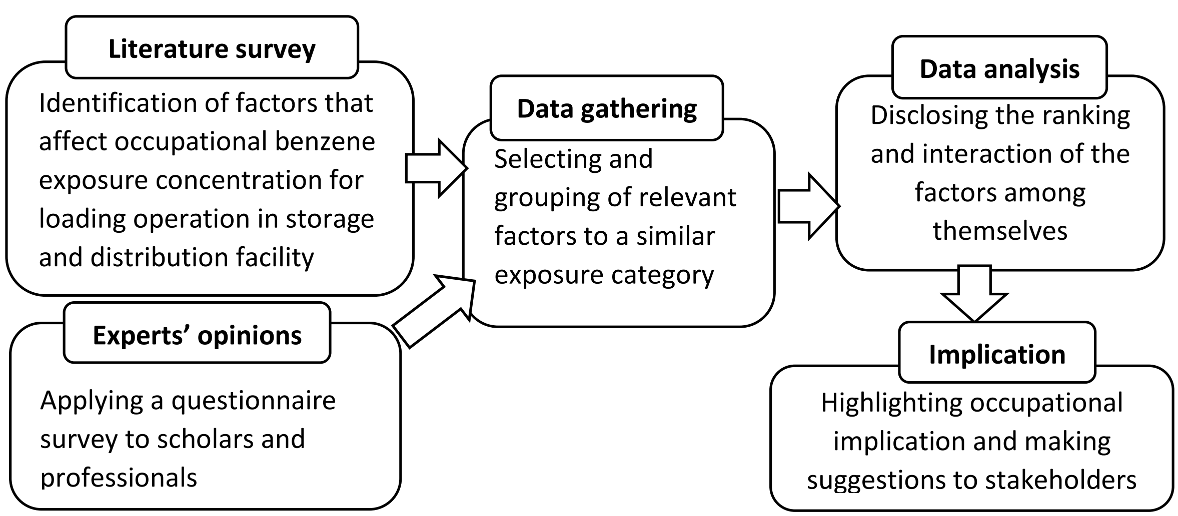

Fig.2.1. Research procedure

2.2. Material and Methods

In the section 2.2.1., the literature survey on the factors influencing benzene exposure concentration during loading operation in GSDF are identified. Section 2.2.2., presents the results from the questionnaire-survey of the experts. Section 2.2.3. the ISM method and the steps process. Section 2.3., shows the results and the discussion and the ISM application; and finally the section 2.4. presents the conclusion.

2.2.1. Identification of factors influencing benzene exposure

In this study, the loading operations from GSDF are focused on loading truck tank operation, loading storage tank operation and loading barge tank operation. In these three working locations, factors that influence benzene exposure concentration were identified during loading operations from the literature review. Then, the factors were grouped into a larger representation of factors influencing benzene exposure concentration. A questionnaire survey was addressed to professionals; scholars and the results were aggregated to the large group of identified factors. We applied the interpretive structural modelling (ISM) to factors of the large group. The results were meant to be used to support management in decision making and stakeholders.

From the literature review, benzene exposure concentration during loading operation in GSDF has always been high in the past [8, 13, 21]. Exposures to benzene during loading truck tank operation occur as a result of several actions. The major sources of exposures are as results of gasoline flow into the empty tank; displacing hydrocarbon vapors; leaking fill lines and draining of tanks also result in exposures from evaporation of the gasoline [22]. The top loading and bottom loading tend to give high benzene exposure concentration during truck tank loading operation [21]. At the barge loading operation, the major sources of high benzene exposure concentration occur from the manual sounding of the tanks; the phase of loading when the tanks were topped up [23]. At the loading storage operation, defective valves; gauging; lack of external floating roof tank; lack of internal roof; lack of vertical roof tank; gauging at the roof top [24, 26].

Then, after identified the sub-factors influencing benzene exposure concentration during loading operation, from the literature review, each sub-factors were grouped into a larger group of factors. The larger group of factors was set, through a generic questionnaire from occupational exposure assessment such as: what product workers handle? Under which meteorology conditions workers perform the task? What task workers perform? How do workers perform the task? Where do workers perform the task? Which regulations cover the task performs by workers? The table 2.1. below summarize the identified factors and sub-factors influencing benzene exposure concentration during loading operation.

Table 2.1. Factors and sub-factors for influencing benzene exposure concentration

Factors	Sub-factors		References	Explanation
P-Product	P1	High level of benzene contain	[27]	The product characteristics (benzene level contain, evaporation process etc.) that impact benzene exposure concentration.
	P2	Evaporation process	[28]	
	P3	Quantity of gasoline sold	[28]	
M-Meteorology conditions	M1	Wind speed	[29]	The different environmental characteristics (wind speed, temperature etc.) affecting benzene exposure concentration.
	M2	Temperature level	[29]	
	M3	Wind direction	[39]	
N-Nature of the task	N-1	Regular task	[30]	The type of tasks (loading operations, maintenance operation etc.) that affect benzene exposure concentration.
	N-2	Loading tasks	[3]	
	N-3	Maintenance tasks	[30]	
W-Working practices	W-1	Lack of appropriate personal protective equipment used	From author's experience base.	The workers skills level and behavior that affect benzene exposure concentration.
	W-2	Irregular procedure application	From author's experience base.	
	W-3	Lack of regular training	From. author's experience base.	
	W-4	Worker behaviour	[32]	
	W-5	Keeping hatches open during loading	[38]	
R-Regulations	R-1	Lack of regular chemical assessment reports	From author's experience base.	The lack of different laws, regulations and procedures that provide a safe working environment from benzene exposure concentration.
	R-2	Lack of workers shift interchange legislation	[29]	
	R-3	Lack of policy in occupational safety and health	[40]	
	R-4	Lack of an update of industrial health policy	[19]	
I-Installation	I-1	Lack of vapor Recovery system	[11, 28]	The lack of different equipment, mechanicals tools, technology that provide safer work from benzene exposure concentration.
	I-2	Defective valves (equipment)	[26]	
	I-3	External floating roof tank	[26]	
	I-4	Vertical fixed roof tank	[26]	
	I-5	Lack of automated operation	[23]	

2.2.2. Questionnaire-based survey

The aim of this questionnaire-based survey was to help developing the first step towards building an ISM-based model by experts, which is the relationship matrix. The respondents were required to point out the importance of the 6 listed factors on the five-point Likert scale and results were weighted based on respondent category. The score from each category was weighted 3; 2; and 1 times for Engineer; Operator and Students respectively. The questionnaire was intended on the five-point Likert scale, with the scale, '1', '2', '3', '4', '5' corresponding to 'Very low', 'Low', 'Moderate', High, 'Very high', respectively. The questionnaire was applied to Engineers in 'Health Safety Environment', 'Operators in charge of loading operations', 'student in the field of Health Safety Environment' and 'Any person willing to participate'. In total, 25 questionnaires were submitted to the 4 categories mentioned above. Only 11 questionnaires were received out of the 25 questionnaires. Thus, making a response rate of 44%, which is above the 20% rates, considered as particularly undesirable for survey findings [25]. The description of the questionnaire-based survey content is in the Table 2.4. of the appendix. The characteristic of the respondents and factors ranking are presented in Table 2.2. and Table 2.3. respectively.

From the literature review the range of survey period was between 1989 to 2016 and the Key papers consulted were from those of: Jackson, 2005; Cruz-Núñez et al., 2003; Eun Kyo Chung et al., 2016; Spyros et al., 2007; Nordlinder, 1989; RAGHAVAN et al., 2005.

Table 2.2. Characteristics of the respondents

Characteristics	Number (NR=11/44%) 25
Gender	
Male	9
Female	2
Status	
HSE	6
Operator	2
Student	3
Other	0

2.2.3. Interpretive Structural Model method

Interpretive Structural Modelling (ISM) was first proposed by J. Warfield in 1973 to analyse the complex socioeconomic systems [36]. Moreover, ISM is a computer-assisted learning process that enables individuals or groups to develop a map of the complex relationships between the many elements involved in a complex situation. Furthermore, ISM is a qualitative tool with the objective of understanding the complex relationship among elements to a particular subject [36]. ISM is a well-established methodology for identifying relationships among specific items, which define a problem or an issue.

This approach has been increasingly used by several researchers to represent the interrelationships among various elements related to the issue. ISM approach starts with an identification of variables, which are relevant to the problem or issue. Then, a contextually relevant subordinate relation is chosen. Having decided the contextual relation, a structural self-interaction matrix (SSIM) is developed based on pairwise comparison of variables. After that, SSIM is converted into a reachability matrix (RM) and its transitivity is checked. Once transitivity embedding is complete, a matrix model is obtained. Further, the partitioning of the elements and an extraction of the structural model called ISM is derived [33]. In our study, we attempt to understand the relationship and the importance between the factors influencing benzene exposure concentration at GSDF during loading operation in developing countries by using ISM approach.

Theorically, the contextual relationship for each factor and the existence of a relationship between two factors (*i* and *j*), then the associated direction of the relationship is questioned. The following four symbols are used to denote the direction of the relationship between two factors (*i* and *j*): (a) *V* for the relation from factor *i* to factor (i.e., factor *i* will influence factor *j*) (b) *A* for the relation from the factor *j* to factor *i* (I.e., factor *i* will be influenced by the factor *j*) (c) *X* for both direction relations (i.e., factors *i* and *j* will influence each other) (d) *O* for no relation between the factors (i.e., barriers *i* and *j* are unrelated). [33, 34, 35, 37]

Then, the four symbols (i.e., *V, A, X, O*) of the SSIM are substituted by 1s or 0s in the initial RM. The substitution rules are follows: (a) if the (*i, j*) entry in the SSIM is *V,* then the (*i, j*) entry in the RM becomes 1 and (*j, i*) entry becomes 0. (b) If the (*i, j*) entry in the SSIM is *A,* then the (*i, j*) entry in the matrix becomes 0 and (*j, i*) becomes 1. (c) If the (*i, j*) entry in the SSIM is *X,* then the (*i, j*) entry in the matrix becomes 1 and the (*j, i*) in the matrix becomes 1. (d) If the (*i, j*) entry in the SSIM is *O*, then the (*i, j*) entry in the matrix becomes 0 and then (*j, i*) entry also becomes 0. [33, 34].

2.3. Results and Discussion

2.3.1. Results from questionnaire survey

The results from the questionnaire survey shown that the factor ''product'' is the most influential for benzene exposure concentration during loading operation in GSDF, with weighted score of 7.66. For most of experts, the benzene concentration in the petroleum product represents the most important element contributing to high benzene exposure concentration on workers. Then, the factors such as ''installation''; ''meteorology conditions''; ''nature of task''; ''working practices'' have quite similar scores. This implies from experts' point of view that elements like: engineering controls; temperature; the type of task; procedures are contributing to benzene exposure concentration at lower level compared to the benzene concentration level in petroleum product. Finally, the lower score is from the factor ''regulation''. This indicates that for experts, elements like existing laws and legislation are no efficient for benzene exposure concentration on workers at GSDF.

Table 2.3. Rank and mean score of the factors influencing benzene exposure

No. Rank	Factors	Mean score
1	**Product**	**7.66**
2	**Installation**	**6.72**
3	**Meteorology conditions**	**6.38**
4	**Nature of the task**	**6.32**
5	**Working practices**	**5.94**
6	**Regulations**	**3.77**

2.3.2. Practical application of ISM

After selecting the identified factors from the literature review and with the author's opinion, we considered them as elements which are related to define the problem. Then, a contextual relationship is established among elements through pairwise technique.

Step1: making a Structural Self-Interaction Matrix (SSIM)

In other to analyse the identified factors, a contextual relationship of ''leads'' or ''influences'' type is chosen. This means that one identified factor influences another identified factor. There are four symbols V; A; X; O; used in ISM to express the interrelationship between two elements (i and j) [34]. The symbol V represents the relationship whereby the identified factor i influences the identified factor j. For example, the identified factor ''meteorology condition'' influences the identified factor ''product''. During a gasoline loading operation ''meteorology condition'' through a ''wind speed and direction'' influences ''product'' by the ''evaporation process'', which changes the benzene exposure concentration level at the working location. Though, the identified factor ''product'' through the ''high level benzene content'' cannot influences ''meteorology condition'' by the ''temperature level''; to enable a change in benzene exposure concentration level, as example for the symbol V. The symbol A represents the relationship between the identified factors j and i. For instance, the identified factor ''product'' does not influence the identified factor ''nature of the task'', because if there is no operation taking place the ''product'' will maintain its benzene exposure concentration level.

In the other hand, during loading operation and in particular for a specific task performed, the benzene exposure concentration level changed. The symbol X is used to express that both identified factors influence each other and direction relations goes for both. The identified factors ''nature of the task'' and ''working practices'' influence each other. The ''nature of the task'' influences ''working practice'', because the task to be performed determine a specific working practice to maintain a safe level of benzene exposure concentration. The working practice used is adapted to the task performed.

Table 2.4. Structural self-interactive matrix

Factors (Si)		S6	S5	S4	S3	S2
meteorology conditions	S1	O	O	V	A	V
Product	S2	A	V	V	A	
Nature of the task	S3	V	V	X		
Working practices	S4	A	V			
Regulations	S5	V				
Installation	S6					

Finally, the symbol O expresses the absence of relationship between the identified factor i and j, such as the identified factors ''meteorology condition'' and the ''installation''. The ''wind speed'' or the ''temperature level'' cannot influence the ''lack of vapor recovery system'' and vice-versa. During loading operation, the ''lack of vapor recovery'' system cannot influence ''wind speed'' or ''temperature level'' to alter the benzene exposure concentration level. Based on the above rules on contextual relationships, the SSIM was built as shown in the Table 2.4.

Step2: converting SSIM into an initial Reachability Matrix (RM)

In other to convert the SSIM to initial reachability matrix, the four symbols (V, A, X, O) were substituted by 1 or 0 s in the initial reachability.

The rules to convert SSIM into initial reachability matrix are as follows: if the (i, j) entry in the SSIM is V, then the (i, j) entry in the RM becomes 1 and the (j, i) entry becomes 0. If the (i, j) entry in the SSIM is A, then the (i, j) entry in the RM becomes 0 and the (j, i) entry becomes 1. If the (i, j) entry in the SSIM is X, then the (i, j) entry in the RM becomes 1 and the (j, i) entry becomes 0. If the (i, j) entry in the SSIM is 0, then the (i, j) entry in the RM becomes 0 and the (j, i) entry becomes 0. Coming after this rule to obtain the initial RM presented in table 2.7., the transitivity relationship is checked [33, 34, 35, 37]. The value 1 is allocated to the element which gives the direction of the matrix and the value 0 to the element which undergoes it. Additionally, the value 1 is giving to the entry when the element influences each other and the value 0, when there is no relationship between the elements in the matrix.

Table 2.5. Reachability Matrix (RM)

Factors (Si)		S1	S2	S3	S4	S5	S6
meteorology conditions	S1	1	1	0	1	1	0
Product	S2	0	1	0	1	1	1
Nature of the task	S3	0	1	1	1	1	1
Working practices	S4	0	0	0	1	1	0
Regulations	S5	0	1	0	1	1	1
Installation	S6	0	1	1	0	1	1

V: i ➡ *j* element *i* influences element *j*
A: i ⬅ *j* element *i* is influenced by element j
X: i ⬌ *j*
element *i* and *j* influences each other
O: *i* ⬌ *j*
element *i* and *j are* unrelated

According to Sharma, the transitivity concept is defined as how the element x relates to element y (xRy); and how the element y relates to element z (yRz); thus, transitivity implies that element x will also relate to element z (xRz). Having done the transitivity relationship, the initial RM can be converted to a final RM as shown in the table 2.6. [35].

Step3: level of partitions on final RM

From the final RM, the reachability set, the antecedent set and intersection set were derived. The reachability set consists of the barrier itself and the other barrier that it may influence; while the antecedent set consists of the barrier itself and the other barrier that may affect it. Then, the intersection of these sets is derived for all the barriers, and the levels of the different barriers are determined [34]. The barriers for which reachability sets and intersection sets are similar, occupy the top level of the ISM hierarchy.

The top-level barriers are those barriers that will not influence the other barriers above their own level in the hierarchy. Once the top-level barriers are identified, it is removed from consideration. Then, the same process is repeated to find out the barriers in the next level. This process is continued until the level of each barrier is found; and these levels help in building the diagraph and ISM model [33, 34]. In our study, the 6 identified factors, as well as their reachability set, the antecedent set, intersection set and levels were disclosed as shown the table 2.7., 2.8. and 2.9.

Table 2.6. Final reachability matrix

Factors (Si)		S1	S2	S3	S4	S5	S6
meteorology conditions	S1	1	1	1*	1	1	1*
Product	S2	0	1	0	1	1	1
Nature of the task	S3	0	1	1	1	1	1
Working practices	S4	0	1*	0	1	1	1*
Regulations	S5	0	1	0	1	1	1
Installation	S6	0	1	1	1*	1	1

The conical matrix is built from the final RM, the factors are grouped in the same level across the rows and the columns, as presented in the Table 2.10. The driver power of the factor is derived by summing up the number of ones (1) in the rows and its dependence power by summing up the number of ones (1) in the columns. Then, in order to have a ranking for the factors, the highest rank are the identified factors with the maximum number of ones (1) in the rows and columns of drive power and dependence power respectively [33, 34]. The driving power of a factor equals to the sum of all values in each row of the final RM matrix and describes the number of factors that can be influenced by the factor being analysed. To the other hand, the dependence power of the factor is the addition of all the values in each column of the final RM matrix, thus presenting the number of factors that can influence that factor [36] as shown in the table 2.10.

Table 2.7. Iteration I

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
S1	S1, S2, S3, S4, S5, S6	S1	S1	
S2	S2, S4, S5, S6	S1, S2, S3, S4, S5, S6	S2, S4, S5, S6	
S3	S2, S3, S4, S5, S6	S1, S3, S6	S3, S6	I
S4	S2, S4, S5, S6	S1, S2, S3, S4, S5, S6	S2, S4, S5, S6	
S5	S2, S4, S5, S6	S1, S2, S3, S4, S5, S6	S2, S4, S5, S6	
S6	S2, S3, S4, S5, S6	S1, S2, S3, S4, S5, S6	S2, S3, S4, S5, S6	

Table 2.8. Iteration II

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Bi) ∩ A (Bi)	Level
S1	S1, S3	S1	S1	II
S3	S3	S1, S3	S3	

Table 2.9. Iteration III

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
S1	S1	S1	S1	III

Step4: constructing the conical matrix and digraph

From the conical matrix, the initial digraph including transitive links is built. The digraph is used to represent the identified factors in terms of nodes and edges also; is the visual representation of the identified factors and their interdependences [33, 34]. In this development, the top level factor is located at the top of the digraph and the second level factor is positioned at second position and so on, until the bottom level is placed at the lowest position in the digraph as describe in the Fig. 2.2. [34].

Table 2.10. Conical matrix

Factors (Bi)		S2	S4	S6	S5	S3	S1	Driving power
Product	S2	1	1	1	1	0	0	4
Working practices	S4	1	1	1	1	0	0	4
Regulations	S5	1	1	1	1	0	O	4
Installation	S6	1	1	1	1	1	0	5
Nature of the task	S3	1	1	1	1	1	0	5
meteorology conditions	S1	1	1	1	1	1	1	6
Dependence power		6	6	6	6	3	1	28/28

Step5: developing an ISM model and MICMAC analysis

In order to obtain an ISM model, the nodes and edges are replaced by the identified factors statements [33, 34]. Moreover, from its French definition, matrice d'impact croises-multiplication applique au classement (cross-impact matrix multiplication applied to classification), MICMAC analysis was first developed by Duperrin and Godet in 1973 to analyse the drive power and dependence power of factors. MICMAC analysis is done to identify the key factors that drive the system in various categories.

In relation to their drive power and dependence power, factors are classified into four categories such as autonomous factors, linkage factors, dependent factors, independent factors [33, 34, 35, 36]. The first category autonomous factors; these factors have weak drive power and weak dependence power. There are relatively disconnected from the system, with which they have few links, which may be very strong.

The second category linkage factors; these factors have strong drive power as well as strong dependence power. These factors are unstable in the way that any action on these factors will have an effect on others and also a feedback effect on themselves.

The third category dependent factors; these factors have weak drive power but strong dependence power. And finally the fourth category independent factors; these factors have a strong drive power but weak dependence power. A factor with a very strong drive power, called 'key factor' falls onto the category of independent or linkage factors as presented in Fig. 2.2 [33, 34]. The results of our study cover the ISM digraph analysis and the MICMAC analysis presented in the Fig.2.2. and Fig.2.3 respectively.

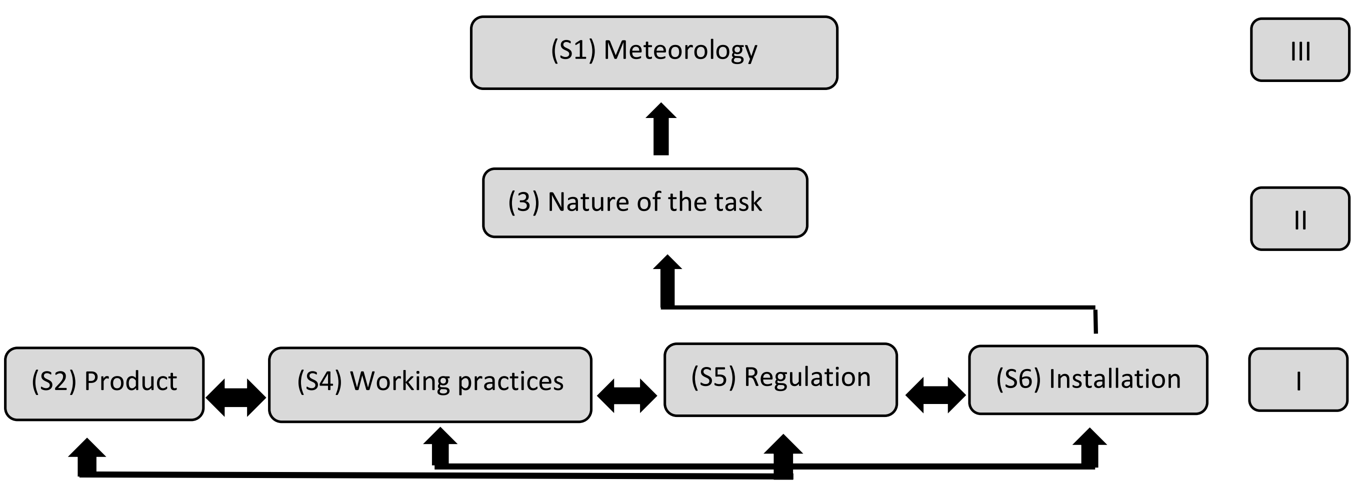

Fig. 2.2. Digraph showing levels of benzene exposure identified factors

From the ISM digraph, the 6 identified factors were partitioning in 3 levels. In the level I, four identified factors were found such as (S2) ''product'', (S4) ''working practices'', (S5) ''regulation'', (S6) ''installation''. The four identified factors occupy the lowest position in the digraph. These identified factors are not impacted by any other identified factor; hence they appear at the bottom of the ISM hierarchy. These identified factors have the most priority to be look at in gasoline storage and distribution facility in developing countries. Then, identified factor (S3) ''Nature of the task'' is the next priority as a result of being positioning in the level II of the ISM hierarchy. This is middle-level identified factor being impacted by lower-level and affecting the upper-level ones. Finally, the identified factor (S1) ''meteorology conditions'' is the less important identified factor to be looking at gasoline storage and distribution facility in developing country. This is the identified factor being affected by the lower-level identified factor.

2.3.3. MICMAC Analysis

For the MICMAC analysis, the driver-dependence matrix figure shows that in the cluster I, autonomous factor there is no identified factor located in that area. Autonomous factors are in the figure with the weak driving power and dependence power and, it does not impact on the system. The lack of autonomous factor implies that all the identified factors play a significant role in influencing benzene exposure concentration at the GSDF in developing country. Although, priorities are set among the identified factors, management should pay attention to consider all the identified factors to be tackled one after the other.

At the cluster II, there are no identified factors into that area of the drive-dependence matrix figure. The dependence factor is the zone in the figure which has weak drive power and strong dependence power. The absence of dependence factor indicates that most of the identified factors are roots cause of benzene exposure concentration at the GSDF. And then, quasi no identified factors depend to other identified factor to influence the benzene exposure concentration.

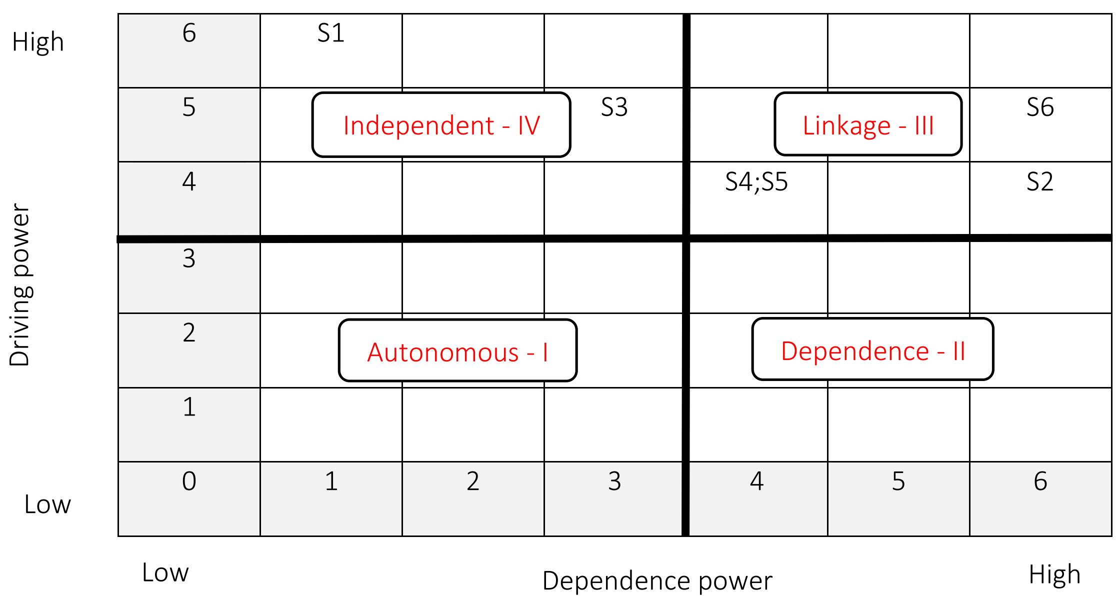

Fig 2.3. Driver-Dependence matrix of the benzene identified factors

Therefore, management has no need to focus on the understanding of the relationship between other levels of identified factor in the ISM model, because the priority identified factors are already known and need to be tackled to make inexistent the other dependence factors.

In the cluster III, four identified factors are located in the Fig 2.3., such as ''product'', ''regulation'', ''working practices'' and ''installation''. The linkage factor is the area in the figure with a high driving power and strong dependence power. This implies that these identified factors to influence benzene exposure concentration, are all impacted at the same time. And then, from a change only one identified factor all the other identified factors are impacted to influence the benzene exposure concentration. In other to tackle these identified factors, management should conduct training and monitoring an in-house procedure for a task implementation.

Finally, in the cluster IV two identified factors were located such as ''nature of the task'' (S3) and ''meteorology condition'' (S1). The independent factor is the zone in the figure which has a strong drive power and weak dependence power. This indicates that the two identified factors located in independent area are independent regardless to the impact they have respectively to that benzene concentration in loading operation for storage and distribution facility in developing countries. Each of these two identified factors influence benzene exposure concentration at their respective level independently.

This study, revealed a total of 23 specific sub-factors that influence benzene exposure concentration during loading operations. The 23 sub-factors were identified in the literature review from studies focusing on benzene exposure during loading operations. These 23 sub-factors were then, grouped into 6 identified factors. The identified factors were selected through more generic factors that can impact a risk exposure assessment during a loading operation and with the experts' opinions on those factors. The 6 identified factors covered the overall exposure scenario for loading operation and are common to developing countries facilities. The rank of the identified factors was observed at 2 levels, through the experts' opinions and ISM hierarchy. From the experts' opinions, the scores assigned to each identified factor was influenced by the number of questionnaire survey obtained. At the ISM hierarchy, the Fig. 2.2. Shows the priority in terms of which identified factor (s) should be tackle first.

From the ISM model, several interactions between the 6 identified factors which influence benzene exposure concentration during loading operations were disclosed. This is well illustrated from the SSIM matrix to the digraph. In the digraph, from the level I, only the identified factor '' (S5) Installation'' and '' (S2) Product'' are interacting in other to influence benzene exposure concentration. Then, to be connected to the next level, only the identified factor '' (S5) Installation'' in the level I is connected to the identified factor '' (S3) Nature of the task'' of the level II. Finally, the identified factor '' (S3) Nature of the task'' is connected to the identified factor '' (S1) Meteorology conditions'' of the level III.

The results of this study, for loading operations of gasoline in developing countries have identified 6 factors that must be assessed; and among them 4 factors should be tackled first. This implies for the hierarchy level I in the ISM model, to reduce the benzene contain in the gasoline product from the refinery. A continuous training and educating workers on working procedures. Developing a watch regulations and laws that could impact negatively the loading operations and finally an updating of the facility with the implementation of engineering control measures, such as vapor recovery system. At the level II hierarchy, resulting of the combination of providing the appropriate personal protective equipment and continuous training on working procedure. Finally, for the level III hierarchy, a collective protective equipment and upgrade of the operation mode, such as automation are necessary to prevent and protect workers' health.

2.3.4. Combine analysis between sub-factors and factors influencing benzene exposure concentration in GSDF

From the analysis of sub-factors by ISM model shown in the Appendix Fig.A.1, the results revealed that sub-factors related to Meteorology; Installation; Nature of the tasks and Regulations factors such as wind direction, temperature level, external floating roof tank, vertical roof tank, regular task, loading task, lack of vapor recovery system, lack of regular chemical assessment reports were the most influential. This implies that, at the sub-factors levels, benzene exposure concentrations are influenced by elements belonging to identified factors and are interrelated. Furthermore, all these sub-factors contribute significantly to influence benzene concentration and required to be all addressed accordingly to priority levels, in other to protect workers' health.

Based on work experience, this analysis discloses the importance of performing the monitoring exposure data at GSDF in developing countries. Due to the fact that the unknown benzene concentration level in gasoline; the poor regulation level; the lack of effective engineering control measures and poor working practice all contribute to increase workers' health risk.

2.3.5. Limitations and scope of the future research work

In this study, the ISM model and MICMAC analysis were applied for 6 identified factors as a result of analysing the factors that influence occupational benzene exposure concentration in loading operations at gasoline storage and distribution facility for developing countries. However, the limitation on relevant articles from the literature survey, and from which the quality of the study rely on, might affected the results with some element of bias.

Having analysing the factors influencing occupational benzene exposure concentration during loading operation at storage and distribution facility in developing countries, assessment of suitable factors from benzene exposure at storage and distribution facility would be crucial for the workers' health protection.

Although, the study has some limitations the results were worthwhile to help describing the current challenges that gasoline storage and distribution facilities in developing countries experience.

2.4. Conclusion

The analysing of factors influencing occupational benzene exposure concentration in loading operations at GSDF in developing countries, has enabled to identify 23 sub-factors influencing benzene exposure concentration from the literature review, and grouped into 6 main factors. Then, the degree of importance of these factors was assessed through their respective ranking.

Moreover, the interaction and relationship among the factors was elucidate, which contributed to first identified the most important factors to tackle when conducting an exposure assessment in gasoline storage and distribution facility in developing country and the behavior of the factors. The above information is crucial to strategize, in other assess benzene exposure in at GSDF country. From the questionnaire-based survey, factors influencing benzene concentration during loading operation were identified and ranked based on respondents' results, with the factor product (S2) being the 1st rank and regulations (S5) last influential factor as shown in the table 2.3. The ISM model discloses the three levels of hierarchy that exist in this study and the interactions between the factors working practices (S4); installation (S6); regulations (S5) and product (S2) at the level 1. The results of this study has pointed out four identified factors such as product (S2); working practices (S4); regulations (S4) and installation (S6) which are the influential factors to benzene exposure concentration at the gasoline storage and distribution facility in developing countries.

The management should take into consideration the priority disclosed in terms of factors to be tackled and the behavior pattern of these factors when conducting an exposure assessment.

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Chapter 3

Occupational exposure estimate of benzene and the effectiveness of control measure in Gabon's gasoline storage and distribution facility

3.1. Introduction

In order to convey refined petroleum products from the refinery to the end users, gasoline storage and distribution facility (GSDF) is considered as a critical step to successfully achieve this operation. GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, truck tank) [1,2,]. GSDF is as the same time a useful tool for a nation's economic growth and health issue to its working population; through economic gain from loading operations activities and health damage such as cancer risk from workers' exposure to petroleum products respectively.

Loading operation is the process of transferring petroleum refined products from storage tank to operating tank [2]. It is also the transfer of petroleum refined products from storage tank to various petroleum storage transport mode such as; barge tank; truck tank, through pipelines, hoses, flexible joint arms [1]. Loading operation is the main activity in petroleum storage and distribution facility and required well trained working force and functional equipment to be run properly [2]. These requirements act as a guarantee for a safe working environment freed from any economic loss and occupational injure. However, during loading operations and storage of petroleum refined products, such as gasoline, benzene vapors escape into the atmosphere [3]. Air toxics are released from the petroleum storage and distribution facility during gasoline loading tank truck; storage tank; barge tank and from the vapor leaks at loading pumps, valves and other equipment in the facility [2,4].

Benzene is one of the volatile components of petroleum products, like gasoline and is an established carcinogenic chemical for human health by the International Agency of Research on Cancer [5]. Short term high exposures to benzene on human can give rise to various adverse effects such as headaches, dizziness, inability to concentrate, impaired short term memory and tremors [6,7] and is considered as acute exposure effects. While long term human exposure can give rise to more complex health effects including hematotoxicity, genetoxicity, immunological and reproductive effects as well as various cancers [8] and is considered as chronic exposure effects. In general, acute exposure effects are considered to be reversible, while chronic exposure effects are probably irreversible [9].

Gabon is a third-world oil exporting country since 1960. Specific hazardous working environments in the oil sector called ''classified petroleum facilities'' with environmental and occupational regulations have been set-up since 2005 [10]. These regulations allow the evaluation of hazardous chemical in ''classified petroleum facilities'' [11]. Gabon's regulations related to chemical inhalation exposure from GSDFs do not meet the current international standards. Additionally, monitoring data for previous assessment are unavailable. Because it is frequently not feasible to measure the exposure of all workers due to limited resources. The lack of using a model that estimate exposure and systematically evaluate the control measures in previous studies for Gabon's GSDFs, makes it challenging to provide an accurate risk assessment of inhalation exposure to hazardous substances. Therefore, in this study, a modelling estimation is recommended. To overcome monitoring challenges and compensate the lack of measured data. The Risk Assessment Regulation (1488/94) allows the use of modelling techniques for the estimation of exposure [12]. Loading operations are characterized by various subtasks which produce vapor emissions [13] and which need to be estimated in other to know the level of exposure concentration workers are exposed to. Modelling techniques help to estimate chemicals emissions from these subtasks.

To the task-level assessment of benzene exposure [14], some predictive exposures models were built, such as European Centre For Ecotoxicology and Toxicology Of Chemicals - Targeted Risk Assessment (ECETOC-TRA) Model, is effective on dermal exposure and chemical properties assessment [15]; the Estimation and Assessment of Substance Exposure (EASE) Model has few features as predictive exposure model [16]; and the Control of Substances Hazardous to Health (COSHH) Essential is a generic exposure predictive model [17]; all have been proposed to assess benzene exposure in GSDF. However, these predictive exposures models provide an estimation of exposures concentrations less accurate regardless of GSDF. Further, without ensuring a safe level of workplace [18], therefore, maintaining a potential high risk on exposure in loading operations. These exposures predictive models are limited to conduct a task process assessment and a systematic control measures assessment effectively for benzene exposure during loading operation in GSDF.

Despite this concern, few detailed researches have been conducted on occupational benzene exposure with a systematic reduction strategy in GSDFs. In order to provide a more accurate estimate exposure concentration with the view of procuring safe working environment. Thus, this study aims to estimate benzene exposures concentrations at the task-levels and evaluate the effectiveness of appropriates control measures to reduce exposure concentrations to the occupational exposure limit (OEL) for loading operations in Gabon's GSDFs. Fig.3.1. shows the analytical procedure of benzene estimate.

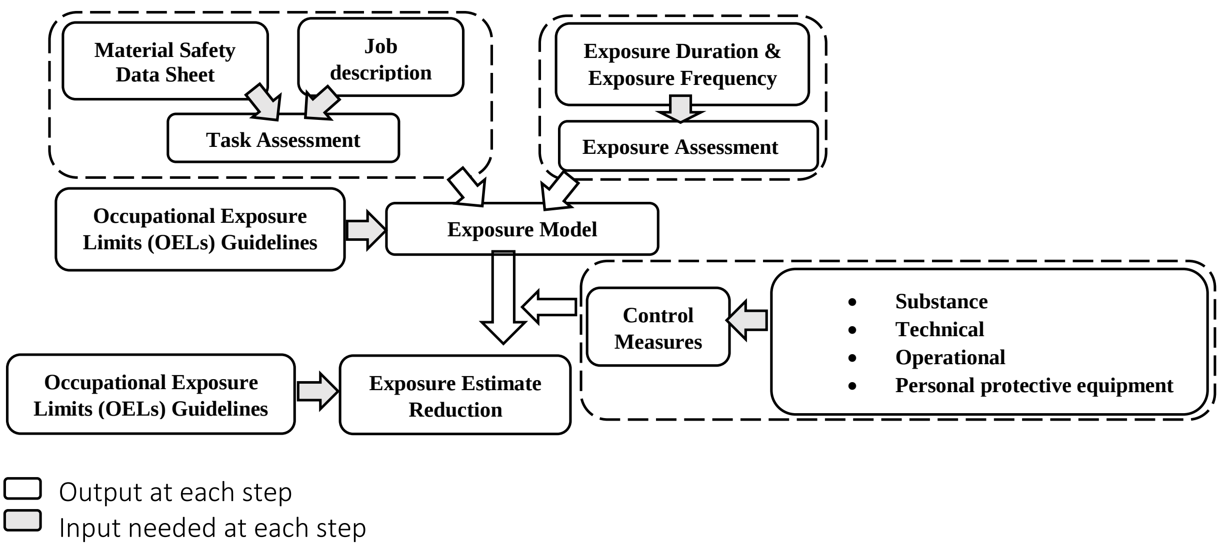

Fig. 3.1. Analytical procedure of benzene estimate

3.2. Material and method

3.2.1. International regulations and standards for benzene OEL

In the petroleum industry, GSDFs are known to result as the highest occupational exposures to chemical [19]. The introduction of various strategies to provide workers a safe working place has been evolving for over six decades. Several specific control measures in general from industrialized countries, those specifics to GSDF have been suggested. The implementation of Stage I vapor recovery (the equipment used to capture and recover emissions from loading operations in GSDF) [20] has become a requirement to adhere to stringent limits on emissions in several countries; under the National Emission Standards for Hazardous Air Pollutant (NESHAP) regulations [21]. Edokpolo [7] showed that the vapor recovery system led to significant great reduction in benzene exposure levels in petroleum distribution facilities [21].

Furthermore, Swick et al. [22] have inventoried the latest regulations related to the handling of hazardous substances in the workplace, especially for gasoline product, which contains benzene as substance. A summary of these regulations is shown in Table 3.1. According to the 1994 European Commission Directive 63/94/EC, storage installations as well as loading and unloading equipment must be designed and operated in accordance with the technical provisions to reduce emissions of volatile organic compound [3]. Benzene is known to adversely affect human health and therefore, regulations have been promulgated to reduce the amount of benzene to which workers and general public are exposed to [21]. Regulatory OELs, based on toxicology data, are set and enforced by government agencies to protect workers' health in the workplace [23]. However, the level of regulations standards for benzene exposure in GSDF can differ from one facility to another; and from one country's legislation to another. These are guided by specifications of benzene on the petroleum product, engineering controls via good industry working practices existing in a country's legislation, or by the company's safety and health guidelines [22]. For the Gabon's GSDF, the Gabonese Hydrocarbon Code, Law No 011/2014 remains unsatisfactory regulations for gasoline storage and distribution industry in comparison to the current international standards. The adoption and the implementation of more mature regulations from international standards by Gabon's GSDF, for its loading operations in reference to the Table 3.1. would determine the level of exposure to benzene in the facility. Table 3.3. presents the current OELs of benzene from various regulatory bodies [7]. These regulations are used worldwide and are based on epidemiological studies. The current guidelines to assess exposure concentration levels of benzene in occupational settings have also been presented.

Table 3.1. Gasoline regulations in petroleum storage and distribution facility

Tasks	Regulations titles & scopes	Explanations	References
Loading truck tank	Loading operation of gasoline from a loading rack to the truck tank must comply with the New Source Performance Standards codified at the 40 Code of Federal Regulations (C.F.R.)	This regulation contributes to lowering VOC emissions during the truck tank loading operation. The loading racks must be equipped with a vapor collection system designed to collect the total organic compound (TOC). Loading rack equipped with a vapor collection system must not exceed emission of 35 mg of TOC per liter of gasoline loaded (mg TOC/L gasoline), or 80mg TOC/L gasoline loaded. Gasoline must only be loaded into a vapor-tight gasoline truck tank.	40 C.F.R. Part 60, Subpart XX - Standards of Performance for Bulk Gasoline Terminals. Standard of Performance Standards New Stationary Sources, 2013: § § 60.500-60.506 Standard of Performance Standards New Stationary Sources, 2013: § § 60.500-60.502 (a) Standard of Performance Standards New Stationary Sources, 2013: § § 60.500-60.502(b) (c) Standard of Performance Standards New Stationary Sources, 2013: § § 60.500-60.502(e)
Loading storage Tanker	Loading tanker operation must comply with the emission limits and management practices set forth at the 40 C.F.R., Part 63, Subpart R	Leakages equipment within the GDSF, must control VOC emissions from large storage tanks (i.e. those at or above 20,000 gallons' capacity) by installing either specified floating roofs and seals or at closed vent system and control device to reduce emissions by 95%.	40 C.F.R., Part 63, Subpart R. NESHAP for Hazardous Air Pollutants for Source Categories, 2013: § 63.422 (b) 40 C.F.R., Part 63, Subpart R. NESHAP for Source Categories, 2013: § 63.423 (b) Transportation of Hazardous Liquids by pipeline, 2013: § § 195.100-195.134; 195.402-195.403; 195.48-195.64 NESHAP. Ill. Administration. Code, Tit. 35, § §215.583, 218.583, 219.583 and Michigan. Administration. Code, r.336.1606-336.1703
Loading barge	Loading barges operations must comply with the Marine Occupational Safety and Health Standards codified at the 40 C.F.R., Part 197.	The observation of the permissible exposure limits (PELs) for benzene and wearing respirators and personal protective equipment in areas where airborne benzene concentration can be expected to exceed the PELs must be complied. Additionally, workers should be informed about benzene hazards, including the Material Safety Data Sheet (MSDS) and trained regarding benzene risk and protective measures. Workers must be removed from areas where the airborne concentration may exceed 5ppm.	40 C.F.R., Part 197. General Provisions: Marine Occupational Safety and Health Standards, 2013: § 197.515, 197.520 and 197.535 40 C.F.R., Part 197. General Provisions: Marine Occupational Safety and Health Standards, 2013: § 197.565. 40 C.F.R., Part 197. Subpart C. General Provisions: Marine Occupational Safety and Health Standards, 2013: § 197.560.

3.2.2. Gabon's Gasoline Storage and Distribution Facility (GSDF)

Several studies, such as those by Irving et al., [32] (422.5 mg/m³) Saarinen., (6.1 mg/m³), and Thomas J. Smith et al., [37] (1 625 mg/m³) have reported short-term exposure at high concentration during loading operations in GSDFs without vapor recovery system. The Gabon's GSDF is located in the Maritime-Ogooue Province in western side of Gabon. An average of more than 765 492 tonnes of refined petroleum products are handled every year [24]. The facility has a pipeline system network connected to the only refinery for receiving petroleum products into storage tanks. The facility possesses a loading rack area for truck tank loading operations and a pumping station for barge loading operations. All the operations are done manually. Additionally, the facility does not have a vapor recovery system for its loading operations as required from the current regulation. Therefore, the gasoline vapor escapes into the atmosphere during storage and loading operations [22].

The main activity at Gabon's GSDF is the loading operation. Loading operation is the transfer of petroleum product from the refinery to the storage tank, the storage tank to the truck tank, or barge tank through pipeline and flexibly jointed loading arms [1,2]. Loading operation is also, a process of combining separated subtasks with the view of transferring refined petroleum products from one storage mode to another. These subtasks operations indicate usually higher benzene exposure concentration for short term exposure and low exposure concentration for the full shift (8 hours – TWA) for the two OELs. In general, short term exposure task during loading operations involve highly variable exposure exceeding the OEL [25]. Thus, this leads to a necessity to employ a suitable exposure model which can assess task-level in GSDF.

3.2.3. Exposure modeling

An exposure model describes how various workplaces parameters affect exposures. More precisely, in our context, the exposure model is a set of equations that predicts the exposure concentration of benzene at different times and at different specific loading operations [39]. Typically, models include a source term and allow for the transport and fate of the contaminant through space and over time to predict concentrations. The workers who move through the contaminated environment or breathing zone, are exposed to the contaminant in proportion to the amount of time they spend in different spatial locations [26, 39].

In GSDF, during loading operations, workers are in the breathing zone, where there is relatively higher exposure intensity near the emission source [39]. This requires an exposure model with a near-field and far-field exposure approach to accurately at the task process assess benzene exposure during loading operations in GSDF [29, 30, 31, 39].

There are several existing exposure inhalation models to assess chemical in working place. However, to assess benzene exposure during loading operation at GSDF, four (5) inhalations exposure predictive models such as, Control of Substances Hazardous to Health (COSHH) essential; Registration, Evaluation, Authorization, and Restriction of Chemicals-Targeted Risk Assessment (REACH ART); Estimation and Assessment of Substance Exposure (EASE); European Centre For Ecotoxicology and Toxicology Of Chemicals-Targeted Risk Assessment (ECETOC-TRA); and STOFFENMANAGER were selected and compared based on five (5) components such as control banding; modify factor; task assessment process; prioritization and control measures evaluation like shown in Table 3.1.

Table 3.2. Comparative analysis of inhalation exposure predictive models

Components / Inhalation exposure models	Control Banding	Modify Factor	Task Assessment Process	Prioritization	Control measures evaluation
COSHH Essential	O	O	O	O	X
REACH ART	O	O	O	O	X
EASE	O	O	X	O	X
ECETOC TRA	O	O	X	O	X
STOFFENMANAGER	O	O	O	O	O

O: Enable
X: Unable

These components cover all the steps to task exposure assessment and systematic control measures from the ''Source-Receptor'' approach. Among the 5 inhalation exposure predictive models, STOFFENMANAGER model fulfilled all the requirements and was selected to be used to estimate benzene exposure during loading operation at GSDF.

Table 3.3. Occupational exposure limits of benzene

Regulatory body	**Description**	**Benzene (mg/m^3)**
Occupational Exposure Limits (OEL)		
American Conference of Governmental Industrial Hygienists (ACGIH), USA	Threshold Limit Values (TLV/8hour)	1.6
	Short Term Exposure Limit (STEL/15mn)	8.1
Occupational Safety and Health Administration (OSHA), USA	Permissible Exposure Limit (PEL/8hour)	3.25
	Short Term Exposure Limit (STEL/15mn)	16.25
National Institute for Occupational Safety and Health (NIOSH), USA	Recommended Exposure Limit (REL/8hour)	0.325
	Short Term Exposure Limit (STEL/15mn)	3.25

3.2.4. Task-level assessment method

Three operations were selected at the Gabon's GSDF, ''tank truck loading operation''; ''storage tank loading operation'' and ''barge loading operation''. These loading operations are at different locations and task are performed through different equipment in the facility such as; loading truck tank from flexible arms; loading storage tank from the pipeline, and loading barge from hoses. Subsequently, the job description of each operation was analysed in details in order to identify the subtasks where workers are directly exposed to benzene exposure. The analysis resulted in the identification of the sources of vapor emission; worker's breathing zone and actions during loading operations that exposed the workers to benzene inhalation.

The Fig. 3.2. shows the exposure process by which workers are potentially exposed to chemical substance during a task. Data on the duration and frequency of each exposures situations were also collected from sample survey of regular loading operation in GSDF. These parameters were used to estimate the benzene concentration in the various loading locations. The Table 3.3. summarize the parameters used to estimate the benzene concentration. Long term exposure subtask (LTES), were defined as those with an exposure duration time > 30 minutes and short exposure subtasks (STES), as those with an exposure duration time < 30 minutes.

The Material Safety Data Sheet (MSDS) for gasoline from SHELL Company was used. The gasoline MSDS was obtained through an internet search engine such as Google. Information concerning health and safety, such as ''risk-phrases'' and ''health-statement'' were retrieved from this MSDS. This information enabled to identify the severity level of benzene hazardous to human health. The ''health – statement'' was ranked into hazard classes according to the severity towards human health. According to this MSDS, the gasoline product was composed of 13 components. The component referred into this study is benzene. These information lead to the estimation of the benzene intrinsic emission, the first element in the exposure process as shown in the Fig. 3.2. In order to estimate exposures at the task process level, scores were assigned at each task process steps. These scores of various values were attributed regardless of the chemical dispersion process according to Cherrie et al. [26]. The logarithmic scale is based on 'source-receptor' approach, of the conceptual model for inhalation exposure assessment [27]. From the emission source of the contaminants to the worker, through the exposure patterns, several modifying factors were identified. The conceptual model in inhalation exposure assessment is built from nine (9) mutually independent principal modifying factors [31]. These modifying factors describe the components and the transport mechanism of exposure process at high level and an approach for exposure quantification [29, 30].

The main source of emission being the loading operations, the Fig. 3.3., 3.4, 3.5. below describe the specific sources locations as well as the corresponding tasks. Fig. 3.3. shows the truck tank loading operation and describes the task and localizes the source of vapor benzene emission. Fig. 3.4. shows the storage tank loading operation and describes the task and the source of vapor benzene emission area. Finally, Fig. 3.5. indicates the barge loading operation and describes the task and identifies the source of vapor benzene emission location.

Table 3.4. Benzene exposure parameters

Operations	Tasks	Time (minutes)	Frequency
Truck tank Loading	checking the manholes (STET)	3	4-5 day a week
	loading truck tank (STET)	25	4-5 day a week
	cleaning spillage and leaks (STET)	10	4-5 day a week
	taking the product sample (STET)	2	4-5 day a week
Storage tank Loading	tanker gauging (STET)	3	4-5 day a week
	loading storage tank (LTET)	360	4-5 day a week
	taking the product sample (STET)	2	4-5 day a week
Barge Loading	opening valve system (STET)	3	2-3 day a week
	Loading and pump monitoring (LTET)	360	2-3 day a week
	taking the product sample (STET)	2	2-3 day a week

The inhalation exposure predictive model used in this study has been validated from various studies such as those by Koppisch et al., [27], and Landberg et al., [28]. In order to estimate the benzene exposure concentration level at the Gabon's GSDF, the facility was divided into three main compartments with regards to breathing zones, i.e: We have ''near-field exposure'', ''far-field exposure'', and ''background exposure''. A source of emission that is relatively far from a worker has a lower influence on the worker than a source very close to the worker. Several equations, in total 9 were applied to quantify the benzene concentration at different levels of exposure during the tasks, are mentioned below. These equations follow the work of Tielemens, [31] and express the development of a quantitative algorithm for exposure predictive model [29, 30].

Table 3.5. Logarithm scale for category scores of dispersion exposure

None	0.01
Very low	0.03
lower	0.1
Low	0.3
Medium	1
High	3
Very high	10

The equation for intrinsic emission of benzene, was applied to determine the concentration level of benzene within the product (gasoline). Before, any modifying factors can either increase or decrease the concentration level. The equation on intrinsic emission is described below as: The intrinsic emission of benzene equation:

$$Eb = Pb / 30\,000 \text{ Pa} \times fb \qquad (3.1.)$$

Eb : intrinsic emission of benzene (mg/m^3)
Pb : vapor pressure of pure benzene substance (kPa)
fb : the fraction of benzene component in gasoline

30, 000 Pa : substances with a vapor pressure equal or superior to 30, 000 Pa which fully evaporated in a very short time and will practically only be available as vapor.

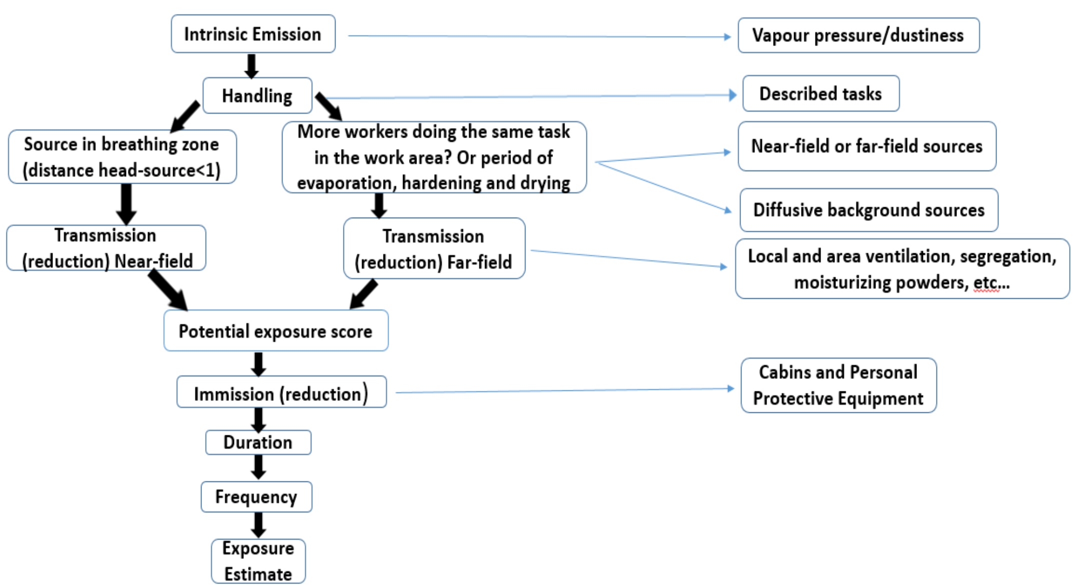

Fig. 3.2. Exposure process diagram

The ‘’near-field exposure’’ was considered as exposure concentration level taking at the source located within one (1) meter of the head of the worker [28]. That is, within a one meter of the area where task is being performed.
The equation for the ‘’near-field exposure’’ (Cnf) is as follow

$$Cnf = Eb \times H \times \eta lc \times \eta gv\_nf \quad (3.2.)$$

The far-field exposure (Cff) was considered as the exposure concentration level taking within one to four meter of the source of emission within the breathing zone. That is, one (1) to four (4) meter away far from where the task is performed.
The equation for the far-field exposure is as follows:

$$Cff = Eb \times H \times \eta lc \times \eta gv\_ff \quad (3.3.)$$

The background exposure (Cds) was considered as the exposure concentration level taking beyond the four (4) meter of the emission source and was described as when there is no loading operation taking place in the facility.
The equation for the background exposure is as follows:

$$Cds = Eb \times a \quad (3.4.)$$

The daily concentration (Dc) is the average exposure concentration for the traditional 8 hour working time for loading operations tasks.
The equation for of the daily concentration is as follows:

$$Dc = Cff + Cnf + fh + th\ (8\ h) \quad (3.5.)$$

Source: Google/loading truck tank operations images

Fig. 3.3. Truck tank loading operation

The long-term exposure concentration (Ltec) is the exposure concentration of tasks above 30 min. The equation of the long- term exposure concentration is as follows:

$$Ltec = Cff + Cnf + th\ (<30\ min) \qquad (3.6.)$$

The short -term exposure concentration (Stec) is the exposure concentration of tasks less than inferior to 30 min.

The equation of the short -term concentration is as follows:

$$Stec = Cff + Cnf + th\ (>30\ min) \qquad (3.7.)$$

Eb: the intrinsic emission of benzene (mg/m^3)
H: handling (or task); (dimensionless)
ηlc: local control measures of the existing reduction transmission ; (dimensionless)
ηgv: Natural ventilation of the existing reduction transmission; (dimensionless)
th: handling time; minutes (min)
fh: frequency of handling; length of exposed time * time in minutes (N*min)
Cds: background exposure; (mg/m^3)
Dc: daily concentration task; (mg/m^3)
Ltec: long- term exposure concentration; (mg/m^3)
Stec: short -term exposure concentration; (mg/m^3)
Cnf: near-field exposure concentration task (mg/m^3)
Cff: far-field concentration task (mg/m^3)

Source: Google/loading storage tank operations images

Fig. 3.4. Loading storage tank operation

From the above equations, the concentrations for STES and LTES during loading operations were performed and known. This leads after, to the reduction of the exceeded concentration levels to the OELs.

Source: Google/loading barge operations images

Fig. 3.5. Loading barge operation

3.2.5. Control measures assessment

The reduction strategy for benzene was addressed at four levels. The measures that impact ''near-field'' level; the measures affecting the ''far-field'' level; the measures impacting the ''background'' level, and the measures influencing the ''adaptation of worker situation''. These measures are based on the hierarchical so-called ''S.T.O.P.-principal'' (substitution measures, technical measures, operation measures, personal protection equipment). Each of these control measures represent a group of various control measures assigned to reduce exposure concentration in their particular dimension level. Thus, we have ''chemical filter mask'' control measure for the ''personal protection equipment'' control measure group or the ''vapor recovery system'' control measure as part of the ''technical'' control measures group.

For every single subtask, relevant control measures were applied at each level from one step to the other. The relevant controls measure of the ''substitution measures'' group were applied before moving to next group, i.e., ''technical measures'' to reach the OELs [31]. To lower the concentrations of benzene to OELs during loading operations, the following reduction equations were used.

Concentration reduction near-field:

$$Cr.nf = Cnf + ηimm \qquad (3.8.)$$

Concentration reduction far-field:

$$Cr.ff = Cff + ηimm \qquad (3.9.)$$

Cr.nf: Concentration reduction near-field (mg/m³)
Cr.ff: Concentration reduction far-field (mg/m³)
ηimm: multiplier for the reduction of exposure due to control measures at work.

3.3. Results & Discussion

The results presented here are based on a case study, investigating the estimation of benzene exposure concentration for STES and LTES during loading operations at the Gabon's GSDF. In total, from the three loading operations in this facility (loading truck tank operation, loading barge operation, and loading storage tank operation), ten exposures subtasks were assessed. Among all the exposures subtasks, we have eight STES concentrations and two LTES concentrations.
From the Fig. 3.6.; 3.7.; 3.8. and table 3.6. appeared the following expressions, benzene concentration; daily concentration and task concentration. The benzene exposure is defined as the concentration level of the subtask during its operating time. The daily concentration is defined as the benzene concentration level of the subtask during the 8h working time. The task concentration is defined as the benzene concentration of the task before and after applying control measures.

3.3.1. Estimation of benzene exposures concentrations during loading operations

3.3.1.1. Loading truck tank operation

The loading truck tank operation presented four (4) subtasks situations, where the workers were considerably exposed to benzene. The benzene concentration of these subtasks varied from 9.86 mg/m³ to 187 mg/m³. The benzene concentration exceeded the 8.1 mg/m³ Occupational Exposure Limits-Short Term Exposure Limit (OELs-STEL) of the American Conference of Governmental Industrial Hygienists (ACGIH), regulatory value for the 15 min STES. Equations (3.5.), (3.7.) were used in all the subtasks for ''daily concentration'' and ''task benzene concentration'' respectively during ''truck tank loading operation''.

A difference between the short-term concentrations and daily concentration of the subtasks was noticed. Another contrast was observed between the short-terms concentrations, where, as shown in Fig. 3.6., the subtasks ''checking the manholes'' and; ''loading truck tank'' has significantly higher concentrations than the subtasks ''cleaning spillage and leaks'' and; ''taking the product sample''. From these concentration variations, it can be inferred that, the nature of the subtask being performed is the primary determinant of the overall benzene exposure [14]. The Fig. 3.7. presents the difference in benzene exposure concentrations for different subtasks and their daily concentrations during the ''loading truck tank operation''. This high difference implies the relevance of conducting more task exposure assessments compared to daily concentrations as recommended by Verma [20].

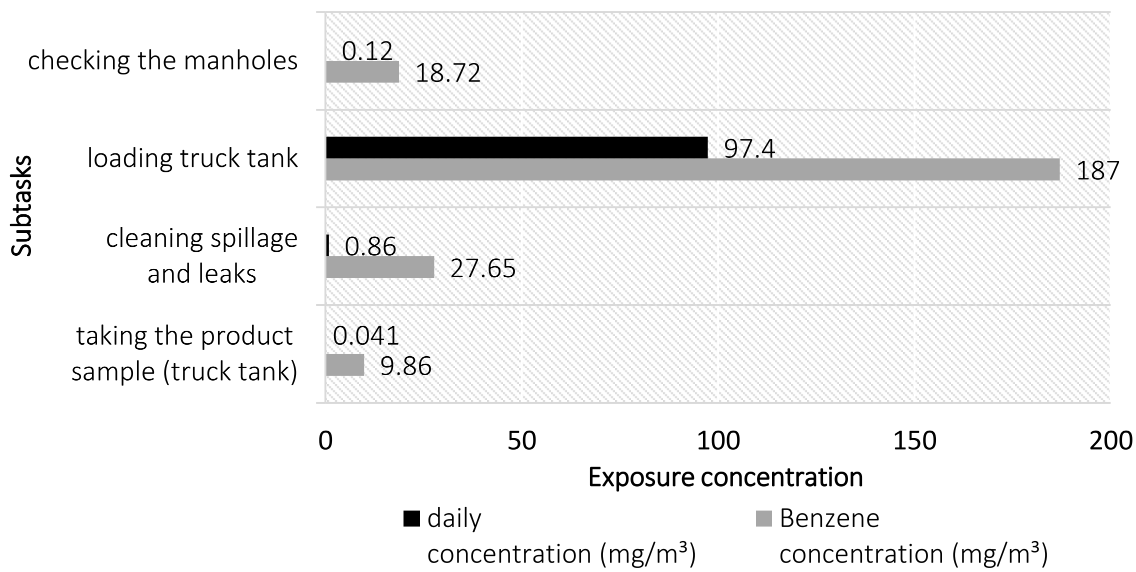

Fig. 3.6. Benzene exposure concentrations for loading truck tank operation

3.3.1.2. Loading storage tank operation

In this study, the estimation of exposure concentrations on benzene for the ‘‘loading storage tank operation’’ were investigated for each of the subtasks. In calculating the ‘‘benzene concentration’’ of the subtasks: ‘‘loading storage tank’’; ‘‘tank gauging’’ and ‘‘taking product sample’’; the equation (3.6.) was used for the first subtask and equation (3.7.) for the other two subtasks respectively. In order to calculate the ‘‘daily concentration’’ of benzene exposure for all the subtasks of loading storage tank operation, we used the equation (3.5.). All the subtasks, exceeded the 8.1 mg/m³ OELs-STEL from the ACGIH-TLV. The ‘‘benzene concentration’’ from the ‘‘tank gauging’’ subtask (187 mg/m³) and the ‘‘loading storage tank’’ task (187 mg/m³) indicated high level of exposure concentration compared to the ‘‘taking product sample’’ subtask (9.45 mg/m³). Thus, revealing that high concentrations are experienced during loading operations in a facility without a vapor recovery system [3; 32].

The ‘‘daily concentrations’’ of LTES (140 mg/m³) were significant compared to the STES (0.74 mg/m³; 1.95 mg/m³) concentrations. Only the ‘‘daily concentration’’ of the LTES (140 mg/m³) was above of the TVL-TWA (3.18 mg/m³). This shows that, time is the determinant of ‘‘daily concentration’’ exposure for this subtask. Fig. 3.7. highlights the difference of benzene concentration between each of the subtasks for ‘‘daily concentration’’ and ‘‘task benzene concentration’’ during ‘‘loading storage tank operation’’. This difference in benzene concentrations implies that subtasks exposure assessment is more relevant and give an insight than the daily concentrations for ‘‘loading storage operation’’.

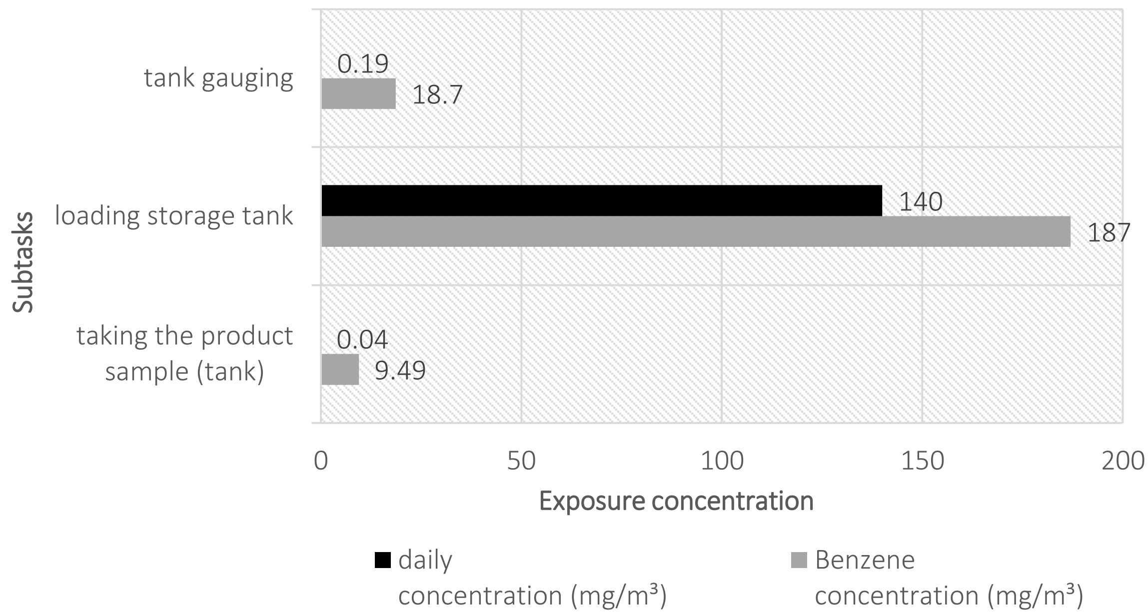

Fig.3.7. Benzene exposure concentration during loading storage tank operation

3.3.1.3. Loading barge operation

The ‘‘loading barge operation’’ indicates high exposures concentrations of benzene for all the subtasks with regards to the 8.1 mg/m³ OEL of STEL-TLV from the ACGIH. The equation (3.5.) was used to calculate the ‘‘daily concentration’’ for all the subtasks. In order to calculate the ‘‘benzene concentration’’, equation (3.6.) was used for the subtask: ‘‘loading and pump monitoring’’ and equation (3.7.) was used for the subtasks: ‘‘opening a valve system’’ and ‘‘taking product sample’’.

As shown in the Fig.3.8., the benzene concentrations for the subtasks ‘‘opening valve system’’; ‘‘loading and the pump monitoring’’, and ‘‘taking product sample’’ were 187 mg/m³; 187 mg/m³, and 9.46 mg/m³, respectively. The exposure concentration of the STES ‘‘opening valve system’’ and the LTES ‘‘loading and the pump monitoring’’ were significant. This implies that, high exposure concentrations of benzene during loading barge are driven primarily by a few specific tasks [19, 20].

According to Kawai et al. [38], jobs involving benzene during loading operations of barges were often associated with higher exposure [22]. The ‘‘daily concentration’’ of the tasks ‘‘opening valve system’’ and ‘‘taking product sample’’ were within the 3.18 mg/m³ OELs of the TVL-TWA from ACGIH. However, the LTES for ‘‘loading and the pump monitoring’’ significantly exceeded the ‘‘daily concentration’’ exposure (140 mg/m³). Fig. 3.8. presents the estimation value of ‘‘benzene concentrations’’ and the ‘‘daily concentrations’’ for all subtasks during the ‘‘loading barge operation’’. The difference in benzene exposure concentrations indicates that the exposure concentration level of the task being performed is highly influenced by the specificity of the task in the gasoline storage and distribution industry.

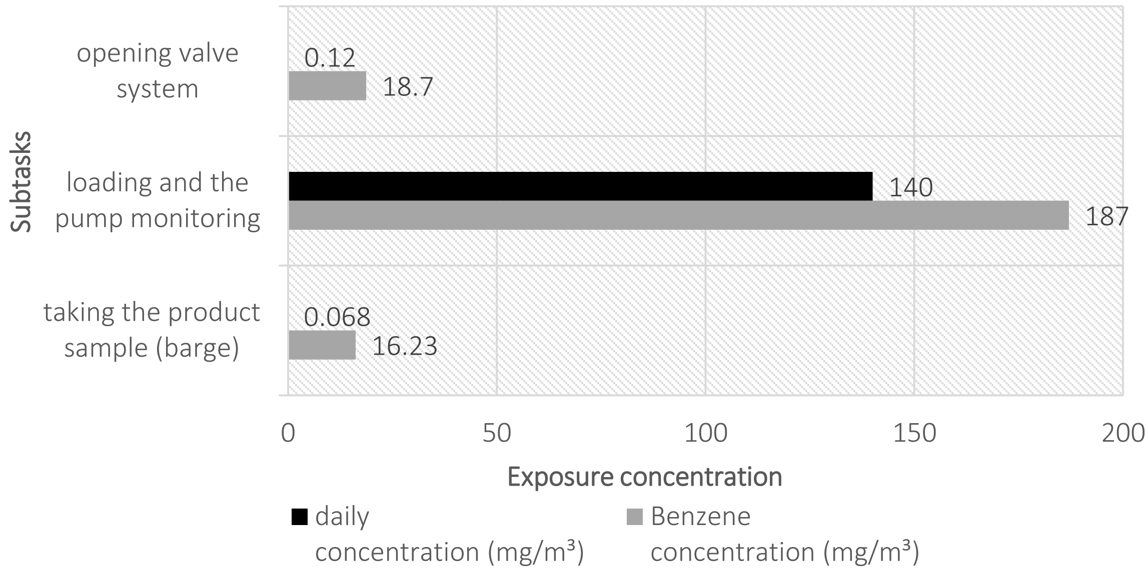

Fig. 3.8. Benzene exposure concentrations during loading barge

3.3.1.4. Summary of estimated benzene exposure concentrations

The benzene exposure concentration for the subtasks of each loading operations exceeded the 8.1 mg/m³ limit for STEL-TVL from the ACGIH. Additionally, a high concentration up to 187 mg/m³ for STEL-TVL regarding the ACGIH regulation was indicated. The subtasks with the highest concentrations were ‘‘checking the manholes’’ and ‘‘loading truck tank’’ for ‘‘loading truck tank operation’’; ‘‘tank gauging’’ for ‘‘loading storage operation’’; ‘‘opening valve system’’ and ‘‘loading and the pump monitoring’’ for ‘‘loading barge operation’’. Thus, the task-level assessment strategy discloses some critical benzene concentrations for STES during the loading operations [14].

The LTES, i.e., ‘‘loading and the pump monitoring’’ and ‘‘loading storage tank’’ had 140 mg/m³ and 140 mg/m³ benzene exposure for daily benzene concentration, respectively. These concentrations were significantly above the 3.18 mg/m³ OELs of the TVL-TWA from ACGIH. Daily benzene concentrations for LTES were higher in comparison to the STES. The results also indicate that the 8 hour-TWA of the subtask influences the benzene concentration in the breathing zone [33].

In the present study, concentrations of benzene exposure to workers are critical for the three loading operations, due to the presence of very high benzene concentrations at the task-level within each of the subtasks. The reduction of the benzene concentration to the OELs for STEL-TVL with regards to ACGIH regulation remains urgent for the Gabon’s GSDF.

3.3.2. Estimation of benzene exposures reduction during loading operations

The STES of the three loading operations (‘‘loading truck tank operation’’, ‘‘loading storage tank’’ operation and ‘‘loading barge’’ operation) selected in this facility indicated critical benzene concentrations. These results indicate an urgent need for reduction of the benzene concentrations at the task-levels to the OELs of STEL-TVL in reference to ACGIH guidelines. The Table 3.5. presents benzene exposure concentrations for all the subtasks before and after the implementation of the control measures. This table also shows a list of control measures used in order to make effective the reduction in benzene exposure concentrations to the OELs.

3.3.2.1. Benzene exposure reduction for loading truck tank operation

For the ''truck tank loading'' operation, control measures were applied to reduce benzene exposure concentrations on the subtasks: ''checking the manholes'', ''cleaning spillage and leaks'', and ''taking the product sample'', the equation (3.8.) was used. On the subtask ''loading truck tank'', the equation (3.9.) was used to reduce the benzene concentration for this subtask during the ''truck tank loading operation''.

The results indicated an effective benzene concentration reduction from 187 mg/m^3 to 4.55 mg/m^3, for the subtask ''checking the manholes'' could be achieved by using a ''vapor recovery system'' and ''chemical filter mask'' for workers during the task. The ''loading truck tank'' subtask indicated reduction in benzene concentration from 187 mg/m^3 to 29.08 mg/m^3, resulting from the use of ''vapor recovery system'', ''quick shut-off valves'' [34], and ''chemical filter mask'' as control measures. The ''cleaning spillage and leaks'' subtask indicated benzene reduction from 27.65 mg/m^3 to 4.52 mg/m^3 with the use of ''chemical filter mask'', and ''standing at the opposite direction from the wind when cleaning'' during ''loading truck tank''. The subtask ''taking the product sample'' indicated benzene reduction from 9.74 mg/m^3 to 4.55 mg/m^3, resulting from the use of ''chemical filter masks'' and ''manila ropes''. All the subtasks from the ''truck tank loading'' operation, except the ''loading truck tank'' was within the 8.1 mg/m^3 OELs of the STEL-TLV with regards to ACGIH guidelines. The results of subtask ''loading truck tank'' illustrates that, other strong external factors can render the control measures less effective in reducing benzene exposure, particularly benzene levels content in gasoline [35], in some developing countries.

3.3.2.2. Benzene exposure reduction for loading storage tank operation

In order to reduce benzene concentrations resulting from ''loading storage tank'' operation, control measures were applied to the subtasks: ''tanker gauging''; ''loading storage tank'', and ''taking product sample''. The equation (3.8.) was implemented for the subtasks: ''tank gauging''; and ''taking product sample''. The equation (3.9.) was implemented for the subtask ''loading storage tank'' during ''loading storage tank'' operation. At the ''tank gauging'' subtask, the use of ''chemical filter masks''; ''floating roofs''; a ''closed vent system''; ''emissions control device'', as control measures while performing the task, reduced the benzene concentration from 187 mg/m^3 to 4.55 mg/m^3.

The installation of ''floating roofs''; a ''closed vent system''; ''emissions control device''; ''making multiple moves out of the breathing zone'', instead of being near the connected pipeline during the ''loading storage tank'' subtask, reduced the concentration from 187 mg/m^3 to 4.55 mg/m^3. The concentrations resulting from the subtask ''taking the product sample'', were reduced from 9.46 mg/m^3 to 4.55 mg/m^3, by using 'chemical filter masks' and, 'manila ropes' as control measures.

These results indicate that the use of appropriate technical measures, protective personal gear, and best practice control measures are effective for benzene reduction on ''loading storage tank'' operation at the Gabon's GSDF.

3.3.2.3. Benzene exposure reduction for loading barge operation

The equation (3.8.) was applied for the subtasks: ‘‘taking product sample’’ and ‘‘opening valve system’’ to reduce benzene exposure during ‘‘loading barge’’ operation. The equation (3.9.) was implemented for the subtask, ‘‘loading and the pump monitoring’’ during ‘‘loading barge’’ operation. The reduction of benzene exposure at the ‘‘barge loading’’ operation, was performed through control measures at the subtasks: ‘‘opening valve system’’, ‘‘taking the product sample’’, and ‘‘loading and the pump monitoring’’. The subtask ‘‘opening valve system’’, by using a ‘‘chemical filter mask’’, ‘‘steel valves’’, and ‘‘standing at the opposite direction from the wind’’ as control measures, reduced the benzene concentration from 187 mg/m³ to 4.55 mg/m³. The subtask ‘‘taking the product sample’’, with the use of a ‘‘chemical filter masks’’, ‘‘manila ropes’’, and ‘‘standing at the opposite direction from the wind’’, reduced the benzene concentration from 178 mg/m³ to 4.55 mg/m³.

The ‘‘benzene concentration’’ of the subtask ‘‘loading and the pump monitoring’’, was reduced from 187 mg/m³ to 4.55 mg/m³, by using a ’’vapor recovery system’’, ’’chemical filter masks’’, and ’’standing at the opposite direction from the wind’’ as control measures. The Fig. 3.9. presents benzene exposure concentration of each of the subtasks before and after applying the control measures. The results imply that technical control measures and work practice control measures are the most effective determinants of benzene exposure reduction at the Gabon’s GSDF for ‘‘barge loading’’ operation. The results of benzene reduction on the subtasks ‘‘opening valve system’’, ‘‘taking product sample’’, and ‘‘loading and the pump monitoring’’ show that, the implementation of engineering control measures, appropriate best practices, as well as technical and protective personal control measures could effectively reduce the benzene masks’’, and ’’standing at the opposite direction from the wind’’ as control measures. The Fig. 3.9. presents benzene exposure concentration of each of the subtasks before and after applying the control measures. The results imply that technical control measures and work practice control measures are the most effective determinants of benzene exposure reduction at the Gabon’s GSDF for ‘‘barge loading’’ operation. The results of benzene reduction on the subtasks ‘‘opening valve system’’, ‘‘taking product sample’’, and ‘‘loading and the pump monitoring’’ show that, the implementation of engineering control measures, appropriate best practices, as well as technical and protective personal control measures could effectively reduce the benzene concentration for ‘‘loading barge’’ operation in this facility.

The results of this study, for most subtasks, were similar to those obtained in the first previous studies on exposure to benzene during loading operation from industrialized countries, such as those of: Irving (130 ppm) [32]; Nordlinder report (33.44 ppm during manual sounding) [36]; Saarinen, (3030 mg/m³ during tanker loading) [36], and Smith (130 ppm during truck tank loading) [37].

Table 3.6. Benzene concentrations before and after applying the control measures

Before applying control measures				After applying control measures	
No	Operation	Tasks	Task concentration (mg/m³)	Control measures	Task concentration (mg/m³)
1	Truck tank loading	checking manholes	18.72	vapor recovery system + chemical filter mask	4.55
2		loading truck tank	187	vapor recovery system + quick shut-off valves + chemical filter mask	29.08
3		cleaning spillage and leaks	27.65	chemical filter mask + personal protective equipment + standing in the opposite direction of wind	4.52
4		taking the product sample (truck tank)	9.86	chemical filter mask + standing in the opposite direction of wind + manila ropes	4.55
5	Storage tank loading	tank gauging	18.7	chemical filter mask + floating roofs + closed vent system + emissions reduce device	4.55
6		Loading storage tank	187	floating roofs + closed vent system + emission reduce device + chemical filter mask	4.55
7		taking product sample (tanker)	18.7	chemical filter mask + standing in the opposite direction of wind + manila ropes	4.55
8	Barge loading	opening valve system	9.49	chemical filter mask + steel valves + multiples moves out of breathing zone	4.55
9		loading and the pump monitoring	187	vapor recovery system + Chemical filter mask	4.55
10		taking the product sample (barge)	16.23	chemical filter mask + standing in the opposite direction of wind + manila ropes	4.55

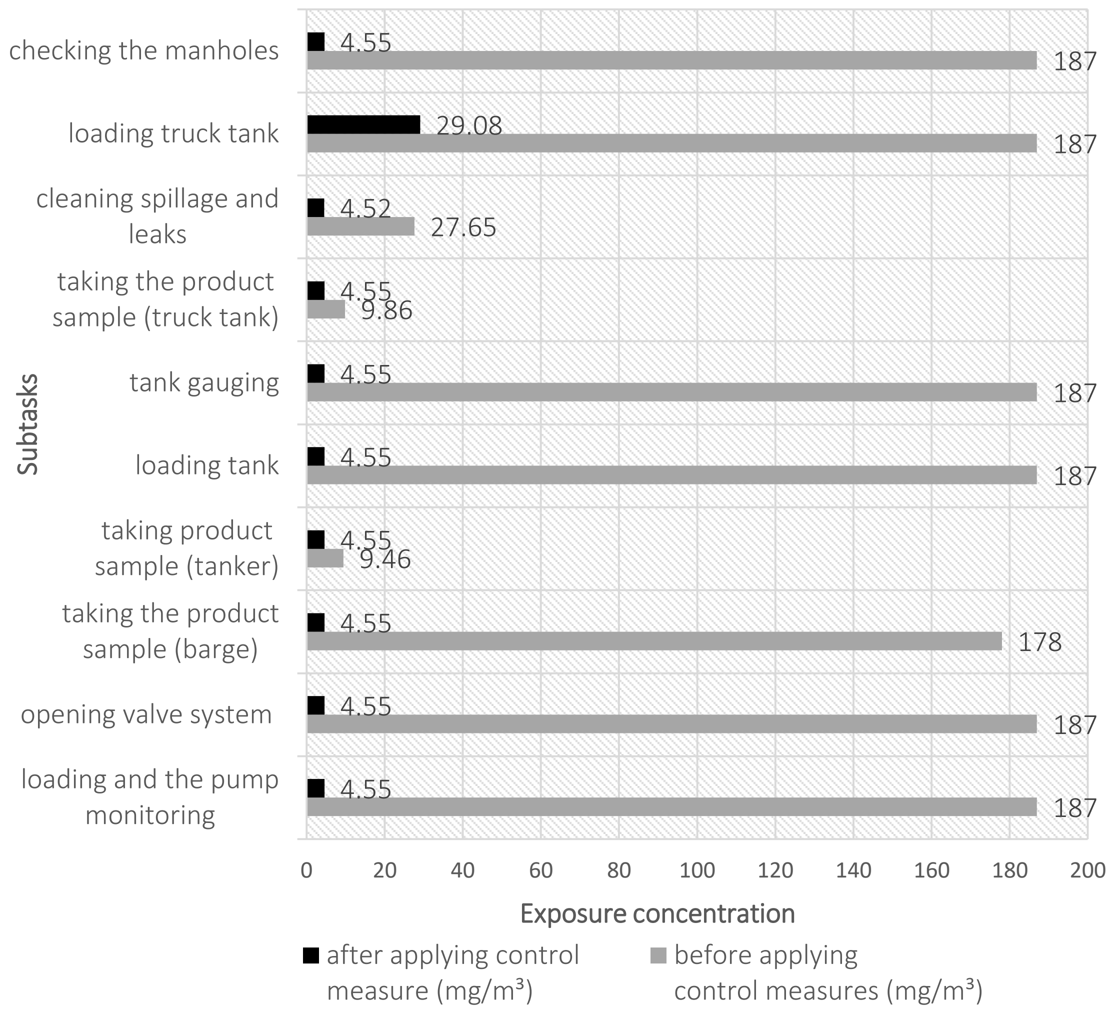

Fig. 3.9. Benzene concentrations before and after applying the control measures

However, the results from this study were not without limitations. The results of this study cannot be generalized to represent loading operations as the only source emission of benzene exposure in Gabon's GSDF. This study did not take into account the risk of benzene exposure during regular maintenance and repair subtasks, which could also increase the level of benzene concentration exposure to workers in the facility. Additionally, the automation of loading operations as a control measure, which could avoid workers to those high benzene exposure concentration subtasks in that facility, was not be evaluated.

Despite these study limitations, the study was worthwhile in its short-term exposure assessment of benzene and its reductions with regards to OELs at the Gabon's GSDF.

3.4. Conclusion

This study evaluated the benzene exposure concentration and the effectiveness of systematic introduction of control measures at the Gabon's GSDF during loading operations. The estimation methodology provided benzene exposure concentration of each of the subtasks and helped elucidate the level of prevention needed to alleviate worker health risks. Additionally, this study determined effective control measures that keep the exposure concentrations of the subtask below the OELs to offer a safe working place to the workers. This is particularly relevant to facilities lacking of relevant exposure concentration data and accurate risk assessment expertise.

The estimated benzene concentrations varied from 9.46 mg/m^3 to 187 mg/m^3 for all subtasks, in the three loading operations. The highest benzene concentrations (187 mg/m^3) were found in subtasks such as ''checking the manholes''; ''loading truck tank''; ''tank gauging''; ''loading tank''; ''loading and the pump monitoring'', and ''opening valve system''. The benzene concentration for STET varied from 9.46 mg/m^3 to 187 mg/m^3 and significantly exceeded the 8.1 mg/m^3 OELs of the STEL-TVL prescribed by the ACGIH. The LTES were 187 mg/m^3 significantly exceeded the 3.18 mg/m^3 OELs of the TVL-TWA from the ACGIH guidelines. The reduction of benzene exposure concentration varied from 4.52 mg/m^3 to 29.08 mg/m^3 for all the subtasks. The reduction was within the 8.1 mg/m^3 OELs of STEL-TVL from the ACGIH guidelines.

The implementation of control measures based on the S.T.O.P.-principal (substitution, technical measures, operations measures, personal protection equipment) enabled the evaluation of appropriates control measures in each of the groups, such as ''vapor recovery system'' control measure from the group of ''technical measures''; and ''chemical filter mask'' from the group ''personal protective equipment'' for effective reduction of benzene concentrations. This study examined and estimated the level of exposure to the carcinogen benzene during loading operations in Gabon's GSDF, focused on assessing short-term high exposure subtasks and systematically evaluate the control measures. The study results are expected to help improve the regulation level and assess workers' health in that facility.

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Chapter 4

Occupational Health Risk Assessment for Benzene Exposure in Gasoline Storage and Distribution Facility: comparison between developing and industrialized countries for the period of 1986-2001

4.1. Introduction

In order to convey refined petroleum products from the refinery to the end users, gasoline storage and distribution facility (GSDF) is considered as a critical step to successfully achieve this operation. The GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, truck tank) [1,2]. GSDF is as the same time a useful tool for a nation's economic growth and health issue to its working population; through economic gain from loading operations activities and health damage such as cancer risk from workers' exposure to petroleum products respectively.

Loading operation is the process of transferring petroleum refined products from storage tank to operating tank [2]. It is also the transfer of petroleum refined products from storage tank to various petroleum storage transport mode such as; barge tank; truck tank; through pipelines, hoses, flexible joint arms [1]. Loading operation is the main activity in GSDF and required well trained work force and functional equipment to be run properly [2]. However, emissions from loading operations at GSDF, contain benzene vapors escape into the atmosphere [3]. Air toxics are released from the GSDF during gasoline loading truck tank; storage tank; barge tank and from the vapor leaks at loading pumps, valves and other equipment in the facility [4,5].

In Industrialized countries, several studies from those of Parkinson [37]; Sherwood [35]; Phillips and jones [1]; Gjorloff [33]; Runion and Scott [36]; Halder [38]; Berlin [39]; Williams [40] had evaluated benzene exposure during loading operations in the GSDFs. The results of those studies revealed that during loading operations benzene exposure concentration were above the occupational exposure limit of the regulatory bodies such as the American Conference of Governmental Industrial (ACGIH) Hygienists and Occupational Safety and Health Administration (OSHA) at those periods, as describe in the table 3.5. in the appendix. The introduction of top loading method and vapor recovery system in loading operation reduced the benzene exposure significantly [6,7].

In other hand, in developing countries the scenario may be worse where management of such exposure-health problems is typically not well-implemented and workers may not be well-protected about such health risk [8]. Although, contamination with benzene is mostly due to uncontrolled industrial activity and lack of the awareness of workers [9], the magnitude of the problem is said to be grave for developing countries [10]. In most benzene occupational researches conducted in developing countries, a comprehensive and harmonious data collecting systems needed as first step to conduct an accurate health risk assessment are unavailable. Ezejiofor et al., [9] and Ngwige et al., [10] assessed chemical hazard at petroleum distribution industry in developing countries by using a check-list, oral interview and walk-through operational sites. This cannot insure an appropriate benzene exposure assessment for workers at the breathing zone.

Benzene is one of the volatile components of petroleum products, like gasoline and is an established carcinogenic chemical for human health by the International Agency of Research on Cancer [11]. Short term human exposures to benzene can give rise to various adverse effects such as headaches, dizziness, inability to concentrate, impaired short term memory and tremors [12] and is considered as acute exposure effects. Whilst long term human exposure can give rise to more complex health effects including haematotoxicity, genetoxicity, immunological and reproductive effects as well as various cancers [13] and is considered as chronic exposure effects. In general, acute exposure effects are considered to be reversible, while chronic exposure effects are probably irreversible [14]. Therefore, benzene under a particular exposure concentration levels can generate cancer adverse effects or non-cancer adverse effects (IRIS, 2002) on workers' health

Exposure to toxicants can be evaluated using guidelines based on the Acceptable Daily Intake (ADI), Minimal Risk Level (MRL) and Reference Dose (RfD) as single points to quantify the risk [15]. However, risk assessment using probabilistic techniques utilizes probability distributions to estimate the risk. This technique gives a quantitative description of uncertainty and variability in evaluating the risk of health adverse effects. Thus, the carcinogenic benzene for low level or high level exposure may potentially provide acute or chronic health adverse effect to workers. Therefore, the health risk assessment of benzene in GSDF for industrialized and developing countries are both relevant. The overall risk probability (ORP) is a probabilistic technic that, in assessing risk, takes into consideration the exposure concentration level and the overall exposed population [16]. The ORP seems to be the indicated health risk assessment methodology, to benzene exposure concentrations for the GSDFs. The Fig.4.1. below shows the study framework.

Thus, this explorative study aims to:

- ✓ Produce a cumulative probability distribution of benzene exposure levels for loading operations of industrialized countries for the period of 1986-2001.
- ✓ Characterize the health risk and evaluate the overall risk probability of benzene exposure concentration of industrialized countries for the period of 1986-2001.
- ✓ Characterize health risk and evaluate the overall risk probability of benzene exposure estimate in developing countries.
- ✓ Compare the overall risk probability on industrialized countries and developing countries.

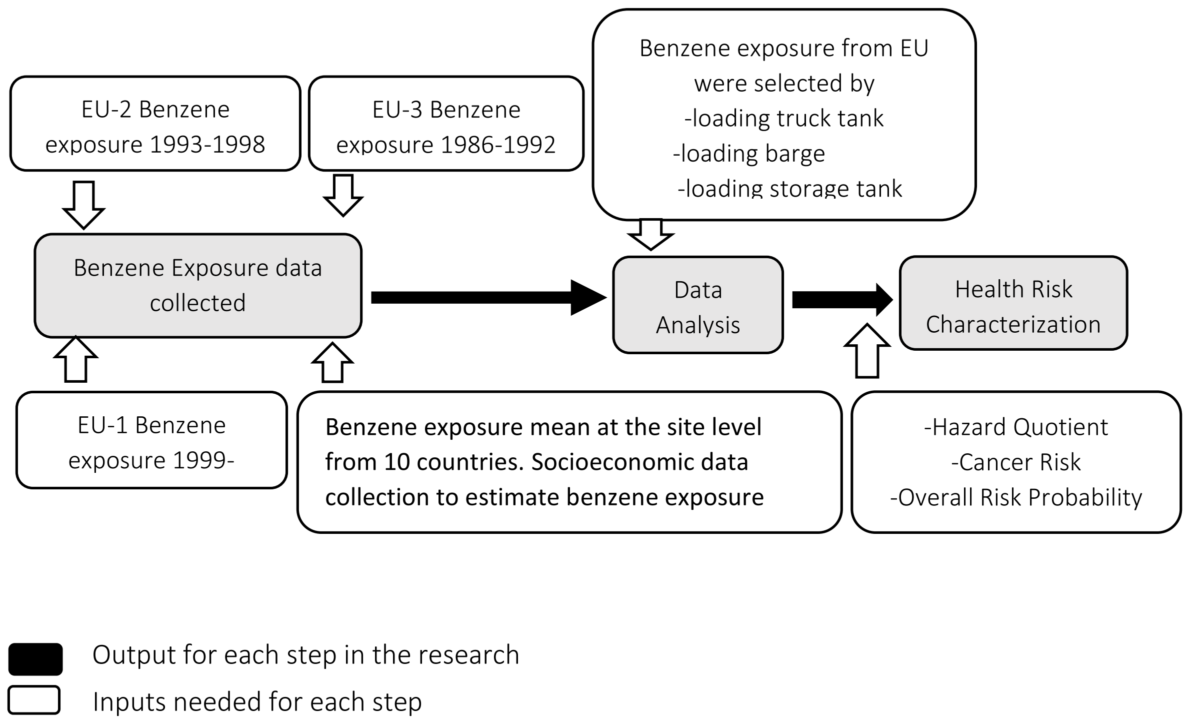

Fig. 4.1. Research procedure

4.2. Material & Method

In the section 4.2.1., briefly explained benzene occupational exposure limit evolution and gasoline distribution and storage facilities. Section 4.2.2. presents the health risk assessment methods. Finally, section 4.2.3. presents in details the research methodology on the investigation of health risk assessment in gasoline storage and distribution facilities.

4.2.1. Occupational exposure limit of benzene and gasoline storage distribution and facilities

Benzene is known to adversely affect human health and therefore, regulations have been promulgated to reduce the amount of benzene to which workers and general public are exposed [17]. Regulatory occupational exposure limits (OELs), based on toxicology data, are set and enforced by government agencies to protect workers' health in the workplace [18]. The OELs evolution of benzene exposure concentration from two internationally well-known regulatory bodies such as the American Conference of Governmental Industrial Hygienists (ACGIH) and Occupational Safety and Health Administration (OSHA) were continually reviewed. The different regulations set on OEL of benzene concentrations at various time periods for ACGIH and OSHA show the trends on benzene reduction in occupational settings. These regulations are used worldwide and are based on epidemiologically studies. The current OEL of benzene exposure at ACGIH and OSHA for 8-hour total weight average are 1.6 mg/m^3 and 3.25 mg/m^3 respectively as shown in the Fig. 4.2. below.

In downstream petroleum industry, GSDF is the highest exposed occupations [19]. During loading operations exposures of volatile organic compounds such as, benzene escaped from gasoline vapors [3]. GSDF is concerned with the handling for storage and transfer of refined petroleum products in loading locations via pipelines to different petroleum storage transport mode (barge tanks, truck tank) [1].

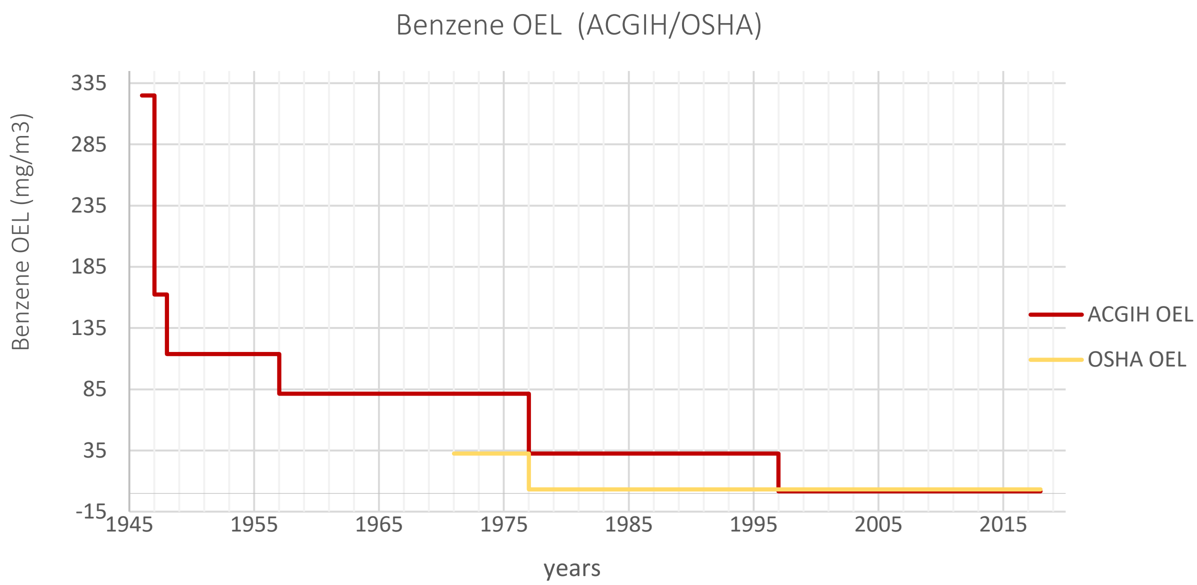

Fig.4.2. Benzene OEL evolution

4.2.2. Health risk assessment

In health risk assessment of toxicants, many methods have been used to evaluate and quantify the adverse effects of the toxicants. These methods can be divided into conventional non-probabilistic (Deterministic) methods and probabilistic-based (Scholastic) methods [20]. In a conventional method, an exposure dose (or concentration), usually in the form of an average or medium value, is compared with a threshold or reference value for a given adverse effect. The hazard quotient (or risk quotient) can be calculated from the ratio of the exposure value to the reference value [16,]. The larger the value of the hazard quotient, the higher the health risks for non-carcinogenic of adverse effects being observed.

In order to provide a more accurate health risk assessment. Many methods exist to assess health risk in GSDFs such as deterministic and scholastic methods. The deterministic is made from a single model with an equation to be used. Deterministic method relies on single point value to estimate risk and the result is also a point value. Characterization of uncertainty and variability with deterministic method are limited [18]. Health quantitative technics such as hazard quotient (HQ); cancer risk (CR) estimate risk for a specific population group only. Thus, providing a single point estimate, representing a part of the affected population.

Scholastic method provides a distribution of possible exposure estimates. The overall risk probability technic is the combination of plotting together exposure cumulative curve and the dose-response cumulative curve. The overall risk probability takes into account multiple points in distribution of exposure and effects curves. Therefore, produces various exposures levels corresponding to different dose-responses [16].

Studies from those of Kirkeleit [21]; Clifford; Navasumrit et al.; Kampeerawipakorn et al; Heibati et al.) had used biomonitoring health approach in order to assess health risk in gasoline storage and distribution facilities [12, 21, 23]. This approach evaluates human body burden through biomarkers, and quantify the amount of hazardous chemical absorbed by the exposed workers. The health biomonitoring is limited by not being able to specify the route of the toxicant exposure [18]. Various sources of exposure, such as the workers' life style can also affect the results from biomonitoring health approach.

From the studies of Cao et al.; Qiming et al.; Edokpolo et al., the use of probabilistic technic to assess health risk of benzene exposure in petroleum environments and chemical for fish in water surface was employed. This approach evaluates the possible adverse effects at different levels of exposure, which provides more detailed understanding of the hazard and the associated risks [7, 15, 16, 20].

Benzene is known as a carcinogenic chemical by International Agency for Research on Cancer, and exposure to certain level of concentration at different time period can result of acute or chronic human health effects [7]. Therefore, there is a need to assess health risk of benzene at various exposures levels and for different adverse health effects outcomes.

4.2.3. Methodology

4.2.3.1. Data collection

The exposure data used for the health risk assessment were obtained from the Conservation of Clean Air and Water in Europe (CONCAWE) database (N0 7/97; N0 2/00 and N0 9/02 Reports) [23] and literature surveys on benzene exposure in GSDFs. The first set of data were collected from the CONCAWE reports with the aim to gather only exposure data for benzene concentrations during loading operations of truck tanks; storage tanks and barges; like presented in Table 4.1. From the database, the years' periods mentioned below were able to satisfy the criteria on the type of data needed to conduct our research due to the non-improvement of technology change and facility conditions in developing countries to be compared with. These data were composed of short term exposure and full shift (8-hours Total Weighted Average - TWA) exposure data from industrialized countries for the period 1986 to 2001. Furthermore, these data provide details on monitoring of tasks description and are specific for the study conducted.

Table 4.1. Benzene exposure data set for loading operation from industrialized countries

a)EU-1: Benzene exposure data for loading operations in petroleum storage and distribution facility (1986-1992)/Full shift (8h-TWA) (mg/m^3)									References
Nbr of sample	Loading truck tank mean (range)		Nbr of sample	Loading barge mean (range)		Nbr of sample	Loading tanker mean (range)		Report no. 7/94: [23]
5	0.08	(0.05-0.87)	6	0.06	(0.05-5.75)	11	0.23	(0.06-1.11)	
b)EU-2A: Benzene exposure data for loading operations in petroleum storage and distribution facility (1993-1998)/Full shift (8h-TWA) (mg/m^3)									Report no. 2/00: [23]
7	0.64	(0.18-2.07)	5	0.56	(0.37-1.41)	2	0.78	(0.32-1.26)	
c)EU-2B: Benzene exposure data for loading operations in petroleum storage and distribution facility (1993-1998)/Short period (8h-TWA) (mg/m^3)									
6	2.2	(1.4-6.84)	3	0.7	(0.23-0.79)	2	2.10	(2.01-2.19)	
d)EU-3A: Benzene exposure data for loading operations in petroleum storage and distribution facility (1999-2001)/Full shift (8h-TWA) (mg/m3)									Report no. 9/02: [23]
38	0.4	(0.1-4.6)	4	0.1	(0.1-0.1)	5	0.1	(0.1-0.6)	
e)EU-3B: Benzene exposure data for loading operations in petroleum storage and distribution facility (1999-2001)/Short period (8h-TWA) (mg/m^3)									
22	0.8	(0.1-5.4)	15	0.2	(0.1-0.8)	19	0.7	(0.2-1.9)	

However, the scope of several studies are more directed to general assessment of the facility and at the vicinity, and making them non less relevant from benzene occupational exposure in GSDF. One of the explanation for the lack of having huge number of specific and details monitoring data available to the general public, it is because those data are privately owned by companies and therefore, are out of reach to general public [24].

a) EU-1: European Union (benzene exposure concentration data) for the period of 1986-1992. These data represent loading truck tank; loading barge and loading storage tank data.
Full shift (8-TWA): this is the exposure concentration for the traditional 8 working hours on daily basis.
b) EU-2A: European Union (benzene exposure concentration data) for the period of 1993-1998. These data represent loading truck tank; loading barge and loading storage tank data.
Full shift (8-TWA): this is the exposure concentration for the traditional 8 working hours on daily basis.
c) EU-2B: European Union (benzene exposure concentration data) for the period of 1993-1998. These data represent loading truck tank; loading barge and loading storage tank data. Short period: this is the exposure concentration < 1-hour time period for loading truck tank; loading barge and loading storage tank data.

d) EU-3A: European Union (benzene exposure concentration data) for the period of the 1999-2001. These data represent loading truck tank; loading barge and loading storage tank data.
e) EU-3B: European Union (benzene exposure concentration data) for the period of the 1999-2001.

These represent loading truck tank; loading barge and loading storage tank data. Short period: this is the exposure concentration < 1-hour time period for loading truck tank; loading barge and loading storage tank data.

The second sets of data were collected from literature surveys. These data were composed of full shift of exposure concentrations mean in the GSDFs of various countries as shown in the Table 4.2.

Table 4.2. Benzene exposure mean data at the site level from various countries

Location	Population size (million)	Mean, Range of benzene concentration (mg/m^3)	Gasoline consumption by country per year in barrel per million	GDP/Capita US Dollar/year
Iran	76.45 (2012)	5.2975 mg/m^3 (0.52 mg/m^3 - 6.29 mg/m^3) Benzene exposure at petroleum depot. (Azari et al., 2012)	128115 (2012)	7 832.90 (2012)
United-Kingdom	58.32 (1998)	14.982 mg/m^3 (9.75 mg/m^3 - 26.650 mg/m^3) Estimation of exposure benzene in petroleum marketing and distribution (Lewis et al.,1997)	187975 (1997)	26 621 (1997)
India	1161.98 (2006)	0.19 mg/m^3 (0.11 mg/m^3 – 0.81 mg/m^3) Assessment of benzene Exposure at the Gantry Gasoline Terminal (Pandya et al., 2006)	75555 (2006)	792.03 (2006)
Israel	5.97 (1998)	0.975 mg/m^3 (0.861 mg/m^3- 28.925mg/m^3) Exposure to benzene in the fuel distribution installations (Peretz et al., 1998)	17155 (1998)	19 423.75 (1998)
South-Africa	55.29 (2015)	29 mg/m^3 (21mg/m3 to 35mg/m^3) Benzene exposure in Diesel-refueling station (Moola et al., 2015)	68620 (2014)	5 746.68 (2015)
Finland	5.19 (2001)	0.15 mg/m^3 (0.02 mg/m^3 0.6 mg/m^3) Benzene exposure for Offloading in a Tankers and Railway Wagon (Hakkola et al., 2001)	15330 (2001)	24 913.24 (2001)
Italy	56.97 (2001)	11.13 mg/m^3 (13.6 mg/m^3 -18.8 mg/m^3) Exposure to Benzene in Petroleum Transport Company. (Figa et al., 2001)	146730 (2001)	20 400.81 (2001)
France	59.75 (1996)	0.15 mg/m^3 (0.07 mg/m^3–0.43 mg/m^3) Benzene exposure in petroleum products distribution (Armstrong et al., 1996)	126655 (1996)	26 871.83 (1996)
Bulgaria	7.66 (1995)	1.495 mg/m^3 (0.0325mg/m^3 -1856.43 mg/m^3) Benzene exposure in petrochemical (Garte et al., 2005)	5475 (2005)	3 869.53 (2005)
Tunisia	9.86 (2002)	0.52 mg/m^3 (0.065 mg/m^3 - 1.36 mg/m^3) Benzene Exposure Monitoring of Tunisian Workers (Chakroun et al., 2002)	3613.5 (2002)	2 346.06 (2002)

4.2.3.2. Data analysis

The loading operations data set of trucks tank; barges and storage tank from the CONCAWE database for the three periods (1986-1992; 1993-1998; 1999-2001), consisted of short terms exposure and full shift exposure as shown in Table 4.1. The data set from the different period were combined based on loading operation types and were plotted as cumulative probability distribution (CPD) by using Microsoft Excel. Then, each CPD was compared with the two OEL guidelines from ACGIH and OSHA.

The mean of exposures from the data set in various countries were plotted as CPD by using also Microsoft Excel. The Table 4.2. shows the list of the countries and the mean of benzene exposure at the site level in gasoline storage and distribution facilities.

The cumulative probability (%) was calculated from the equation (4.1.):

$$CP\ (\%) = (i/n+1) * 100 \qquad (4.1.)$$

Where cumulative probability (CP) (%); ith point; n, total number of data points.

4.2.4. Health Risk Characterization

4.2.4.1. Health Risk Characterization for benzene exposure from industrialized countries

The data set for benzene exposure of each loading operations were used to develop CPD plots. From these CPD, the estimation of the concentration exposure at 50% (CEXP50) and 95% (CEXP95) representing the main exposed population segment and the highest exposed population segment respectively. Then, the benzene concentrations for each type of loading operations were calculated into Lifetime Average Daily Dose (LADD) by using the defaults parameters values summarized in the Table 4.3. The LADD were used to calculate the Hazard Quotient (HQ), Cancer Risk (CR) and Overall Risk Probability (ORP). The HQ was used to calculate the non-carcinogenic adverse health effect related to benzene exposure. The CR, to calculate the carcinogenic adverse health effect of being exposed to benzene concentrations. The ORP for cancer, was used to estimate the entire population health risk exposed to benzene exposure. The values of USEPA Inhalation Reference Dose (RfD) and Slope Factor (SF) were used to estimate HQ and CR as referred in the Table 4.3.

$$LADD = (CEXP * IR * EL * ED) / (BW * LT) \qquad (4.2.)$$

Where CEXP is exposure concentration (mg/m3); IR, Inhalation Rate (m3/day); EL, Exposure Length (day/day); ED, Exposure Duration (days); BW, Body Weight (kg); LT, Lifetime (days).

4.2.4.2. Health Risk Characterization for benzene exposure from developing countries

The mean data set for benzene exposure at the site level for GSDF from the Table 4.2., was collected from literature surveys of various countries. Developing countries in the table 4.2. were selected and then, all the site levels exposures data of developing countries were used to develop the CPD. The CPD was plotted against the OEL Guidelines from ACGIH and OSHA. The CPD was converted into LADD by using the equation (4.2.). The HQ was estimated by using LADD and RfD. The CR was estimated by using LADD and SF.

4.2.5. Hazard Quotient (HQ)

The HQ method for risk characterization was used to estimate the adverse health effects for non-cancer risk of benzene exposure. In order to estimate the HQ, the USEPA Inhalation Reference Dose (RfD) derived from benzene was applied for each loading operations and all the exposures data set of developing countries and industrialized countries by using the equation (4.3.). The benzene exposure at CEXP50 (representing the main population segment) and at CEXP95 (representing the highest exposed population segment) were converted in LADD for all loading operations by using the equation (4.2.) and estimated in HQ by using the equation (4.3.).

$$HQ = LADD / RfD \qquad (4.3.)$$

Where HQ is Hazard Quotient; LADD, Lifetime Average Daily Dose (mg/kg/day); RfD, USEPA reference dose (mg/kg/day).

4.2.6. Cancer Risk (CR)

The Cancer risk is expressed as excess risk of developing a cancer over lifetime of exposure (70 years). The USEPA inhalation slope factor derived for benzene was used to quantify the estimate excess cancer risk for each exposures data of developing countries and industrialized countries at CEXP50 and CEXP95 for each loading operations by using the equation (4.4.)

$$\text{Cancer Risk} = \text{LADD (mg/kg/day)} * \text{SF (mg/kg/day)}^{-1} \qquad (4.4.)$$

Where SF is the slope factor for benzene.

4.2.7. Overall Risk Probability (ORP)

The overall ORP method is based on the use of ORP curve. The ORP curve is the plot of the CP exposure exceedance values against the corresponding CP values for dose-adverse effects.

Exposure Exceedence (%): 1-CP (%)

Where CP (%) represents the cumulative probability in percentage.

Affected Population (%): i(LADD)/(n+1) *100

Where *i*th point represents the LADD value; *n,* total number of LADD data points value.

Table 4.3. Summary of default exposure factors

Parameter	Unit	Default values
Lifetime (LT)	Years	70
Body weight (BW)	Kg	70
Exposure Length (EL)	Day/day	0.33 (8h/day) (workers) 0.17 (4h/day) (outdoor)
Exposure Duration (ED)	Years	25 (commercial/industrial) 30 (residential)
Inhalation Rate (IR)	m^3/day	0.83 (indoor) 1.4 (outdoor)
Inhalation Reference Dose (RfD)	mg/kg/day	0.0085
Slope Factor (SF)	mg/kg/day	0.0273
	Value	
Lifetime (LT)	7 days/week * 52 weeks/year * 70 years =	25 480 days
Exposure Duration (ED)	5 days/week * 48 weeks/year * 25 years =	6 000 days

4.3. Results & Discussion

4.3.1. Benzene exposure concentration for loading operations from industrialized countries

The table 4.1. presents the data on the mean and range of benzene exposure from industrialized countries for the period of 1986 to 2001, during loading operations in GSDF. The data availability was structured in the way that, benzene exposure for loading truck tank; loading barge and loading storage tank were selected. Then, the full shift exposure data was available for the 3 periods, 1986 to 1992, 1993 to 1998 and 1999 to 2001. And then, the short term exposure data was available only for the time period of 1993 to 1998 and 1999 to 2001. These data were reported by the conservation of clean air and water in Europe (CONCAWE) from its various countries members. The Fig. 4.3. discloses the CPD plots of benzene exposure data for full shift in the period of 1986 to 2001 for loading operations in industrialized countries. The loading storage tank is the only loading operation that did not exceed the OELs from ACGIH and OSHA. This implies that loading storage tank knows less activities for a full shift compare to the other two loading operations modes. The truck tank and loading barge operations have a benzene concentration exceeded the two OELs standards selected (ACGIH and OSHA) due to their intense activities compare to loading storage tank. The size of loading the loading truck tank and loading are not big enough to perform several operations in the day, thus increasing the benzene exposure concentration at the breathing zone [6, 24, 25].

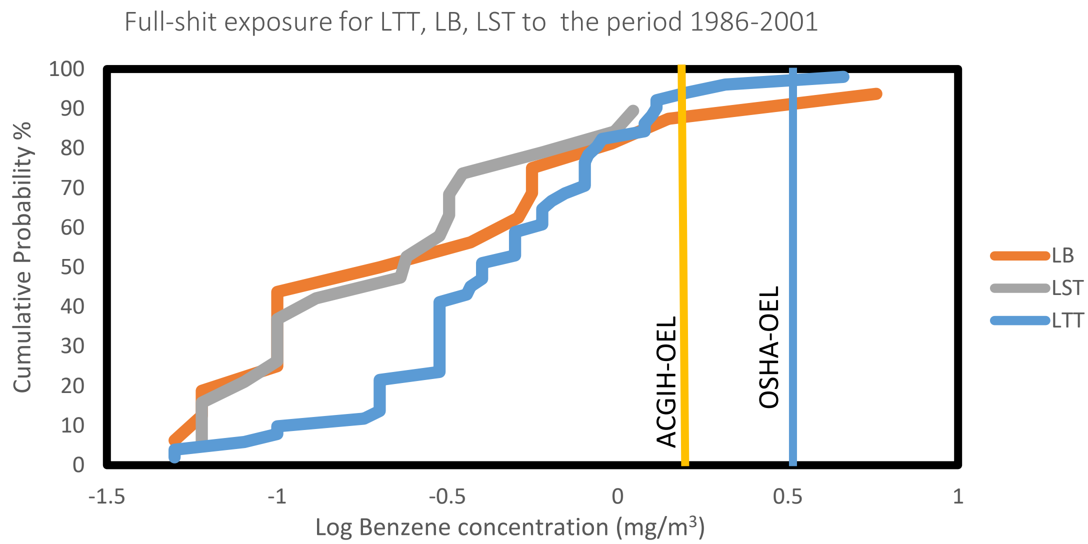

Fig.4.3. CPD plots to benzene Log concentration for loading operations in Long term exposure from 1986 to 2001 of industrialized countries

LTT: Loading Truck Tank

LB: Loading Barge

LST: Loading Storage Tank

ACGIH-OEL: Occupational Exposure Limit of the American Conference of Governmental Industrial Hygienists

OSHA-OEL: Occupational Exposure Limit of the Occupational Safety and Health Administration

For the period of 1986 to 2001, the short term exposure to benzene, from the Fig. 4.4. presents that all the loading operations were below the OELs. This indicates that, despite the introduction of new OEL regulation on benzene of 1 ppm in 1997, and the EU Directive 63/94/EC, on storage installation and loading and unloading equipment, most facilities were still using the previous OEL of 10 ppm [27]. This can also indicate that, for short term exposure a considerable change had occurred from the reduction of benzene contain in the gasoline to the implementation of vapor recovery system and best working practices [3, 7, 27, 29].

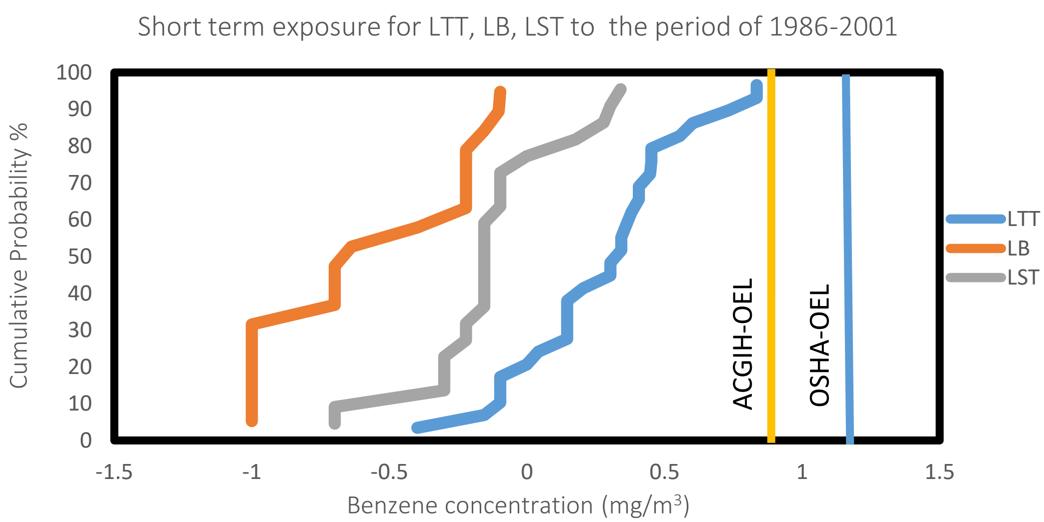

Fig. 4.4. CPD plots to benzene Log concentration for loading operations in Short term exposure from 1986 to 2001 of industrialized countries

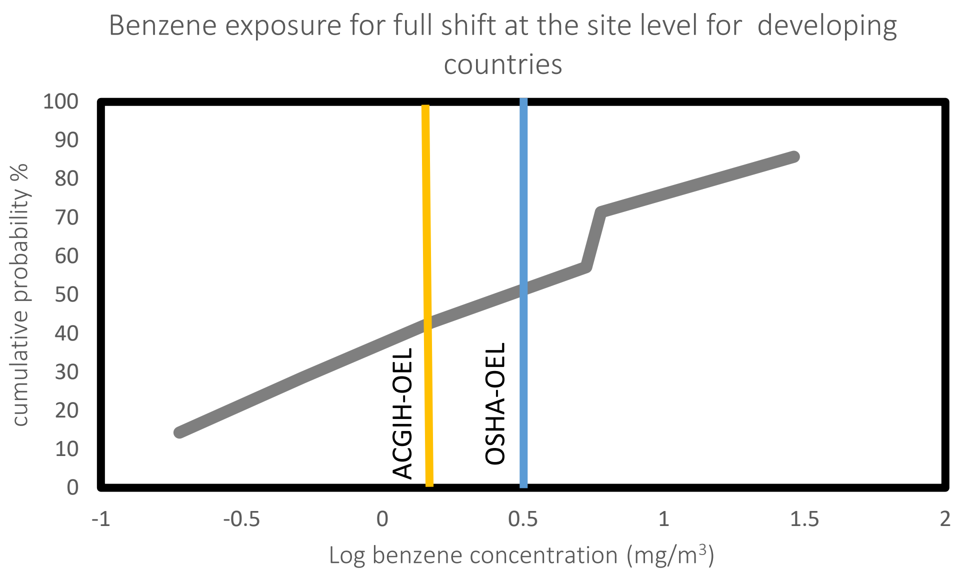

Fig. 4.5. CPD plots to benzene Log concentration at the site level in developing countries

The Fig. 4.5. Shows the benzene exposure concentration for the full shift at the site level for developing countries. From the observation, half of the data set exceed the OELs, which presents a highly exposure concentration of benzene at the site level. This implies that, there is a significant benzene exposure concentration for the full shift at the site level, as a result of high benzene contain level in gasoline [27], lack of vapor recovery system and poor working practices [3, 8, 9, 10, 29] at site level in developing countries.

The LADD for the period of 1986 to 2001 at full shift presented a significant LADD level for loading barge and loading truck tank, as compared to loading storage operation in the Fig.4.6. This implies that loading workers at the breathing zone for truck tank and loading barge are exposed to a significant average daily dose compare to loading storage tank workers at the breathing zone.

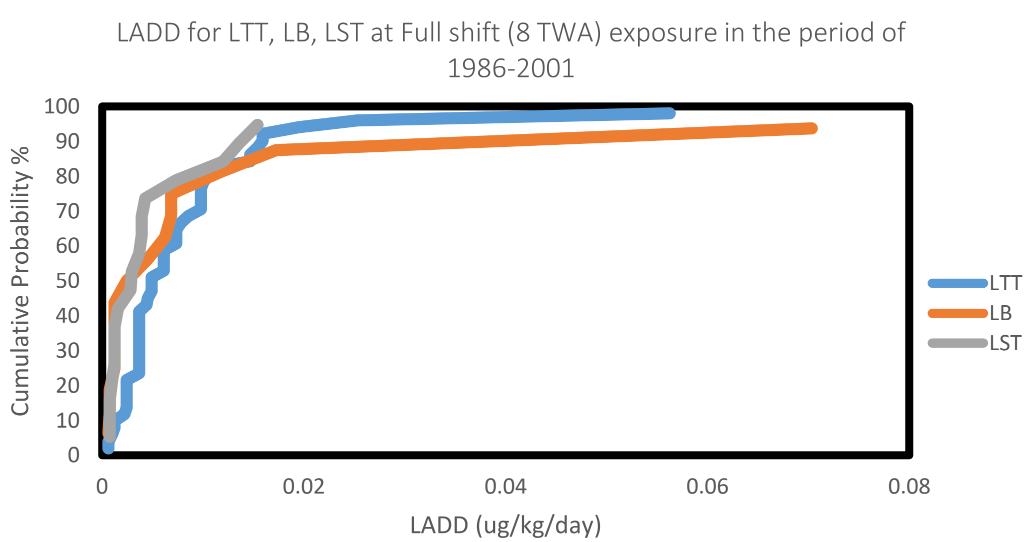

Fig.4.6. CPD plots to benzene LADD exposure for long-term exposure of loading operations from 1986 to 2001 of industrialized countries.

Long term benzene LADD exposure for the period of 1986 to 2001, indicates that loading truck tank and loading barge workers are highly exposed to adverse effects for a long period, due to repeated tasks as compared to loading storage tank which is seldom within a working day, like shown in the Fig. 4.6.

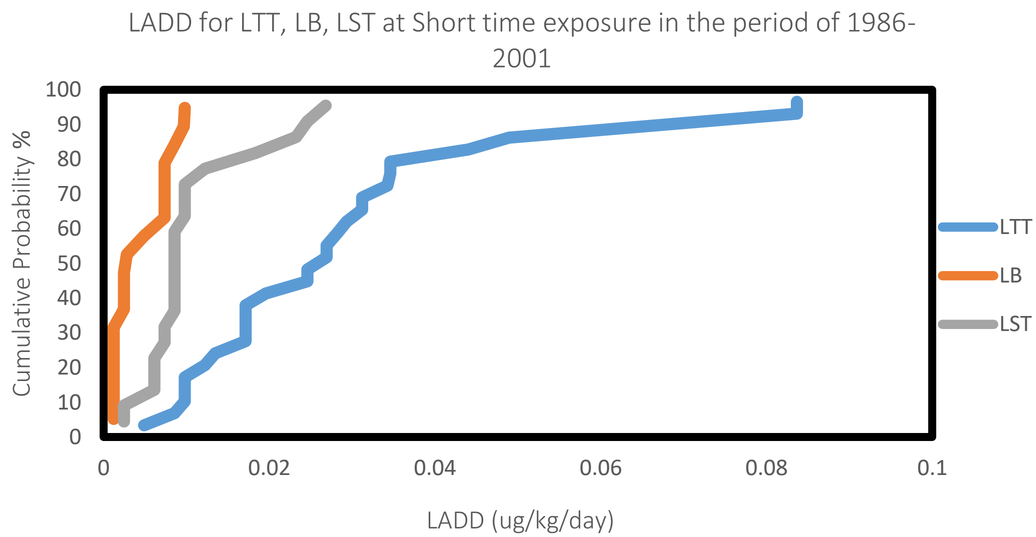

Fig.4.7. CPD plots to benzene LADD exposure for short-term exposure of loading operations from 1986 to 2001 of industrialized countries

From the short term benzene LADD exposure for the period of 1986 to 2001, we observed significant adverse effects for loading truck tank as compared to the loading barge and loading storage tank. This implies that, for short term loading truck tank being the task with highest rate of repetition present the highly adverse effect as shown in the Fig. 4.7. Thus, loading truck tank workers are exposed to high concentration as compared to the loading barge and storage tank.

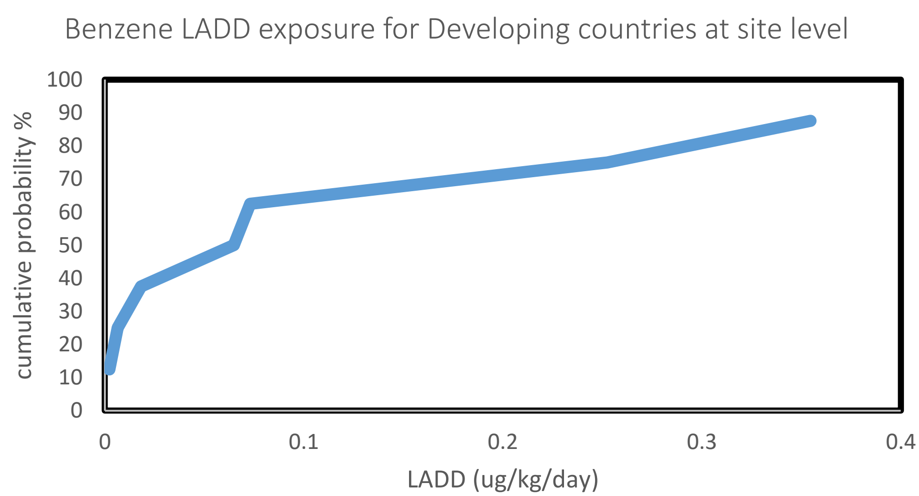

Fig. 4.8. CPD plots to benzene LADD exposure for full shift exposure of developing countries

The benzene LADD exposure for developing countries presents a significant level of adverse effects for workers at the site in developing countries as shown the Fig. 4.8. This indicates that, workers at site in developing countries are exposed to a highly adverse effect due to loading operations activities, consider as the most exposed occupational settings in petroleum downstream [19].

4.3.2. Hazard Quotient for benzene exposure in loading operations

The Table 4.4. shows the estimating hazard quotient (HQ) for loading operation of benzene exposure from industrialized countries, calculated at Cexp50 and Cexp95 of LADD. The HQ was calculated at Cexp50 and Cexp95 to assess tasks of the main population exposed and tasks of highest population exposed during loading exposure.

For the full shift period of 1986 to 2001, loading truck tank operation presents the highest exposed daily concentration for the main exposed population and loading barge presents the highest concentration for the highly exposed population. At the short term exposure, loading truck tank has the highest concentration for the main population and for the highly exposed population.

In the full shift period of 1986 to 2001 for daily dose benzene exposure concentration at the main exposure population, loading truck tank has the highest daily dose concentration, and loading barge is the highest exposed population. For the Short time period of 1986 to 2001, loading truck tank is the main population exposed to benzene and the also the highest exposed population. This indicates that loading truck tank for has highest adverse effects for the main exposure population at full shift and short time. Therefore, the most exposed workers at the facility are loading truck tank operators. At the highest exposed population, loading barge and loading truck tank for full shift and short time respectively.

Table 4.4. Health characterization of benzene exposure for industrialized

Exposure Period	Tasks	$Cexp_{50}$ (mg/m^3)	$Cexp_{95}$ (mg/m^3)	$LADD_{50}$ at 10^6 (mg/kg/day)	$LADD_{95}$ at 10^6 (mg/kg/day)	HQ/$LADD_{50}$ at 10^6	HQ/$LADD_{95}$ at 10^6	CR/$LADD_{50}$ at 10^6	CR/$LADD_{95}$ at 10^6	CR at 10^6 estimated by ORP
(1986-2001) Full shift/8-TWA	LTT	0.40	1.60	6.4E-10	2.56E-9	0.07	0.30	0.17×10^{-8}	0.69×10^{-7}	0.03
	LB	0.20	5.75	0.57×10^{-8}	9.20E-9	0.03	1.08	0.87×10^{-9}	0.25×10^{-5}	0.02
	LST	0.23	1.26	3.68E-10	2.01E-9	0.04	0.23	0.10×10^{-7}	0.55×10^{-7}	0.04
(1986-2001) Short time/15 min	LTT	2.01	6.84	3.21E-9	0.1×10^{-10}	0.37	1.28	0.87×10^{-7}	0.29×10^{-5}	0.002
	LB	0.20	0.80	3.20E-10	1.28E-9	0.03	0.15	0.87×10^{-9}	0.34×10^{-6}	0.045
	LST	0.70	2.01	1.12E-9	3.21E-9	0.13	0.37	0.30×10^{-7}	0.87×10^{-7}	0.007

For the period 1986 to 2001 for all the loading operations, the estimating HQ at LADD50, showed that HQ at LADD50 were < 1. For the HQ at LADD95 two tasks were > 1. Loading barge workers for a full shift and Loading truck tank workers for short term exposure. Indicating that, loading barge operations are significantly high exposed tasks for full shift, with the connecting and disconnecting of hoses, and also the length of time of the operation, where main exposure population of loading operations workers remain in the breathing (Williams et al., 2000). The loading truck tank workers for a short time exposure, had a high exposed benzene concentration. The continuous repeated action of loading truck tank workers in checking the manhole, make loading truck tank workers the highest exposed population. This implies that, an excessive HQ exist for the industrialized countries workers, which reveals that the breathing zone for the loading barge and at full shift and loading truck tank at short term operations have significant level of benzene exposure concentration. From the developing countries the LADD, the HQ and CR were estimated at a single point value. The LADD from the Table 4.5. shows that, the workers at the site level in South-Africa and Israel had an excessive adverse effect exposure and India's workers has the lowest adverse effect.

The HQ was >1 for Israel and South-Africa workers at the site level for these developing countries. This reveals that, the ratio gasoline consumption per barrel and population size, which gives an overview of the industry level contribute to high benzene concentration in these developing countries. Therefore, these countries have a highly HQ estimate.

Table 4.5. Health characterization of benzene exposure for developing countries

Nber	Developing countries	Benzene Exposure Estimate (mg/m^3)	LADD 10^6 (mg/kg/day)	Hazard Quotient (LADD 10^6)	Cancer Risk (LADD 10^6)
1	India	0.19	3.04E-10	0.03	0.0000083
2	Tunisia	0.52	8.32E-10	0.09	0.00002
3	Bulgaria	1.49	2.38E-9	0.28	0.00006
4	Iran	5.29	8.48E-9	0.99	0.00023
5	Israel	5.97	9.55E-9	1.12	0.00026
6	South-Africa	29	0.5×10^{-9}	5.46	0.0126
7	Gabon	75.96	0.92×10^{9}	14.3	0.039

4.3.3. Cancer risk for benzene exposure in loading operations

The excess CR was calculated for exposure to benzene at the Cexp50 and Cexp95 level representing the main group of the exposed workers and the highest exposed group of workers respectively as shown on Table 4.4.

The CR at the main exposure population had shown a low risk of cancer for the full shift loading operations and short time exposure. This implies that, for the main exposure population, workers are safe from cancer risk adverse effect. At the highly exposed population, only loading barge and loading truck tank for full shift exposure and short time exposure were exposed to CR respectively. This reveals that, for full shift, loading barge operation shown a high CR for workers at the breathing zone due to the duration loading barge operation, compare to loading truck tank for instance. Then, for the short time exposure, loading truck tank presents a CR, due to highly exposed repetitive tasks performed as gauging, checking the manhole [26].

From the developing countries in the Table 4.5., the CR was estimated at a single point at the site level. The CR was significant for South-Africa, then Israel and Iran workers. This implies that, workers at site in South-Africa are highly exposed to excess CR, workers in Israel and Iran sites are exposed to CR also. Revealing a lack of engineering control measures, such as vapor recovery system implemented in the site for loading operation. Further, a high level contains of benzene in the gasoline [30] for the countries with excess CR.

4.3.4. Explorative estimate of developing countries benzene concentration through regression analysis

In the Table 4.2., a list of several countries with mean and range of benzene exposures for loading operations in petroleum storage and distribution facilities were selected from literature reviews. All these countries had in common benzene exposure mean and range for loading operations. From the Fig.9., the mean of benzene exposure at GSDF of these countries were plotted against their GDP/Capita at the corresponding years.

Gabon is developing country with a lack of benzene exposure data to assess a health risk. In order to estimate the Gabon's benzene exposure, a linear regression line, the GDP per CAPITA for the year 2017 of all countries listed in the Table 4.2. were used to plot the estimated value of benzene exposure in Gabon for loading operations. Then, another selection of only developing countries from the same list were made effective to characterize benzene exposure for developing countries.

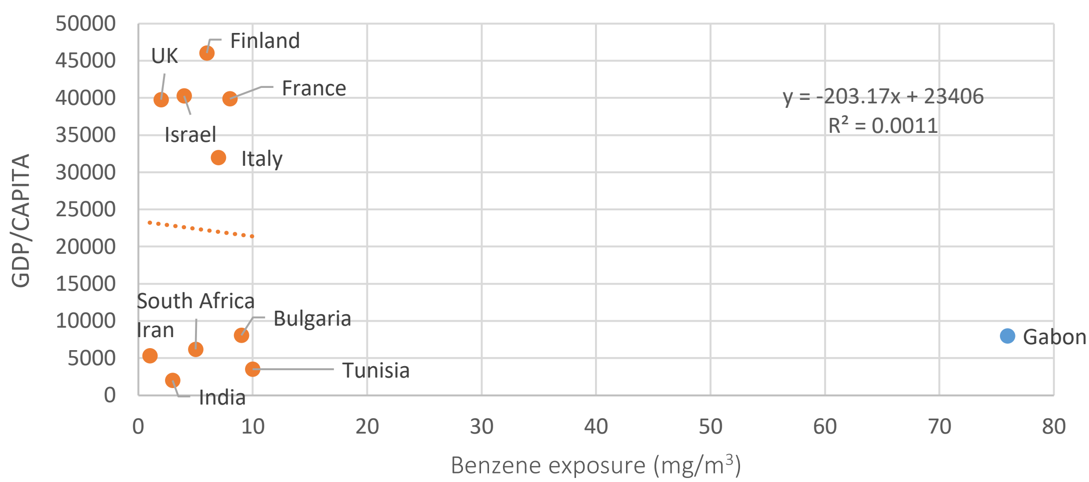

Fig. 4.9. Ratio on GDP per CAPITA and benzene exposure for developing countries

4.3.5. Overall risk probability for benzene exposure in loading operations

In order to quantify the estimate of the ORP for benzene exposure, the exposure exceedance values as percentage were calculated and plotted against the percentage of the affected population to obtain an ORP curves for each set of periods at specific loading operation. The LADD values of exposure dose-adverse effects were calculated and put into percentage, to obtain the percentage of the affected population with cancer risk adverse effects.

The overall risk probability was plotted with the CP exposure exceedance values against the corresponding CP values for dose-adverse effects. The ORP at the full shift in the period of 1986 to 2001 for industrialized countries shown in the Fig. 4.10., presents the loading truck tank, loading barge and loading storage tank ORP curves. The loading barge operation has the highest health risk adverse effects. Following by the loading storage tank and loading truck tank.

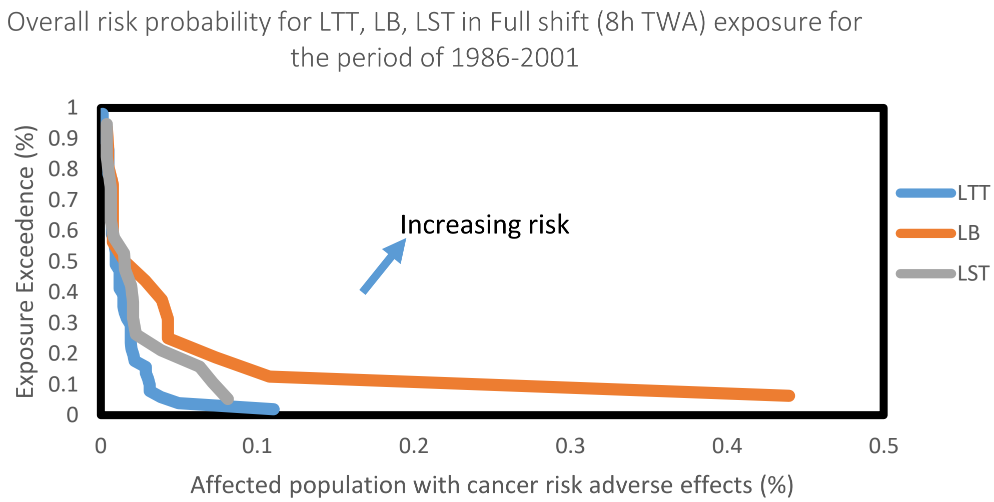

Fig. 4.10. Overall risk probability for cancer as a result of full shift exposure to benzene concentrations during loading operations from 1986 to 2001 from industrialized countries

This discloses that, workers at the breathing zone during loading barge operation are exposed in the long run to chronic adverse health effect. The ORP at short time in the period of 1986 to 2001 for industrialized countries presented in Fig.4.11., shows a significant health risk adverse effect for loading truck tank as compared to loading storage tank and loading barge. This implies that, workers at the breathing zone for loading truck tank operation are exposed in the short time to significant acute adverse health effects.

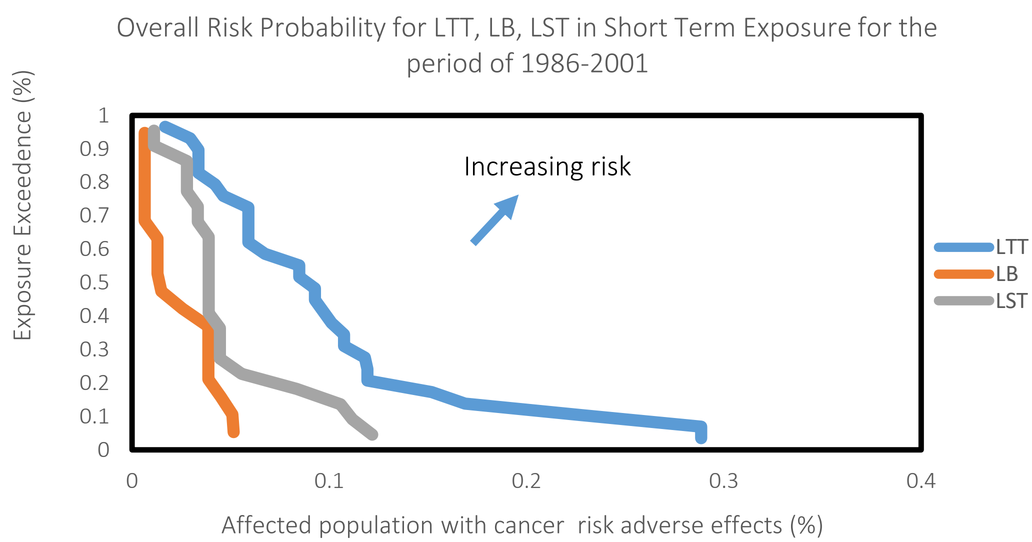

Fig.4. 11. Overall risk probability for cancer as a result of short time exposure to benzene concentrations during loading operations from 1986 to 2001 from industrialized countries

4.3.6. Comparison of Health risk exposure to benzene at site level between Developing and Industrialized countries

In order to compare the overall risk probability to benzene exposure in developing and industrialized countries, only the full shift of exposure data from the table 4.4. on all the loading operations were considered. From the plotting of cumulative probability to the ORP, the data passed through the all process. In other hand, the countries' data selected from the table 4.5. as developing countries were used to be compared with industrialized countries. The results from the Fig.4.12. revealed that, for an ORP of health assessment for non-carcinogenic and carcinogenic adverse health effect to exposure on benzene, developing countries has a high health risk compare to industrialized countries which did not cross the 2.5%, considered as the safe health area.

This can be translated by the investment made by industrialized countries in occupational health and safety, where developing countries are more focused on the economic benefits from gasoline storage and distribution activities [31]. The high level of benzene volume percentage in gasoline and other petroleum products in developing country, representing 5% by volume content for oil exporting developing countries members of the Africa Refinery Association [30] contributes to the results of this study. While in industrialized country, such as United State of America, the annual average benzene volume content in gasoline is 0.62% by volume [32]. The lack of engineering control measures such as vapor recovery system and outdated facilities in most of developing countries at GSDFs [10], also witness the high level of the ORP of cancer risk in developing countries compare to industrialized countries; where vapor recovery system significantly reduces the benzene exposure concentration [10]. Finally, a need for a strengthen regulation in developing countries for benzene exposure in GSDF is also revealed by this study [22]. Meanwhile, industrialized countries have implemented a strong regulation for benzene exposure for loading operations in GSDF [32].

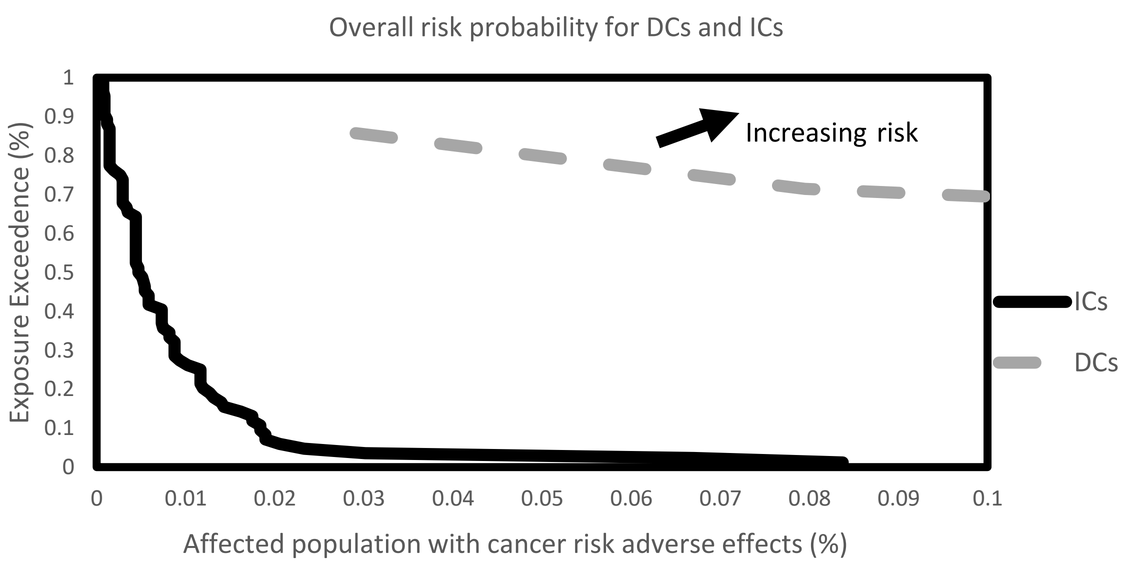

Fig. 4.12. ORP of cancer risk comparison for benzene exposure between industrialized and for developing countries

4.4. Conclusion

In order to estimate health risk of benzene exposure for loading operations, in gasoline storage and distribution facility, probabilistic method was used. This was more relevant for loading operations, where various levels of benzene concentrations occur in the breathing zone. Deterministic method which uses single point value to evaluate health risk would not be appropriate.

The cumulative probability distribution (CPD) enables to show the trend of benzene exposures measured of loading operations in various locations of industrialized countries. The CPD for the period of 1986 to 2001 was plotted against occupational exposure limits (OEL) guideline of benzene; where loading barge, loading truck tank exceeded the OELs for the full shift exposure; and none of the loading operations exceeded the short time exposure for the industrialized countries. High benzene exposure concentrations at the site level were observed for the countries.

Health risk for benzene exposure was characterized through lifetime average daily dose and also by estimating the hazard quotient and the cancer risk at Cexp50 and Cexp95. Then, the overall risk probability was estimated to overcome variability and uncertainty while conducting health risk assessment. The overall risk probability of industrialized countries and developing countries were compared, and developing countries as a huge difference, as a result of high contains of benzene volume in gasoline; lack of engineering control measures such as vapor recovery system; poor regulations and working practice.

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Chapter 5

Conclusion and Recommendations

5.1. Conclusion

5.1.1. Overview

Despite the significant improvement made in petroleum industry to provide a safe working environment to workers at GSDF, this remains the occupation in petroleum industry with an excessive exposure to benzene for loading operations. In developing countries, more have to be done due to the important numbers of existing challenges. Thus, required a specific model to address this situation in developing countries. This research study has developed a framework to assess occupational health risk from benzene exposure during loading operations in GSDF and the following is the details description.

5.1.2. Chapter 2: Identification of factors influencing benzene concentration during loading operation

From the topic1, an analysis of factors that influence benzene exposure concentration during loading operations in GSDF was performed. The lack of benzene monitoring data compelled the use of analytical tool to identified the most influential factors and understand their interactions. This enabled to identified among the factors the ones that should be tackled first in order to conduct an exposure assessment.

Firstly, from the literature review factors influencing benzene concentration were identified based on previous studies on benzene exposure during loading operations. These studies presented some similar characteristics on working environment at that time to those of current developing countries. A total of 23 factors were identified and then grouped into 6 identified factors. Then, the interpretive structural modelling was applied to rank and understand their relationship. As a result, 4 identified factors, such as the product; working practices; regulations and installation were considered as the most influential factors to be looked at when conducting an exposure assessment at GSDF in developing countries.

5.1.3. Chapter 3: Estimation of benzene exposure and the effectiveness of control measures

Secondly, at the topic 2 from the task level, the benzene exposure concentration was estimated. The product safety data sheet; the job description; the frequency and duration were used as parameters to estimate benzene exposure through a predictive and quantified exposure inhalation model called Stoffenmanager. Then, the results were compared against with the occupational exposure limit (OEL) of benzene from American Conference of Governmental Industrial Hygienists guidance standard. Once the estimations are above the standard, the control measures are selected and are assessed to be effective to reduce the exposure concentration estimate lower than the OEL. As a result, in developing countries the control measures ‘‘vapor recovery system''; and ''chemical filter mask'' and ''working behaviour'' were the most important at GSDF for effective reduction of benzene concentrations.

5.1.4. Chapter 4: Health risk assessment for benzene exposure

Thirdly, at the topic3, health risk has been assessed at the task and site level for GSDF in developing countries. A collection of available data from loading operations at the task level in industrialized countries and data at the site level for developing countries was performed. The data from industrialized countries were selected when the working conditions in those countries were similar to current conditions in developing countries. The benzene exposure concentration trends on the 3 loading operations were compared against the OEL. The health risk was assessed at the task level for industrialized countries at the main exposure population and at the highly exposed population for non-cancer and cancer risk. This was done by using hazard quotient and cancer risk equations for non-cancer disease and cancer disease respectively.

Moreover, health risk was assessed at the site level for industrialized countries by combining the results for each loading operations of 8h total weighted average. Furthermore, a health risk was assessed in developing countries at the site level by using the overall risk probability method. The overall risk probability method was used to quantify health risk adverse effects of the all exposed population. Finally, the curve for industrialized and developing countries were plotted together and compared. As a result, workers at GSDF in developing countries, present the highest health risk due the lack of vapor recovery system; poor regulations and working practice.

5.1.5. Limitations of the study

The completed work and the findings of this research revealed an useful approach to assess health risk of benzene exposure at GSDF during loading operations in developing countries. Nevertheless, the study presents some limitations in the implementation stages of the health approach.

In the topic 1, the lack of sufficient number of factors affecting benzene exposure collected for each loading operations and in developing countries. This reduces the complete picture of what factors should be taken into consideration and their interrelation, for benzene exposure during loading operations in GSDF. This could be helpful to identify the factors for benzene exposure that would be used as parameters to estimate the concentration at the task level.

Related to topic 2, the lack of monitoring data and current studies on benzene exposure during loading operations in GSDF provide a less accuracy in the estimation of benzene concentration. This is a hamper to deliver appropriate control measures and provide more accurate health risk assessment to protect workers.

Regarding the topic 3, the lack of current monitoring data on benzene exposure during loading operations from various locations. This is helpful, to assess accurately health risk for benzene exposure at various exposures points during loading operations, to generate non-cancer and cancer risk.

5.1.6. Contribution of the study

This research study provides a methodology approach to assess occupational health risk GSDF during loading operation for developing countries. From the previous studies in industrialized countries, loading operations studies were focused on measurement strategies of exposure benzene concentration, then compared them with the occupational exposure limit at that period.

Health improvement was made through the difference in emission of other style of loading operations (Kawai et al.,1991). All aspects of exposure factors for a task were integrated to be The estimation at the breathing zone with a consideration of the near-filed and far-field method and systematic evaluation of control measures were performed, where in other studies the estimation only are done and the evaluation of the effectiveness of control measures are done separately after. The assessment of health risk for the all population exposed in using several exposure adverse effect points, where different to the traditional evaluation of health risk at a single point. This methodology approach can be applied to several developing countries which present similar working conditions to what have been mentioned above and can also be adapted to particular working environment in developing countries. The below table 5.1. summarizes the contribution of this study.

Table 5.1. Study contribution

Previous researches	Contributions	Gap on previous researches
Francesca Milazzoa et al., 2017	Emissions of volatile organic compounds during the ship-loading of petroleum products: Dispersion modelling and environmental concerns.	No research has identified exposure benzene concentration in gasoline storage facility using ISM.
Verma et al., 2010	Assess benzene exposures in downstream petroleum industries (refineries; gasoline storage and distribution facilities; services stations) at the traditional 8 hours' time weighted average.	No task-based exposure was performed to assess potential harmful that may not be captured by long-term full shift.
Pandya et al., 2006	Assess occupational exposure of volatile organic compounds at the Gantry gasoline Terminal	No systematic evaluation of control measures was performed to assign the appropriate one for the specific task.
Heibati et al.,2017	Evaluate BTEX at gasoline storage and distribution facility for 8h TWA and quantified health risk at the single point HQ, CR and ELCR	No consideration of several exposure value for all the exposed population.
Edokpolo et al., 2015	Characterize Health risk for exposure to benzene for ambient air in service stations and petroleum refineries environments using human adverse response data.	Lack of health risk characterization for gasoline loading operation in GSDF.

The above study contribution has risen the following implication from Industrial countries and Developing countries:

In Industrialized countries: in more than 2 decades 77 vapor recovery system is implemented. Since, 1997 in European Union benzene volume percentage in gasoline is set at 1% and currently in USA is 0.62%. The regulation regarding petroleum industry are evolving. While, in Developing countries: they Invest part of the benefits to solve urgent social issues. The Vapor recovery system is not yet implemented. From the African Refinery Association benzene volume in gasoline should be set at 1% from 2020, therefore the 5% volume is still relevant. the regulation concerning petroleum industry are static.

5.2. Recommendations

Based on this study, the following recommendations must be taken into consideration:

1. To reduce the benzene concentration of factors that influence exposure during loading operation, 4 factors should be reduced simultaneously. That is ‘’product’’; ‘’installation’’; ‘’regulation’’ and ‘’working practice’’.

2. To reduce benzene exposure concentration into the OEL at GSDF in developing countries, the following control measures should be implemented in the facility; such as: ‘’vapor recovery system’’; ‘’chemical filter mask’’ and ‘’worker behavior’’.

3. To significantly reduce health risk from benzene exposure during loading operations at GSDF in developing countries, the following should be done: ‘’reduce the volume of benzene contains in gasoline product’’; ‘’improve the regulation’’; ‘’improve the working practice’’ and implement ‘’vapor recovery system’’.

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Appendix

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Osaka University

Questionnaire :

Context and Objectives:

In order to promote new techniques to occupational risks in the petroleum sector, particularly those related to exposure to chemicals, we carry out this survey to obtain information with a view to improving the assessment of occupational exposure risks in gasoline storage and distribution facilities and other working sites where handling and storage of petroleum products in developing countries take place.

Female				
Male				
Occupation	**HSE**	**Operator**	**Student**	**Other**

Question : *According to you, what degree of influence the following factors can have on benzene concentration during a loading operations at gasoline storage and distribution facility in developing countries ?*

Very low Influence	low Influence	Moderate influence	High influence	Very high influence
1	2	3	4	5

Factors	**Score**
Meteorology conditions (Wind speed , Wind direction, Temperature level)	
Product (Evaporation process, Quantity of gasoline sold, level of benzene contain)	
Installation (working place conditions, equipments)	
Nature of the task (loading task, maintenance task)	
Regulations (existing laws and regulations)	
Working practices (respect des procédures)	
Please; You are allowed to propose any other factor you think can fit into, and give a score according to the above format	

** We thank you for your time and your contribution to this study, and if you are interested on the conclusions of this study, please leave your e-mail address to receive a copy.*

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Osaka University

Questionnaire :

Contexte et Objectives:

Dans le but de promouvoir les nouvelles techniques aux risques professionnels dans le secteur pétrolier, notamment ceux lies a l'exposition aux produits chimiques, nous réalisons cette enquête afin obtenir des informations en vue d'améliorer l'évaluation des risques professionnels dans les dépôts d'hydrocarbures et autres lieux de manipulation et stockage des produits pétrolier dans les pays en voie de développement.

Femme				
Homme	X			
Qualité	**HSE**	**Operateur**	**Etudiants**	**Autres**
	X			

Question : *Quel peut être selon vous l'****influence*** *des facteurs suivant sur le* ***niveau de concentration*** *des* ***vapeurs d'hydrocarbures (benzène)*** *pendant une opération de* ***chargement/déchargement*** *des produits pétrolier ?*

Pas d'influence	Faible influence	Moyenne influence	Grande influence	Tres grande influence
1	2	3	4	5

Facteurs	**Note**
Conditions Météorologiques (vitesse des vents, direction, température)	3
Produit (composantes, quantité, qualité)	5
Installation (équipements, lieux des opérations)	4
Nature de la tache	2
Règlements et législation	1
Pratique du travail (respect des procédures)	5
Vous pouvez également suggérer d'autres facteurs et note suivant le format au-dessus	
Sensibilisation et Formation HSE	4

**Nous vous remercions de votre temps et de votre contribution à cette étude, et si toutefois les conclusions de cette étude vous intéressent, nous vous prions de laisser votre e-mail adresse afin d'en recevoir un exemplaire.*

Table A.1. Final reachability for matrix sub-factors

Sub-Factors	P-1	P-2	P-3	M-1	M-2	M-3	N-1	N-2	N-3	W-1	W-2	W-3	W-4	W-5	R-1	R-2	R-3	R-4	I-1	I-2	I-3	I-4	I-5
P-1	1	1	1	1*	1	1*	1	1*	0	0	0	1	1	1*	1	1	1	1	1	0	0	0	1
P-2	1	1	0	0	0	0	0	0	0	1	1	1	1	1*	1	1	1	1	1	1*	0	0	1
P-3	1	1	1	1*	0	0	0	0	0	1	1	1	1	1*	1	1	1	1	1	1*	1	1	1
M-1	0	1	0	1	0	0	1	1	1	1*	1	1	1	1*	0	0	0	0	0	0	0	0	0
M-2	1	1	1	1*	1	1*	1	1	1	1	1	1	1	1	1*	0	0	0	0	0	0	0	0
M-3	0	1	0	0	0	1	1	1	1	1*	1	1	1	1	1*	0	0	0	0	0	0	0	0
N-1	1	1	1	1*	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1*	0	0	0	0
N-2	1	1	1	1*	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1*	0	0	1
N-3	1	1	0	0	0	0	0	0	1	1	1	1	1	1*	1	1	1	1	1	1*	0	0	0
W-1	0	0	0	0	0	0	0	0	0	1	0	1*	1*	0	0	0	0	0	0	0	0	0	0
W-2	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
W-3	0	0	0	0	0	0	0	0	0	1	1	1	1	1*	1	0	0	1	0	0	0	0	0
W-4	0	0	0	0	0	0	0	0	0	0	0	1*	1	0	1	0	0	0	0	0	0	0	0
W-5	1	1	0	0	0	0	1	1	1	0	1	1	1	1	0	0	0	0	0	0	1	1	1
R-1	0	0	0	0	0	0	0	0	0	1	1	1	1*	0	1	1	1	1	0	0	0	0	0
R-2	0	0	0	0	0	0	0	0	0	0	1	1	1	1*	1	1	1	1	1*	0	0	0	0
R-3	0	0	0	0	0	0	0	0	0	1	1	1	1	1*	1	1	1	1*	0	0	0	0	0
R-4	0	1	1	0	1	1	0	0	0	1	1	1	1	1*	1	1	1	1	1*	0	0	0	0
I-1	0	0	0	0	0	0	0	0	0	1	1	1	1	1*	0	0	0	0	1	1	0	0	1
I-2	1	1	1	1*	0	0	1	1	1	1	1	1	1	1	1	1*	1	1	1	1	1*	1*	1
I-3	1	1	1	1*	1	1*	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	1*	1
I-4	1	1	1	1*	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1*	1	1	1
I-5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table A.2. Iteration I

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, W-5, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2, W-5	I
P-2	P-1, P-2, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3 , R-4, I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3W-5, R-4, I-2, I-3, I-4	P-1, P-2, W-5, R-4, I-2	
P-3	P-1, P-2, P-3, M-1, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1	P-1, M-2, R-4, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1	P-1, M-1, M-2, M-3, R-4, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1	P-1, M-1, M-2, M-3, N-1, W-5, R-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, W-5, R-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, W-1, W-2, W-3, W-4, W-5 R-1, R-2, R-3, R-4, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, W-5, I-2, I-3, I-4	P-1, M-1, N-2, W-5, I-2	
N-3	P-1, P-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2	M-1, M-2, M-3, N-3, W-5, I-2, I-3, I-4	N-3, W-5, I-2	
W-1	W-1, W-3, W-4	P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-3, R-1, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-1, W-3	
W-2	W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-2, W-3, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
W-3	W-1, W-2, W-3, W-4, W-5, R-1, R-4	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-1, W-2, W-3, W-4, W-5, R-1, R-4	
W-4	W-3, W-4, R-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5 R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-3, W-4, R-1	
W-5	P-1, P-2, N-1, N-2, N-3, W-2, W-3, W-4, W-5, I-3, I-4, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-5, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-2, N-1, N-2, N-3, W-2, W-3, W-5, I-3, I-4, I-5	
R-1	W-1, W-2, W-3, W-4, R-1, R-2, R-3, R-4	P-1, P-2, P-3, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-4,R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, W-3, W-4, R-1, R-2, R-3, R-4	
R-2	W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3,W-2, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, R-1, R-2, R-3, R-4	
R-3	W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4	P-1, P-2, P-3, N-1, N-2, N-3, W-2, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, R-1, R-2, R-3, R-4	
R-4	P-2, P-3, M-2, M-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, W-2, W-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	P-2, P-3, W-2, W-3, W-4, R-1, R-2, R-3, R-4, I-1	
I-1	W-1, W-2, W-3, W-4, W-5, I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, W-2, R-2, R-4, I-1, I-2, I-3, I-4, I-5	W-2, I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5		
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3 I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	
I-5	W-1, W-2, W-3, W-4, W-5, R-1, R-2, R-3, R-4, I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, W-2, W-5, I-1, I-2, I-3, I-4, I-5	W-2, W-5, I-1, I-2, I-3, I-4, I-5	

Table A.3. Iteration II

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, W-5, R-1, R-2, R-3, R-4, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, W-5, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2, W-5	II
P-2	P-1, P-2, W-1, W-2, W-5, R-1, R-2, R-3 , R-4, I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-5, R-4, I-2, I-3, I-4	P-1, P-2, W-5, R-4, I-2	
P-3	P-1, P-2, P-3, M-1, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1, W-2, W-5	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-5, R-1	P-1, M-2, R-4, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3, W-1, W-2, W-5, R-1	P-1, M-1, M-2, M-3, R-4, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1	P-1, M-1, M-2, M-3, N-1, W-5, R-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, W-5, R-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, W-1, W-2, W-5 R-1, R-2, R-3, R-4, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, W-5, I-2, I-3, I-4	P-1, M-1, N-2, W-5, I-2	
N-3	P-1, P-2, N-3, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2	M-1, M-2, M-3, N-3, W-5, I-2, I-3, I-4	N-3, W-5, I-2	
W-1	W-1,	P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-3, R-1, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-1, W-3	
W-2	W-2,W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-2, W-3, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
W-5	P-1, P-2, N-1, N-2, N-3, W-2, W-5, I-3, I-4, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-5, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-2, N-1, N-2, N-3, W-2, W-3, W-5, I-3, I-4, I-5	
R-1	W-1, W-2, R-1, R-2, R-3, R-4	P-1, P-2, P-3, M-2, M-3, N-1, N-2, N-3, W-2, W-3, W-4,R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, R-1, R-2, R-3, R-4	
R-2	W-2, W-5, R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3,W-2, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, R-1, R-2, R-3, R-4	
R-3	W-1, W-2, W-5, R-1, R-2, R-3, R-4	P-1, P-2, P-3, N-1, N-2, N-3, W-2, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	W-2, R-1, R-2, R-3, R-4	
R-4	P-2, P-3, M-2, M-3, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, W-2, W-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	P-2, P-3, W-2, R-1, R-2, R-3, R-4, I-1	
I-1	W-1, W-2, W-5, I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, W-2, R-2, R-4, I-1, I-2, I-3, I-4, I-5	W-2, I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3 I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	
I-5	W-1, W-2, W-5, R-1, R-2, R-3, R-4, I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, W-2, W-5, I-1, I-2, I-3, I-4, I-5	W-2, W-5, I-1, I-2, I-3, I-4, I-5	

Table A.4. Iteration III

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, R-1, R-2, R-3, R-4, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2,	III
P-2	P-1, P-2, W-1, R-1, R-2, R-3 , R-4, I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-5, R-4, I-2, I-3, I-4	P-1, P-2, R-4, I-2	
P-3	P-1, P-2, P-3, M-1, W-1, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1,	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, R-1	P-1, M-2, R-4, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3, W-1, R-1	P-1, M-1, M-2, M-3, R-4, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, W-1, R-1, R-2, R-3, R-4, I-1	P-1, M-1, M-2, M-3, N-1,R-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, R-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, W-1, R-1, R-2, R-3, R-4, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, W-5, I-2, I-3, I-4	P-1, M-1, N-2, I-2	
N-3	P-1, P-2, N-3, W-1, R-1, R-2, R-3, R-4, I-1, I-2	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3, I-2	
W-1	W-1,	P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, R-1, R-3, R-4, I-1, I-2, I-3, I-4, I-5	W-1,	
R-1	W-1, R-1, R-2, R-3, R-4	P-1, P-2, P-3, M-2, M-3, N-1, N-2, N-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	, R-1, R-2, R-3, R-4	
R-2	R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
R-3	W-1, R-1, R-2, R-3, R-4	P-1, P-2, P-3, N-1, N-2, N-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
R-4	P-2, P-3, M-2, M-3, W-1, R-1, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, R-1, R-2, R-3, R-4, I-2, I-3, I-4, I-5	P-2, P-3, R-1, R-2, R-3, R-4, I-1	
I-1	W-1,I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, W-2, R-2, R-4, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, W-1, R-1, R-2, R-3, R-4, I-1, I-2, I-3 I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, W-1, R-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-3,I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-5	W-1, R-1, R-2, R-3, R-4, I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-3, I-4, I-5	

Table A.4. Iteration IV

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, R-2, R-3, R-4, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2,	IV
P-2	P-1, P-2, R-2, R-3 , R-4, I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, R-4, I-2, I-3, I-4	P-1, P-2, R-4, I-2	
P-3	P-1, P-2, P-3, M-1, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-1, P-3, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1,	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, R-4, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3,	P-1, M-1, M-2, M-3, R-4, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, R-2, R-3, R-4, I-1	P-1, M-1, M-2, M-3, N-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, R-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, R-2, R-3, R-4, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, I-2, I-3, I-4	P-1, M-1, N-2, I-2	
N-3	P-1, P-2, N-3, R-2, R-3, R-4, I-1, I-2	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3, I-2	
R-2	R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-3, R-4, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
R-3	R-2, R-3, R-4	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-3, R-4, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
R-4	P-2, P-3, M-2, M-3, R-2, R-3, R-4, I-1	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-3, R-4, I-2, I-3, I-4, I-5	P-2, P-3, R-1, R-2, R-3, R-4, I-1	
I-1	I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-4, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, R-2, R-3, R-4, I-1, I-2, I-3 I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, R-2, R-3, R-4, I-1, I-2, I-3, I-4, I-5	P-3,I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-5	R-2, R-3, R-4, I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-3, I-4, I-5	

Table A.5. Iteration V

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, R-2, R-3, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2,	V
P-2	P-1, P-2, R-2, R-3 , I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, R-4, I-2	
P-3	P-1, P-2, P-3, M-1, R-2, R-3, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, R-3, I-1, I-2, I-3, I-4, I-5	P-1, P-3, R-3, R-4, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1,	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, R-4, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3,	P-1, M-1, M-2, M-3, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, R-2, R-3, I-1	P-1, M-1, M-2, M-3, N-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, R-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, R-2, R-3, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, I-2, I-3, I-4	P-1, M-1, N-2, I-2	
N-3	P-1, P-2, N-3, R-2, R-3, I-1, I-2	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3, I-2	
R-2	R-2, R-3, I-1	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-3, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
R-3	R-2, R-3,	P-1, P-2, P-3, N-1, N-2, N-3, R-2, R-3, I-2, I-3, I-4, I-5	R-1, R-2, R-3, R-4	
I-1	I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, R-2, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, R-2, R-3, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, R-2, R-3, R-4, I-1, I-2, I-3 I-4, I-5	P-3, W-2, W-5, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, R-2, R-3, , I-1, I-2, I-3, I-4, I-5	P-3,I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-5	R-2, R-3, I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-3, I-4, I-5	

Table A.6. Iteration VI

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, I-1, I-5	P-1, P-2, P-3, M-2, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, P-3, M-2, N-1, N-2,	VI
P-2	P-1, P-2, I-1, I-2, I-5	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-2, I-2	
P-3	P-1, P-2, P-3, M-1, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, I-1, I-2, I-3, I-4, I-5	P-1, P-3, I-1, I-2, I-3, I-4, I-5	
M-1	P-2,M-1, N-1, N-2, N-3, W-1,	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, I-3	P-1, M-2	
M-3	P-2, M-3, N-1, N-2, N-3,	P-1, M-1, M-2, M-3, I-3	M-3	
N-1	P-1, P-2, P-3, M-1, N-1, I-1	P-1, M-1, M-2, M-3, N-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, I-2, I-3, I-4,	
N-2	P-1, P-2, P-3, M-1, N-2, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, I-2, I-3, I-4	P-1, M-1, N-2, I-2	
N-3	P-1, P-2, N-3, I-1, I-2	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3, I-2	
I-1	I-1, I-2, I-5	P-1, P-2, P-3, N-1, N-2, N-3, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-5	
I-2	P-1, P-2, P-3, M-1, N-1, N-2, N-3, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-2, P-3, N-2, N-3, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-2, P-3, M-1, M-2, M-3, N-1, N-2, N-3, I-1, I-2, I-3 I-4, I-5	P-3, W-2, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-4	P-1, P-2, P-3, M-1, N-1, N-2, N-3, I-1, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-5	I-1, I-2 I-3, I-4, I-5	P-1, P-2, P-3, N-2, I-1, I-2, I-3, I-4, I-5	I-1, I-2, I-3, I-4, I-5	

Table A.7. Iteration VII

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
P-1	P-1, P-3, M-1, M-2, M-3, N-1, N-2, I-1, I-5	P-1, P-3, M-2, N-1, N-2, N-3, I-2, I-3, I-4	P-1, P-3, M-2, N-1, N-2,	VII
P-3	P-1, P-3, M-1, I-1, I-2, I-3, I-4, I-5	P-1, P-3, M-2, N-1, N-2, I-1, I-2, I-3, I-4, I-5	P-1, P-3, I-1, I-2, I-3, I-4, I-5	
M-1	M-1, N-1, N-2, N-3, W-1,	P-1, P-3, M-1, M-2, N-1, N-2, I-2, I-3, I-4, I-5	M-1, N-1, N-2	
M-2	P-1,P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, I-3	P-1, M-2	
M-3	M-3, N-1, N-2, N-3,	P-1, M-1, M-2, M-3, I-3	M-3	
N-1	P-1, P-3, M-1, N-1, I-1	P-1, M-1, M-2, M-3, N-1, I-2, I-3, I-4,	P-1, M-1, M-3, N-1, I-2, I-3, I-4,	
N-2	P-1, P-3, M-1, N-2, I-1, I-2, I-5	P-1, M-1, M-2, M-3, N-2, I-2, I-3, I-4	P-1, M-1, N-2, I-2	
N-3	P-1, N-3, I-1, I-2	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3, I-2	
I-2	P-1, P-3, M-1, N-1, N-2, N-3, I-1, I-2, I-3, I-4, I-5	P-3, N-2, N-3, W-2, I-1, I-2, I-3, I-4, I-5	P-3, N-2, N-3, I-1, I-2, I-3, I-4, I-5	
I-3	P-1, P-3, M-1, M-2, M-3, N-1, N-2, N-3, I-1, I-2, I-3 I-4, I-5	P-3, W-2, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	
I-4	P-1,P-3, M-1, N-1, N-2, N-3, I-1, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	

Table A.8. Iteration VIII

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
M-2	P-1,P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, I-3	P-1, M-2	VIII
M-3	M-3, N-1, N-2, N-3,	P-1, M-1, M-2, M-3, I-3	M-3	
N-2	P-1, P-3, M-1, N-2, I-5	P-1, M-1, M-2, M-3, N-2, I-2, I-3, I-4	P-1, M-1, N-2	
N-3	P-1, N-3,	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3,	
I-3	P-1, P-3, M-1, M-2, M-3, N-1, N-2, N-3, I-3 I-4, I-5	P-3, W-2, I-2, I-3, I-4, I-5	P-3, I-3, I-4, I-5	
I-4	P-1,P-3, M-1, N-1, N-2, N-3, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	P-3, I-3, I-4, I-5	

Table A.9. Iteration IX

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
M-2	P-1,P-3, M-1, M-2, M-3, N-1, N-2, N-3,	P-1, M-2, I-3	P-1, M-2	IX
M-3	M-3, N-1, N-3,	P-1, M-1, M-2, M-3, I-3	M-3	
N-3	P-1, N-3,	M-1, M-2, M-3, N-3, I-2, I-3, I-4	N-3,	
I-3	P-1, P-3, M-1, M-2, M-3, N-1, N-3, I-3 I-4, I-5	P-3, W-2, I-2, I-3, I-4, I-5	P-3, I-3, I-4, I-5	
I-4	P-1,P-3, M-1, N-1, N-3, I-3, I-4, I-5	P-3, I-2, I-3, I-4, I-5	P-3, I-3, I-4, I-5	

Table A.10. Iteration X

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
M-2	P-1,P-3, M-1, M-2, M-3,	P-1, M-2, I-3	P-1, M-2	X
M-3	M-3	P-1, M-1, M-2, M-3, I-3	M-3	
I-3	P-1, P-3, M-1, M-2, M-3, I-3 I-4,	P-3, W-2, I-2, I-3, I-4	P-3, I-3, I-4,	
I-4	P-1,P-3, M-1, N-1, I-3, I-4,	P-3, I-2, I-3, I-4	P-3, I-3, I-4,	

Table A.11. Iteration XI

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
M-2	P-1,P-3, M-1, M-2, M-3,	P-1, M-2	P-1, M-2	XI
M-3	M-3,	P-1, M-1, M-2, M-3,	M-3	

Table A.12. Iteration XII

Factors (Si)	Reachability set R (Si)	Antecedent set A (Si)	Intersection set R (Si) ∩ A (Si)	Level
M-2	P-1,P-3, M-1, M-2, M-3,	P-1, M-2	P-1, M-2	XII

Table A.13. Conical Matrix

Sub-Factors	P-1	P-2	P-3	M-1	M-2	M-3	N-1	N-2	N-3	W-1	W-2	W-3	W-4	W-5	R-1	R-2	R-3	R-4	I-1	I-2	I-3	I-4	I-5	Driving power
P-1	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	17
P-2	1	1	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	14
P-3	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	18
M-1	0	1	0	1	0	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	10
M-2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	15
M-3	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	11
N-1	1	1	1	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	15
N-2	1	1	1	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	1	17
N-3	1	1	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	14
W-1	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	3
W-2	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	13
W-3	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	0	0	1	0	0	0	0	0	7
W-4	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	3
W-5	1	1	0	0	0	0	1	1	1	0	1	1	1	1	0	0	0	0	0	0	1	1	1	12
R-1	0	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1	1	1	0	0	0	0	0	8
R-2	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	9
R-3	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	9
R-4	0	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	14
I-1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	1	1	0	0	1	8
I-2	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
I-3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23
I-4	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21
I-5	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Dependence power	11	14	9	9	4	5	9	9	8	18	20	23	23	20	19	15	15	16	14	10	7	7	11	

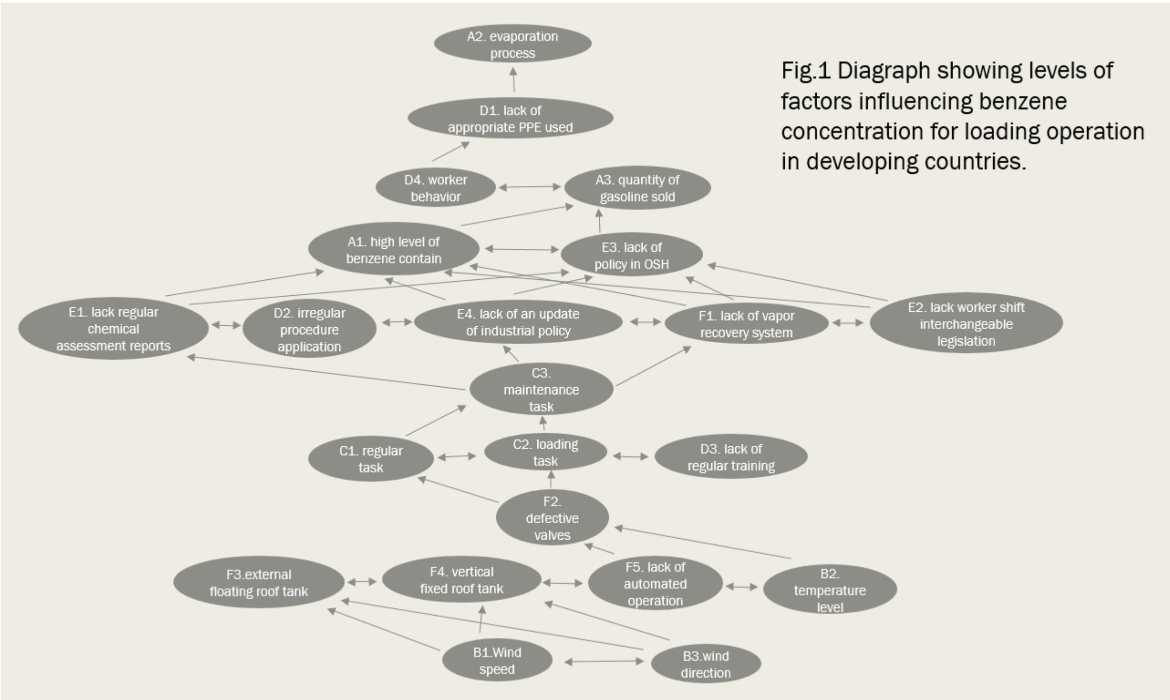

Fig. A.1. Digraph

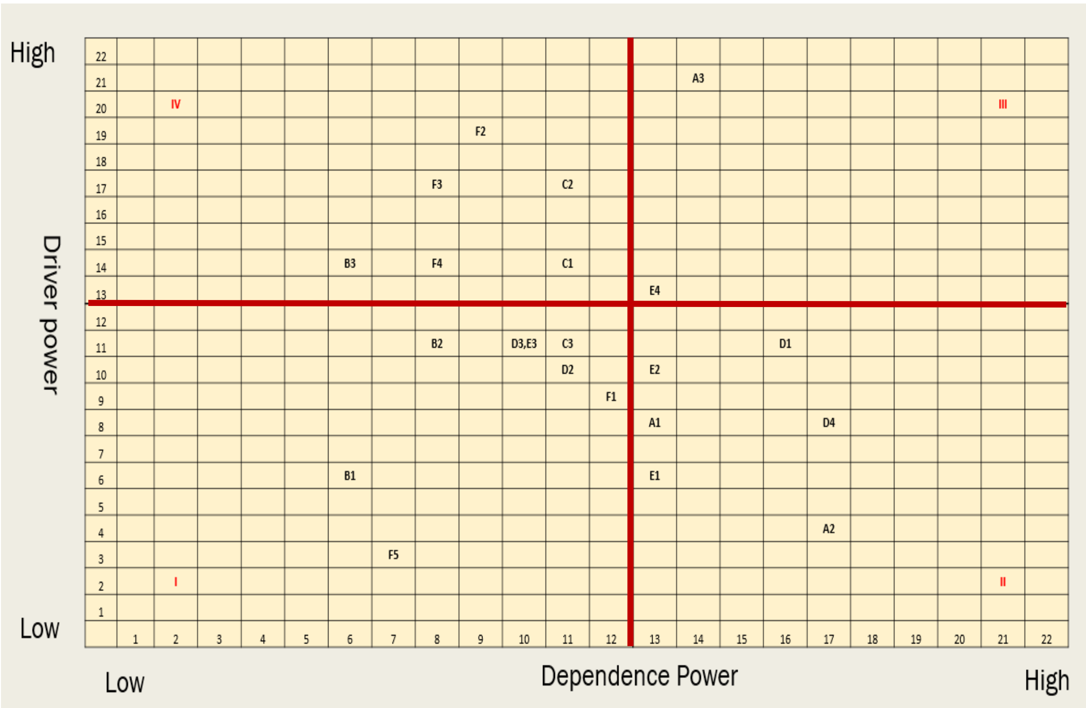

Fig.A.2. Driver-Independence matrix