Human Risk Assessment and Mitigation Using Bow Tie Strategy

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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WAN ZULKHAIRI BIN WAN MAZELAN

ABSTRACT

Human reliability assessment (HRA) techniques are used for quantifying human error probability for the purpose of providing feedback regarding the overall performance, and most importantly, safety of the system. Performing HRA involves various activities, including task analysis, conducting experiments, which have been found generally difficult, time-consuming and costly. In this project, the whole process will be based on HRA methodology. For problem identification, a survey and interview are conducted. The task analysis of the finding was then constructed and the cause of human error is identified using human HAZOP and to be considered in Fault Tree Analysis (FTA) while all the controls will be developed. The Event Tree Analysis then developed based on consequences of the human error and all the control will be developed as well. The analysis then combined and Bow-Tie analysis is developed.

ACKNOWLEDGEMENT

I would like to express my deepest gratitude to the Chemical Engineering department of Universiti Teknologi PETRONAS (UTP) for providing the chance to undertake this Final Year Project (FYP). My knowledge and skills has been put to a test after completing various kinds of project during my five years intensive chemical engineering course. This course has a good coverage on the overall chemical engineering program whereby a student with any majors has been assigned with different scope of the study thus contribute the effort and knowledge towards achieving a project goal.

My heartfelt gratitude goes to my family and friends for providing me continuous support throughout the duration of this project. Also, a very special note thanks to my supervisor Prof Dr. Azmi Mohd Shariff, who was always willing to assist and provided good support throughout the project completion. Your excellent support, patience and effective guidance have helped my project to completion.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

By general definition, risk is determined as the likely of losing something of value. The ‘value’ mentioned can be categorized as physical health, emotional well-being, social status, or financial prosperity. In this research context, the risk is classified under industrial angle which is operation, production, maintenance and etc.

One of the field area focused under risk management is the field of human factor where behavior and psychology act as a factor in understanding and decision making. For example, in road accident, human errors contribute over 70 percent of accidents and this percentage value is not far different from industrial accident.

In overcoming the risk, first, the risk must be assessed. Risk assessment is the process where the hazard is recognized, the risks associated with the hazard is studied or assessed and the proper way to eliminate or control the hazard is determined. In a simpler term, risk assessment is a systematic observation at workplace to identify hazards and then decide what measure should be taken to successfully prevent or control the harm from occur.

After assessing the risk, prevention or mitigation measure will be taken into account. Mitigation is a process which an organization introduces specific measure to minimize or eliminate the unacceptable risk associated within operations to an acceptable level or to a more tolerable level. Risk mitigation a step to establish and implement an appropriate strategies and effective measure in order to minimize risk to a level that is as low as reasonably practical.

One of the techniques to assess and mitigate human factor is using Bowtie approach. Bowtie is one of many barrier risk models available to support the identification and management of risk. It is a visual tool which defines risk providing a prospect to recognize and assess the key safety barrier. This method is exclusive in its ability to represent complex risk from an understandable viewpoint yet also allow detailed risk based on improvement plans.

1.2 Problem Statement

- The approach of Bow Tie does not emphasize on the criticality of the task specifically related to human error.
- Currently known Human Risk Assessment technique does not establish preventive and mitigative control simultaneously for human factor aspect

1.3 Objective

- To develop Bow Tie strategy to assess human error by their critical task
- To establish preventive and mitigative control in human factor that act simultaneously under one strategy

1.4 Scope of Study

Risk mitigation using Bow Tie strategy can be implemented into many fields of industries but for this project, the scope will be narrowed down to process industries. All considerations and scenarios that will be used in the development of the mitigation process will be based on process industry. To be more specific, this project will be conducted and monitored among UTP's very own community.

The system that will be tested will be limited since the result will be based on the range of availability and adequacy of UTP's equipment and facilities. The participation of students in this project would also affect the result but nevertheless it will be sufficient to generate a valid outcome and to prove theories.

CHAPTER 2
LITERATURE REVIEW

2.1 Risk Assessment

Risk is a driving consideration in decisions that determine how engineering systems are developed, produced, and sustained (Garvey, 2009). According to (Aven & Vinnem, 2010), risk is the combination of probability and consequences, where the consequences relate to various aspects of HSE, for example loss of life and injuries. Risks also defined as events that, if the occur, will cause unwanted change in the cost, schedule, or technical performance of an engineering system; therefore, the occurrence of risk is an event that has negative consequences to an engineering system project (Garvey, 2009).

Risk assessment is the process where the hazard is identified, the risks associated with the hazard is analyzed or evaluated and the proper way to eliminate or control the hazard is determined. Risk assessment also defined as a formal and systematic analysis to identify or qualify frequency or probabilities and magnitude of losses to recipient due to exposure of hazard (physical, chemical or microbial agent) from failures involving natural events and failures of hardware, software and human systems (Modarres, 2006). Risk assessment not only aim to estimate risk, but also to evaluate its significance, so as to consider if the risk is acceptable or not. These considerations are the crucial part of the human dimension to risk assessment, in risk assessment there is a human dimension in causing accidents and a human dimension in estimating risk and evaluating its significance. Thus the acceptance of risk is not straightforward (Wong, 2010). According to (Wong, 2010), the five step procedure is suitable to assess risk in the work place. The five steps mentioned are:

- Identify the hazards;
- Decide who might be harmed and how;
- Evaluate the risk and decide on precautions;
- Records the findings and implement them; and lastly
- Review the assessment and update as necessary.

However, the general principle for risk assessment in industry is different where the key elements are as follows:

- Identify hazards, which have a potential of harm;
- Risk is defined as the probability that a hazardous event could occur;
- Consequence is the harm resulting from a hazardous event occurring;
- Risk assessment is the consideration of risk and the consequences of a hazardous event in order to decide if any action is necessary to avoid or to reduce the risk; and
- Record the results of the risk assessment and the action taken.

2.2 Identification of Hazard

Risk identification is the first step and the most important one is risk management process. Garvey stated that risk identification defines the set of future event that, if any occur, could have unwanted impact on an engineering system project's cost, schedule, technical performance or any other evaluation criteria defined by engineering team. Hazard is a condition or physical situation with a potential for an undesirable consequence (loss) (Modarres, 2006). Hazard can be categorized into several categories as follows:

Table 2.1: Categories of hazard

Category	Example
Chemical	Toxins, corrosive agents, smoke
Biological	Viruses, microbial agents, biocontaminants
Thermal	Explosions, fire
Mechanical	Impact, explosions
Electrical	Electromagnetic fields, electric shock
Ionizing radiation	X-rays, gamma rays
Nonionizing radiation	Microwave radiation, cosmic rays
Information	Propaganda, computer virus

Each of the hazards will be a part of the system and normal system barrier will be used as their containments (e.g., using firewall to prevent unauthorized access of information). Provided the system is uninterrupted, the barriers that contain the hazard remain unchallenged.

Risk identification is done to reckon known risks. Risk identification as a continuous process which operate regularly throughout the engineering phase and evolving system (Garvey, 2009).

2.3 Human Factor / Human Reliability

Human factor plays an essential role in determining the magnitude of risk possessed in any risk assessment. According to The Reactor Safety Study, more than 60 percent of the accidents occurred in nuclear industry are related to human error (Modarres, 2006) (Wong, 2010). In engineering approaches to risk assessment, it is possible to attempt to quantify the contribution made by human action or inaction to the overall risk from the system where as the quantification is mainly concerned with human action or omission as a direct cause of accidents, not aspect of human failing which result in poor design or bad decision (Hurst, 1998).These approaches is known as Human Reliability Assessment (HRA), where the process of task analysis which helps with the identification of all points in a sequence of operation at which incorrect human action or the failure to act may lead to adverse consequences for plant and/or for people is included. According to (Modarres, 2006), there are limitations and difficulties in current HRA which are:

a) Human behavior is complex subject that cannot be described as a simple hardware in a system. Human performance can be affected by social, environmental, psychological, and physical factors that are difficult to quantify.
b) Human action cannot be considered to have binary success and failure states, as in hardware failure. Moreover, the full range of human interaction has not been fully analyzed by HRA method.
c) The most difficult part of HRA is the lack of appropriate data on human behavior in extreme situations.

2.4 Risk Handling

There are plenty of ways to handle risks. In general, there are several categories that the risk handling strategies can be divided, such as *Risk Avoidance, Risk Control, Risk Acceptance,* or *Risk Transfer.*

2.4.1 Risk Avoidance

This risk strategy involves a change in the concept, requirements, specifications, and/or practices that reduce risk to an acceptable level. A risk avoidance strategy eliminates the source of high or possibly medium risks and replaces them with a lower risk solution. Solution like stated before should be supported by a corresponding cost-benefit analysis. Normally, this strategy may be conducted in parallel with up-front capability planning or requirements analyses and supported by cost tradeoff studies (Bahnmaier, 2003).

2.4.2 Risk Control

Risk control actively engages strategies to reduce or mitigate risk. It monitors and manages risk in a manner that reduces its occurrence probability and/or consequences on the project. Risk control is a widely exercised handling strategy by a project's management. Because of this, various approaches to monitoring the progress of mitigation strategies have been developed (Bahnmaier, 2003) (Garvey, 2001) (Garvey, 2005).

2.4.3 Risk Acceptance

Risk acceptance is an acknowledgement of the existence of a particular risk situation and a conscious decision to accept the associated level of risk without engaging in special efforts to control it. However, a general cost and schedule reserve may be set aside to deal with any problem that may occur as a result of various risk acceptance decision. This strategy recognizes that not all identified program risk warrant special handling; as such, it is most suited for those situations that have been classified as low risk (Garvey, 2001).

2.4.4 Risk Transfer

This strategy is one that relocates risk from one part of the projects to another or redistributing risks between the organization acquiring the system and the system's prime contractor. Risk transfer is a form of risk sharing. It should not be viewed as risk abrogation. An example is the transfer of a function from hardware implementation to software implementation. The effectiveness of risk transfer depends on the use of successful system engineering techniques, such as modular design and functional partitioning techniques (Bahnmaier, 2003).

2.5 Bow Tie

The Bow-Tie is a model that represents how a hazard can be released, escalate, and how it is controlled. It contains the elements required to successfully manage the hazard such that the risks are tolerable and ALARP. Bow-Ties can also be used to support risk management of non-HSE processes.

For each severity or high level hazard, the Bow-Tie methodology allows for:

1. Identification of the hazard release, escalation and consequence scenarios
2. Identification of controls, e.g. barriers and escalation factor controls required to manage the hazards
3. Categorization of controls into Inherent Safety, Safety Critical Element (hardware) or Critical activity (procedures, processes, operator action)
4. A clear visual representation to enable the ALARP review to be undertaken
5. An aid in the incident review process if occurrence of such a major incident has occurred.

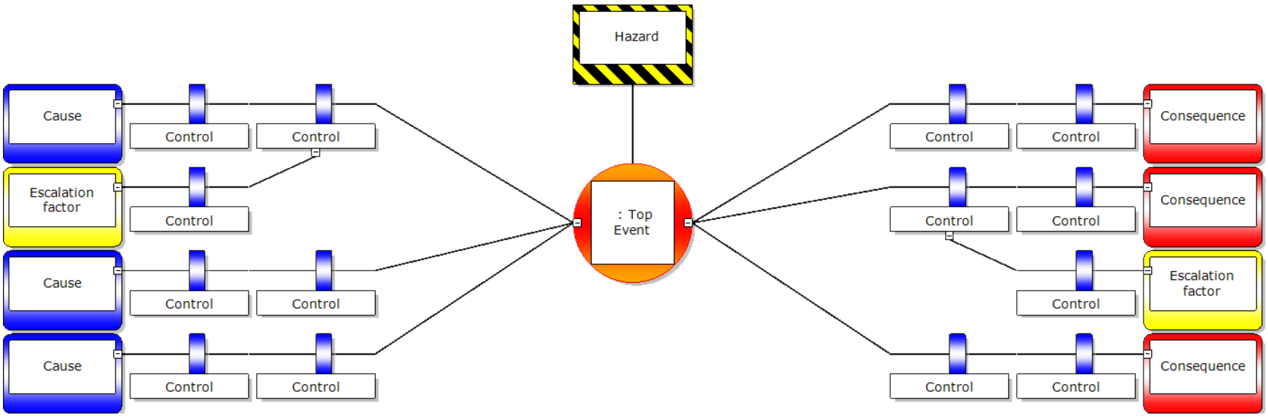

Figure 2.1: Generic Bow Tie model

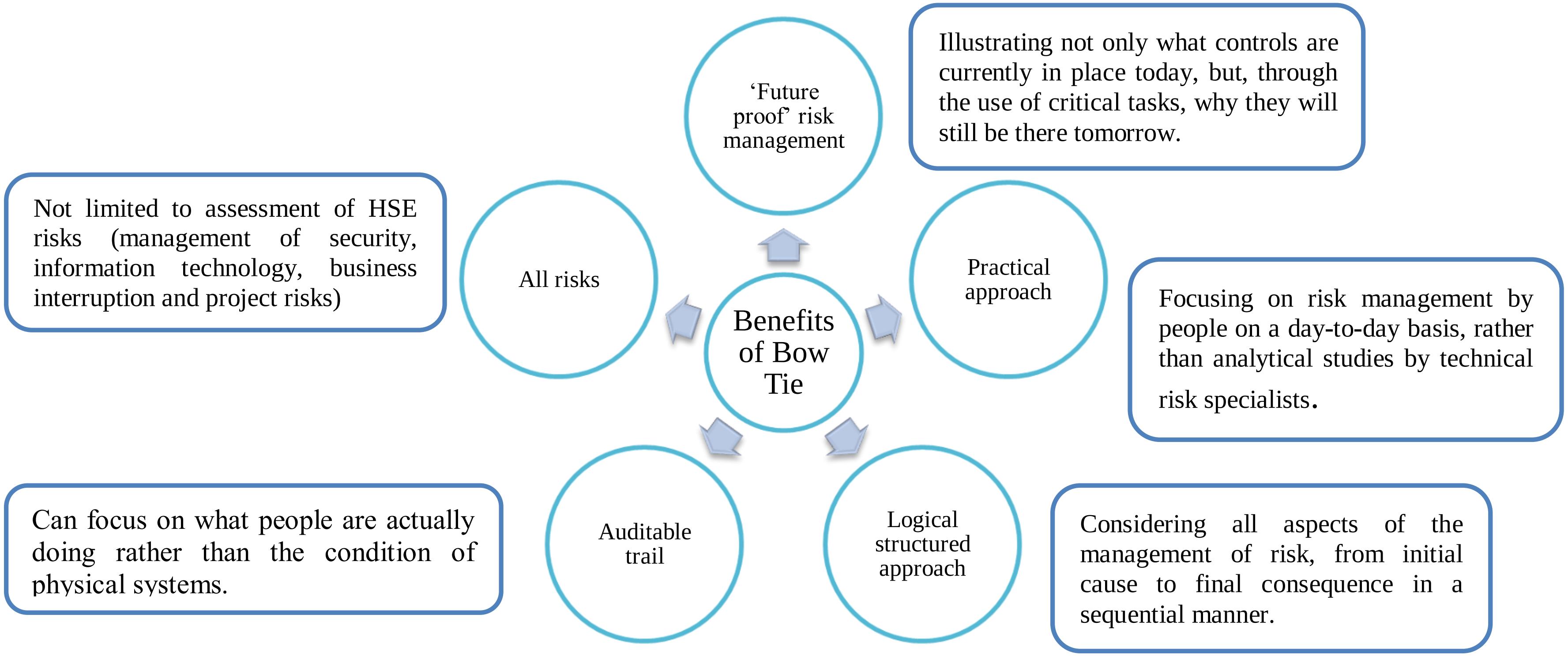

Figure 2.2: Benefit of Bow Tie

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The framework to build Bow-Tie analysis was shown as figure 3.1 below:

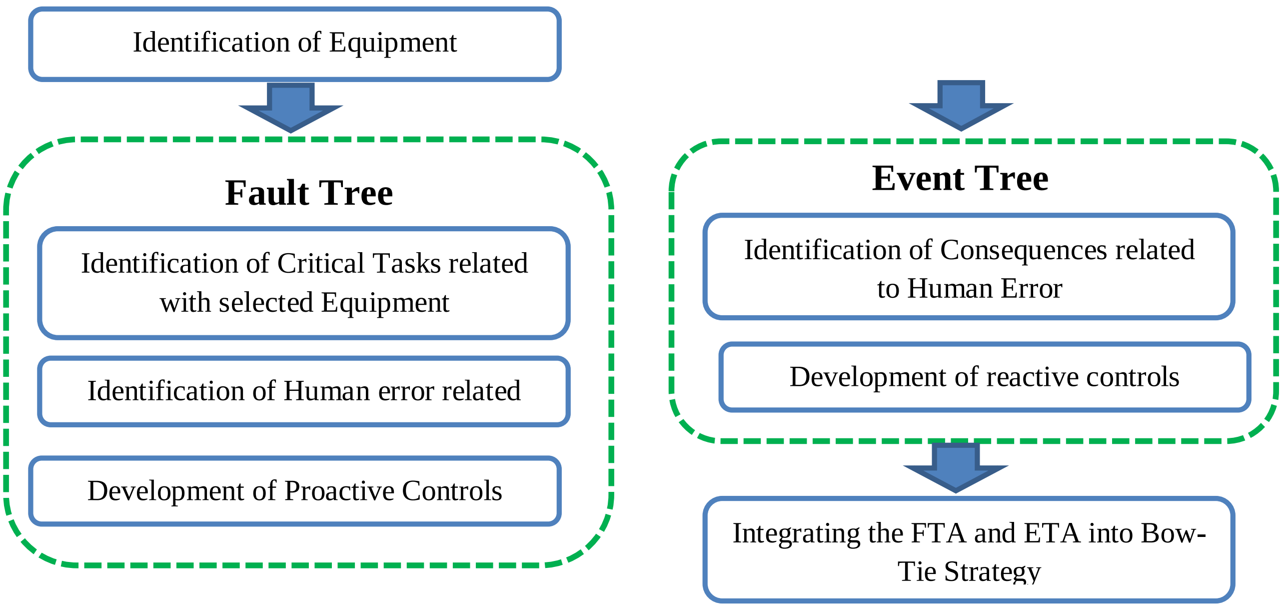

Figure 3.1: Bow-Tie construction framework

3.1.1 Identification of Error-Inducing Equipment

In this study, a survey will be conducted for students and staffs to identify the flaw in risk control in several category of the system. The equipment will be specified based on what the student is working on. The categories and their attributes that will be studied are;

Table 3.1: Attributes of categories used in survey form

Categories	Attributes	Remark
Facilities and Equipment	Condition	Overall condition of facilities and equipment in the laboratory
	Usefulness	
	Adequacy	Adequacy of equipment and facilities against the number of student in need
Training provided	Instruction clarity	Before, during and after operation.
	Impact	Competency and safety level
	Adequacy	Adequacy of trainings given with all equipment to be operated
Implementation of PPE	Inspection frequency	How frequent does person in charge inspect the implementation of PPE during experiment?
	Emphasis	How serious is the use of PPE to be emphasized
	Adequacy	Adequacy of numbers of PPE provided with the number of person during any operation in laboratory
Signs and Labels	Clarity	Easy to observe and listen
	Understanding	Based on provided sign and labels, how well it promote understanding?
	Emphasis	
Standard Operating Procedures (SOP)	Clarity	How clear the procedure provided
	Understanding	Based on instruction in SOP, how well the understanding about the instruction?
	Emphasis	How well is the emphasis of SOP before, during and after performing an experiment?

A survey form will be distributed and the scores for every attributes in the categories will be tabulated and studied. Sample of survey form is attached in APPENDIX.

3.1.2 Representation of Tasks

Based on the previous finding, the equipment that identified with most possible human error will be studied to extract a proper and complete step-by-step sequence to develop Hierarchical Task Analysis (HTA). From the HTA developed, all possible causes that can lead to human error can be identified.

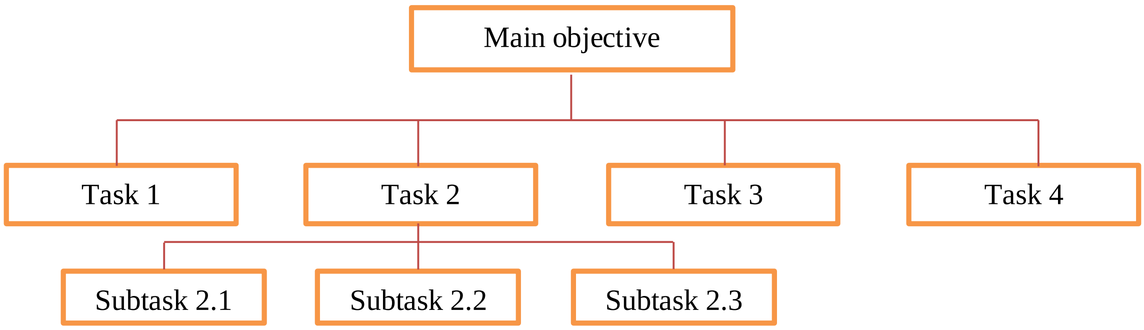

Figure 3.2: HTA concept

3.1.3 Identification of Critical Tasks

Based on Hierarchical Task Analysis, the task required to operate the equipment already listed down. The tasks cover equipment start up, maintenance, commissioning, shut down, etc. The list of steps to operate the equipment then will be undergoing a screening by Human HAZOP to determine the criticality of the task according to the risk matrix.

Table 3.2: Guide Word for Human HAZOP

Guide word	Interpretation
No	Task not done/complete
Less	Task done less than required action
More	Task done more than required action
Reverse	Task done opposite of required action
Part of	Task partially done (step omitted)
As well as	Additional task added to original task
Other than	Task done differently
Sooner	Task done before time specified

Later	Task done after time specified
Other	Different factor that may be influence actions

Table 3.3: Risk Matrix

Severity / Probability	Catastrophic (1)	Critical (2)	Marginal (3)
Frequent (A)	High	High	Medium
Probable (B)	High	High	Medium
Occasional (C)	High	Medium	Low
Remote (D)	Medium	Medium	Low
Improbable (E)	Medium	Low	Low

Source: Mil STD 882-E

From the risk matrix above, the criticality of the task for this project is focused on the higher ranking. As referred to the table below, the task criticality will be classified in the risk ranking column where the probability and severity of each task will determine the ranking of risk for every task performed.

Table 3.4: Human HAZOP Worksheet Template

Intention:							
No.	Guide Word	Deviation	Cause	Consequence	Risk Ranking	Safe guard	Action
1							
2							

3.1.4 Development of Fault Tree Analysis (FTA)

From Human HAZOP, the list of causes of human error will be used to develop FTA. To prevent and counter the causes from becoming the real risk, all possible control measure is identified. In this step, causes of the top event which is the human error will be studied carefully to completely identify all control that can be used to prevent the risk from happening. One causes of human error may have more than one control layer.

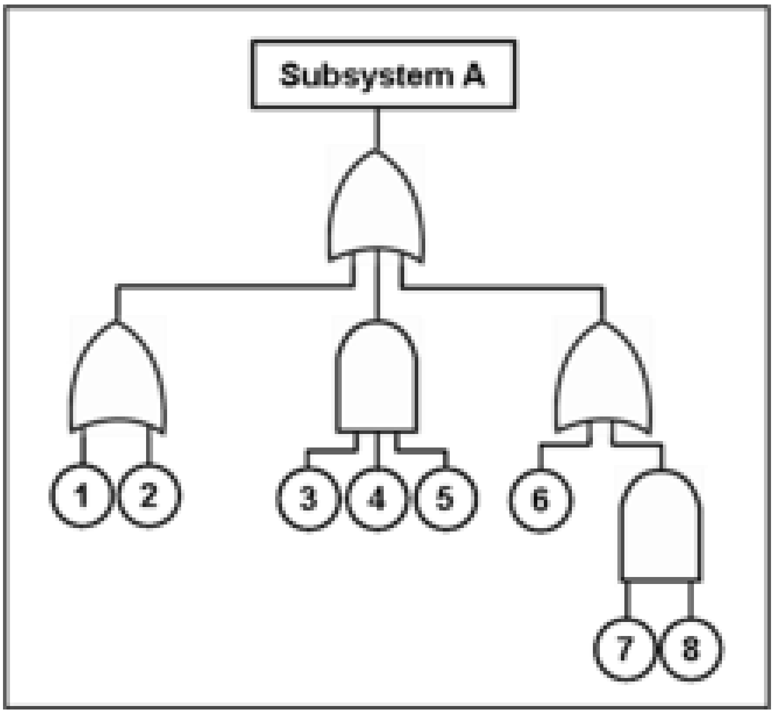

Figure 3.3: Fault Tree Analysis

3.1.5 Development of Event Tree (ETA)

In this step, all possible consequences associated with human error will be identified first. And then the countermeasure and control is determined to mitigate and prevent the worst case scenarios from the consequence lists. The control to overcome the consequences may have one or more layers.

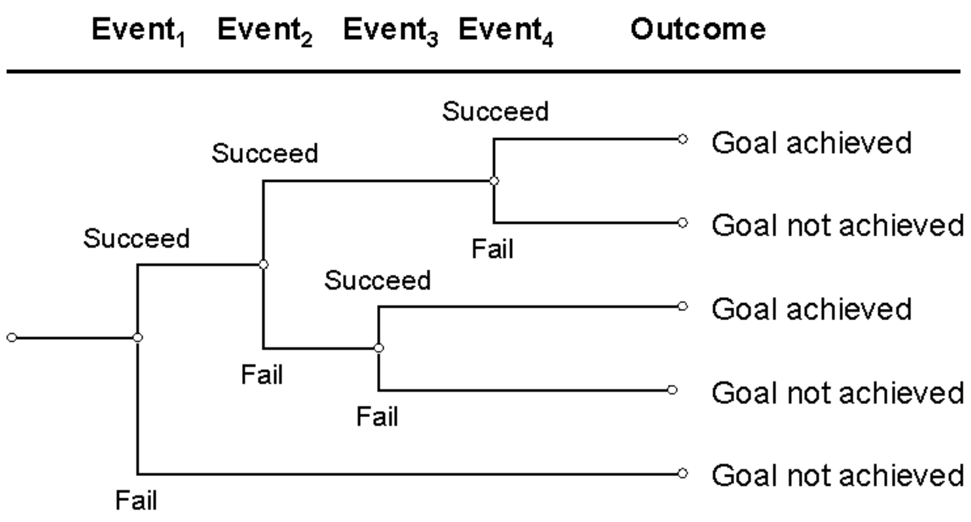

Figure 3.4: Event Tree Analysis

3.1.6 Development of Bow Tie

Since bow tie is basically the combination of fault tree and event tree, the data collected in previous step will be gathered and combined. Adjustment will be made where and when required.

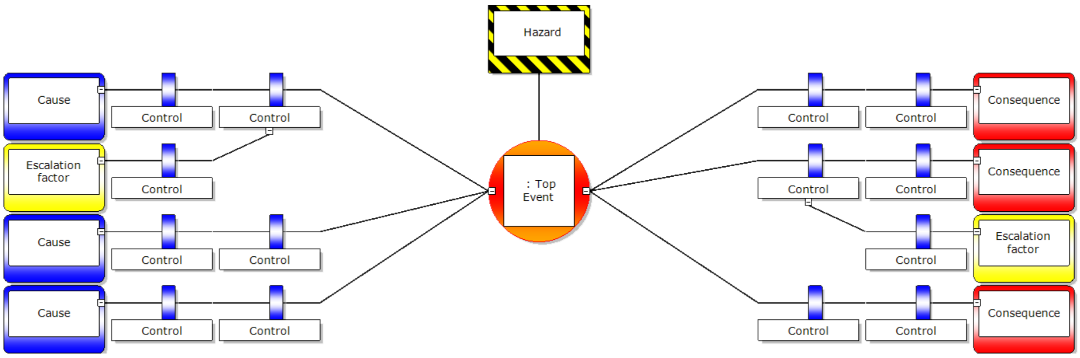

Figure 3.5: Bow Tie Model

3.2 Project Activities

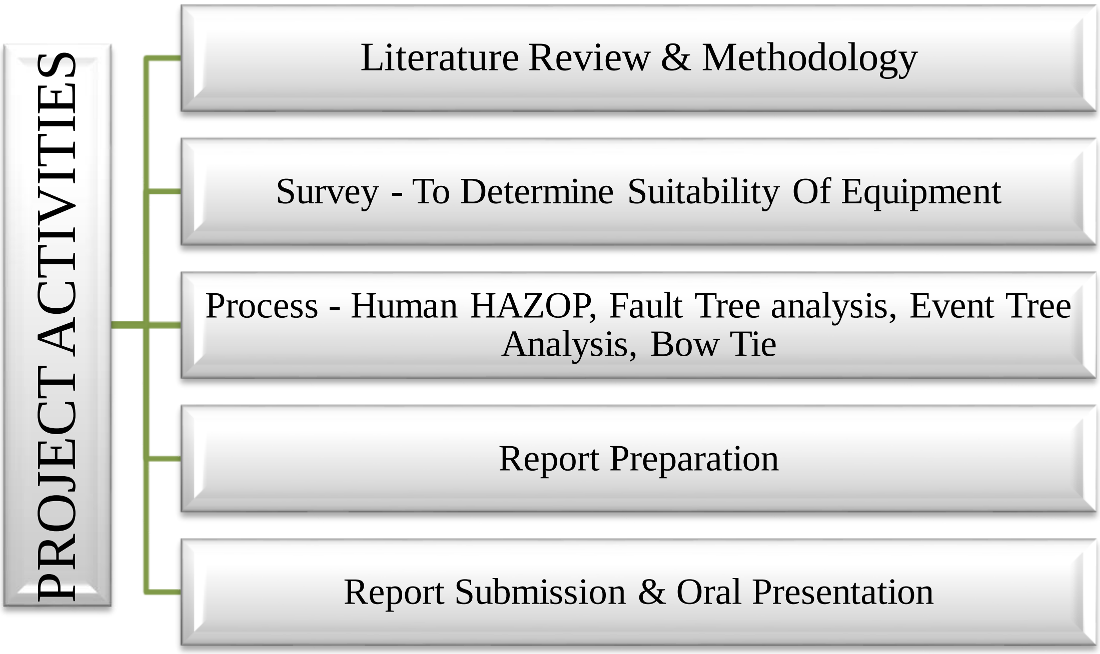

Figure 3.6: Project Activities

3.3 Gantt Chart & Key Milestone

Table 3.5: Gant Chart & key milestone for FYP1 & FYP 2

No	Detail Work (FYP1)	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Preliminary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defense														
5	Project Work Continues														
6	Submission of Interim Draft Report														
7	Submission of Interim Report														

No	Detail Work (FYP2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues															
2	Submission of Progress Report															
3	Project Work Continues															
4	Pre-SEDEX															
5	Submission of Draft Final Report															
6	Submission of Dissertation (soft bound)															
7	Submission of Technical Paper															
8	Viva															
9	Submission of Project Dissertation (Hard Bound)															

	Process
	Milestone

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Identification of Error Inducing Equipment

The identification of error inducing equipment is determined by a run of survey among UTP student who using laboratory equipment for their experiments. This step is performed to determine the equipment that possesses high potential of human error in 5 aspects which are condition of equipment, trainings provided, personal protective equipment, sign and labels, and standard operating procedures.

The table below shows the average score of each attribution for every aspect to be considered in selection of equipment as responded by every respondent in the survey.

Table 4.1: Average score for Equipment and Facilities category

Equipment and facilities	Condition	Usefulness	Adequacy	Average score
Furnace	4.5	4.5	4.5	4.5
Oven	4.7	5.0	4.0	4.6
Centrifuge	3.0	5.0	2.0	3.3
UV-Vis	4.0	5.0	4.0	4.3
Spray Dryer	4.0	4.0	1.0	3.0
SEM	4.0	4.0	4.0	4.0
HPLC	5.0	4.0	4.0	4.33
Magnetic Heater	4.0	4.0	4.0	4.0
Solubility Testing	3.0	3.0	2.0	2.7

As shown to the table below, all average scores for all categories are tabulated. The scores then used to determine the equipment which possesses high risk of human error.

Table 4.2: Average scores for all categories

	Equipment and Facilities	Training	Personal Protective Equipment (PPE)	Signs & Labels	Standard Operating Procedures (SOP)
Furnace	4.5	4.2	4.5	3.2	4.0
Oven	4.6	3.8	4.1	3.4	3.9
Centrifuge	3.3	3.7	4.3	3.0	4.0
UV-Vis	4.3	4.0	2.7	5.0	4.0
Spray Dryer	3.0	3.3	3.0	4.0	2.0
SEM	4.0	4.0	3.7	3.0	3.0
HPLC	4.3	3.0	3.0	3.0	3.0
Magnetic Heater	4.0	4.0	3.3	3.0	2.7
Solubility Testing	2.7	4.0	4.0	3.7	2.0

By summing up all the average scores based on the individual attributes for each equipment, equipment with the most error inducing condition can be determined. Table below shows the total score for each equipment:

Table 4.3: Determination Score for Error Inducing Equipment

Equipment	Total Score
Furnace	20.4
Oven	19.8
Centrifuge	18.3
UV-Vis	20.0
Spray Dryer	15.3
SEM	17.7
HPLC	16.3
Magnetic Heater	17.0
Solubility Testing	16.4

From table above, it is observable that the score for spray dryer is the lowest among the other equipment. So, spray dryer will be selected as the error inducing equipment for further assessment.

4.2 Representation of Tasks

The representation of human error related task in operation of spray dryer is using Hierarchical Task Analysis (HTA). Before the identification of any causes and consequences for every human error related to this equipment, first, the steps to operate the equipment should be known. Listed below are the operation steps for spray dryer:

1. Mix feed solution in tank(s) located behind the spray dryer.
    1.1. Verify that the feed tank valves remain closed until you are ready to run.
2. Set (open) valves on feed tanks to feed stock solution to pump as desired.
3. Open pump petcock valve
    3.1. Until feed stock flows out of valve
    3.2. Close the valve.
4. If feedstock does not flow out of the pump valve, contact the lab manager.
5. Open the main gas pipe valve ½ turn so that the valve headpiece is in line with the pipe. The valve is located on the rear of the spray dryer.

From the operation steps listed, the tasks and the subtasks involved then will be listed and transferred into HTA diagram.

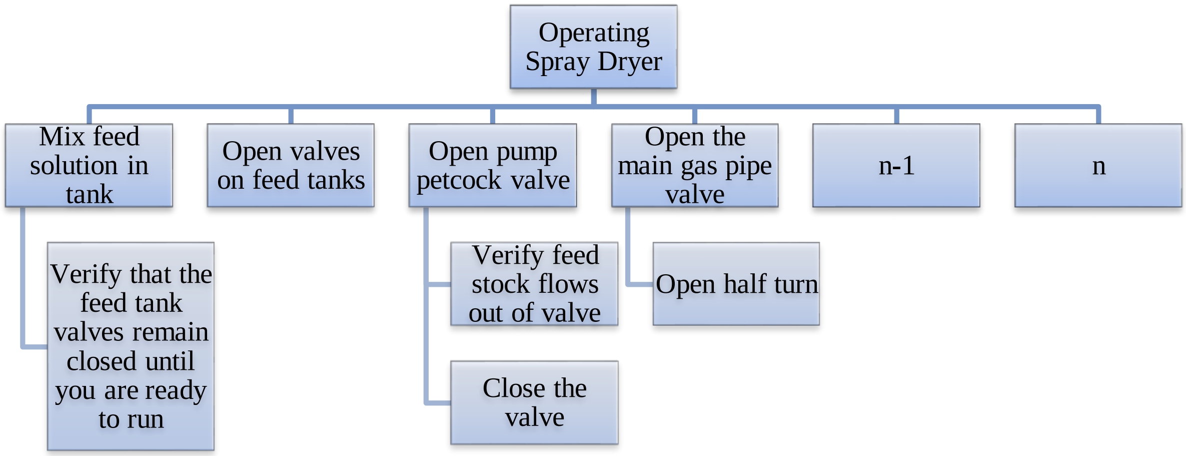

Figure 4.1: Developed HTA model

4.3 Identification of Critical Tasks

To determine the criticality of the listed task, the list then will be undergoing a screening process by Human HAZOP. Human HAZOP will determine whether the task classified as high, medium or low risk based on the risk ranking. Determination of ranking for each task criticality is based on the probability of the incident happened against the severity of the accident. The table below shows how some the risk of the task will be classified:

Table 4.4: Human HAZOP Worksheet

Intention: Set (open) valves on feed tanks to feed stock solution to pump as desired.							
No.	Guide Word	Deviation	Cause	Risk ranking	Consequence	Safe guard	Action
1	No	Valve not opened	• Operator distracted/lapse • Operator does not know the proper sequence of operation • Operator might not see the signs and labels clearly.	B2	Cavitation occurs to pump and damaged. Loud sound can impair operator's hearing	1. Provide proper training for operator 2. Establish merit system 3. Require presence of supervisor 4. Reposition signs 5. Increase clarity of label (resizing, color coded)	• Operator lower the pump RPM • Operator must wear ear protection
	Less	Valve partially opened	Operator miscalculate condition of valve	C2	Refer to valve not closed	Refer to valve not closed	Refer to valve not closed

4.4 Development of Fault Tree Analysis (FTA)

After conducting Human HAZOP, the causes that lead to the main event are identified. The safeguards that have been developed to prevent the cause from occurring are also listed. The FTA concept that will be applied is slightly different from the generic method. In this case study, the probability calculation is omitted. Instead, the safeguards are added with respect to the causes to make it parallel with the qualitative assessment. The FTA below shows the causes that may lead the operator to run the pump without having the feed. The OR gate is use, to show that any of the action will be the cause for the main event (run pump without feed) to occur

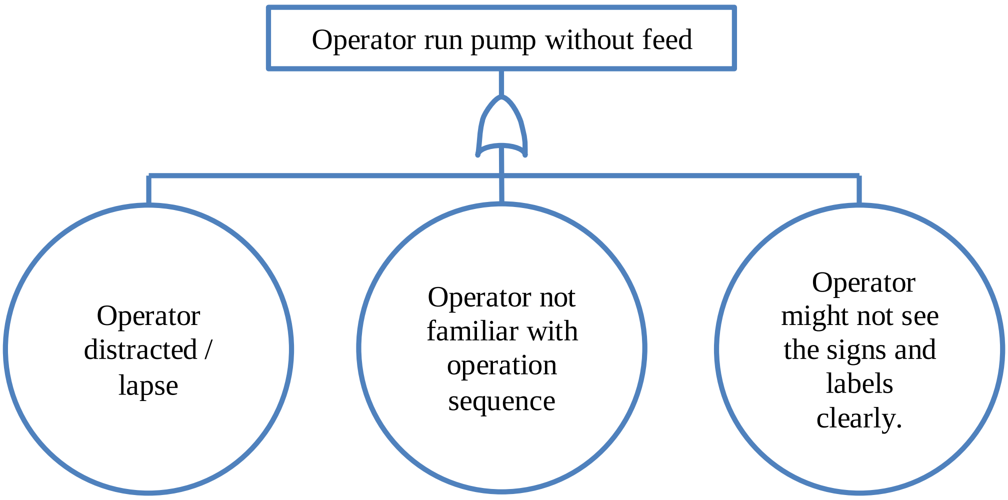

Figure 4.2: FTA Model without control

The table below shows the simplification of code for safeguard to be applied in the fault tree.

Table 4.5: Safeguard for FTA Model

Code	Safeguard
SG 1	Provide proper training for operator
SG 2	Establish merit system
SG 3	Require presence of supervisor
SG 4	Reposition signs
SG 5	Increase clarity of label (resizing, color coded)

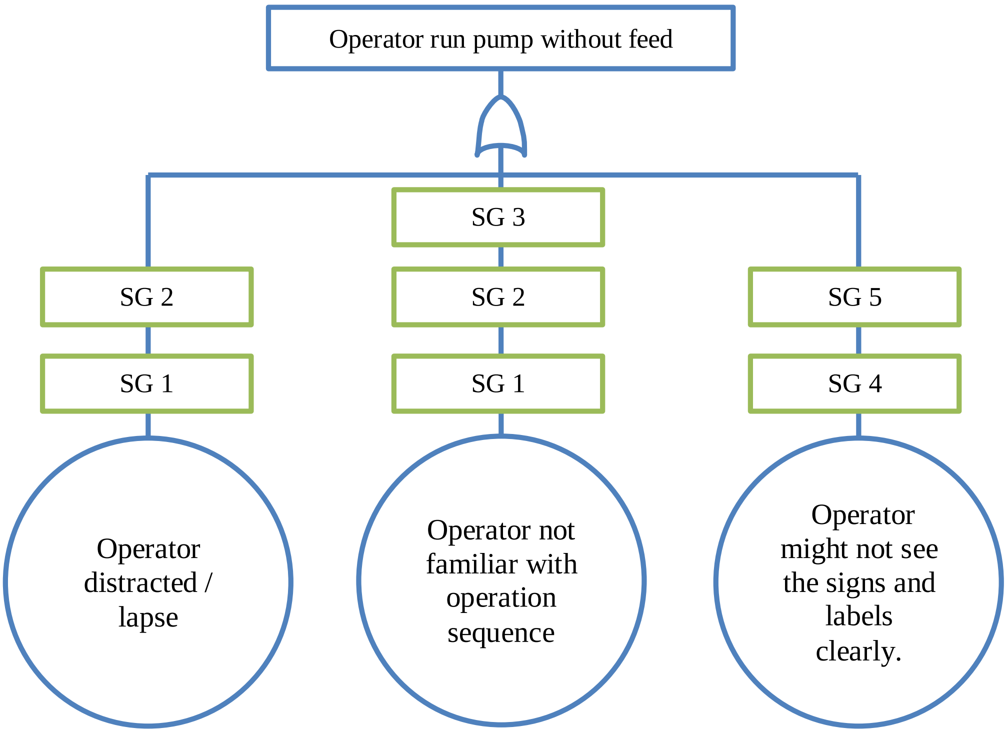

Figure 4.3: Developed FTA Model with control

The preventive measure (safeguard) will be applied to the causes in order to eliminate or at least reduce the possibility for the top event to occur. Every control may or may not eliminate the threat successfully. Sometimes more than one layer of control is required in order to minimize the threat as possible.

4.5 Development of Event Tree

Developing Event Tree for this case study is to represent the mitigative control for every consequence as listed in the Human HAZOP. The concepts applied are similar to the generic ETA methodology but the applications are different. The intermediate events which to determine the consequences from the initiating event are replaced with mitigative control which will confirm the occurrence of the consequences as identified in Human HAZOP.

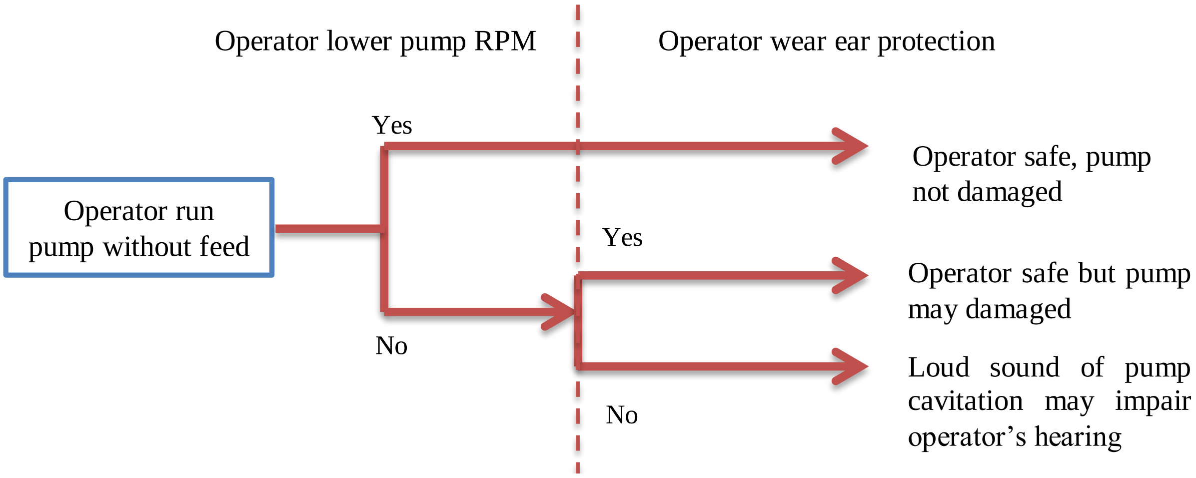

Figure 4.4: Developed ETA Model

Without any control to the initiating event (Operator run pump without feed), the operator might experience hearing loss and the equipment (pump) will damage. The mitigative control is applied to the possibility of occurrence to minimize and eliminate the risk of injury and mechanical damage. The control may be applied in several layers to ensure the effectiveness.

4.6 Integration of FTA and ETA into Bow Tie

After the development of FTA and ETA is done, the Bow Tie model will be developed by integrating both of the Tree analysis. The model might be a little different than the generic Bow Tie model as developed from the software but the components are provided are similar. Figure below shows the Bow Tie as developed from FTA and ETA:

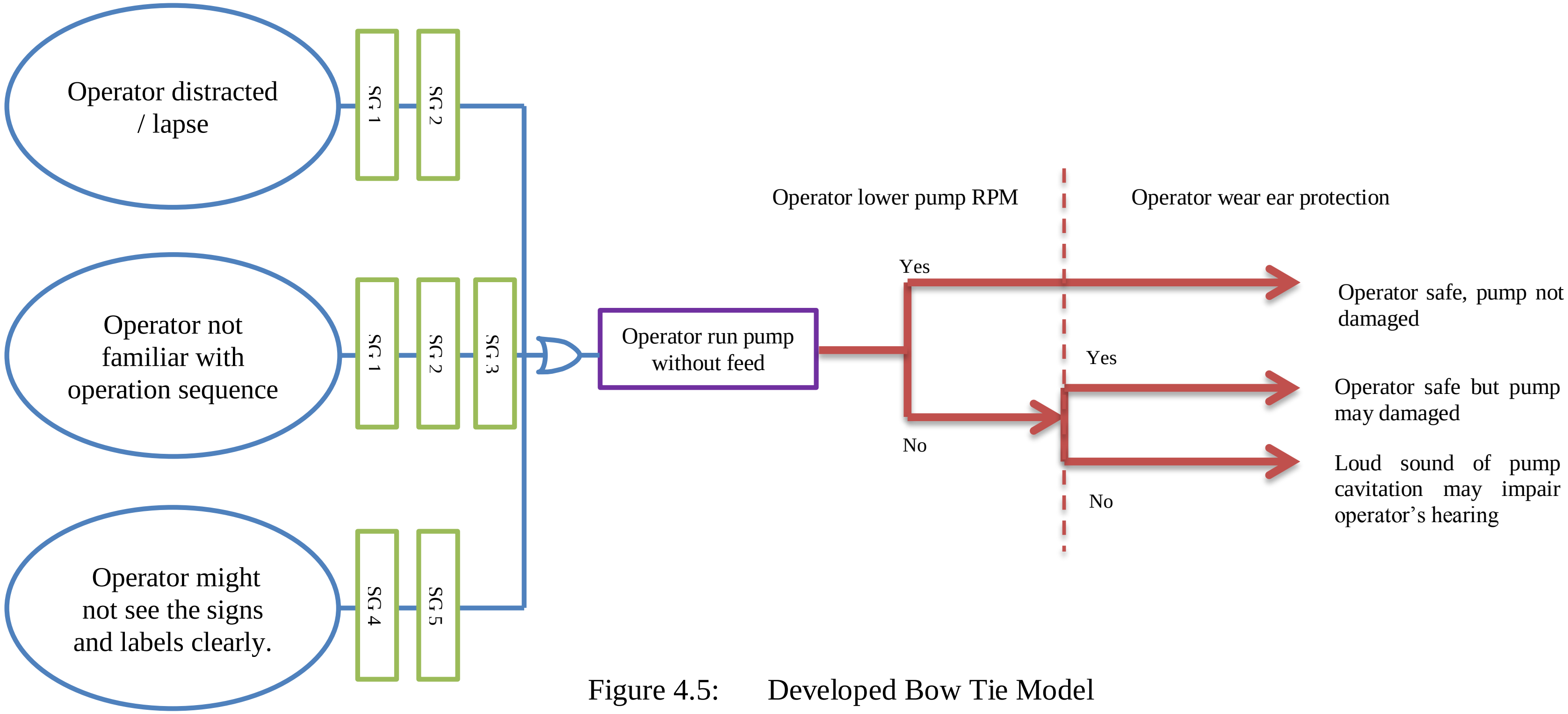

Figure 4.5: Developed Bow Tie Model

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

This project is conducted because the existing Human Reliability Assessment (HRA) techniques existed was ill defined in the aspect to mitigate the human risk where the tools used to control and mitigate risk was not specifically aim for human error. The existing technique mostly is not appropriate for realistic analysis and the error diagnosis is insufficient. The aim for this project is to develop a model for safety critical task analysis into sequence of control and consequences and also to integrate said sequence into Bow-tie working system where then can be embedded into daily industrial operations.

This project is focused only within UTP's community. Perhaps for further study or for broader sample set, it is recommended to conduct the information gathering at a much bigger location such as industry itself. The qualitative and quantitative analysis for this project can be improved and enhance a little bit more if all the assumption, and consideration to be taken deeper.

This approach is important as it deals with human lives. The mitigation of human risk by Bow Tie model is believed can be used to reduce the potential accident caused by human error by a significant percentage. By implementing these systems, major accidents can be avoided and fatality can be reduced.

The execution of this project is within capability of a final year student with the help and guidance from the supervisor, co-supervisor and the coordinator. The time frame is also feasible and the project can be completed within the time allocated. It is hoped that the acquiring of equipment and materials needed for the experiment runs smoothly for the accomplishment of this project at the end.

REFERENCES

Alileche, Nassim, Cozzani, Valerio, Reniers, Genserik, & Estel, Lionel. (2015). Thresholds for domino effects and safety distances in the process industry: A review of approaches and regulations. *Reliability Engineering & System Safety, 143*, 74-84.

Aqlan, Faisal, & Mustafa Ali, Ebrahim. (2014). Integrating lean principles and fuzzy bow-tie analysis for risk assessment in chemical industry. *Journal of Loss Prevention in the Process Industries, 29*, 39-48.

Aven, Terje, & Vinnem, Jan Erik. (2010). *Risk management with application from offshore industry*. University of Stavanger, Norway: Springer.

Badreddine, Ahmed, & Amor, Nahla Ben. (2013). A Bayesian approach to construct bow tie diagrams for risk evaluation. *Process Safety and Environmental Protection, 91*(3), 159-171.

Badreddine, Ahmed, Romdhane, Taieb Ben, HajKacem, Mohamed Aymen Ben, & Amor, Nahla Ben. (2014). A new multi-objectives approach to implement preventive and protective barriers in bow tie diagram. *Journal of Loss Prevention in the Process Industries, 32*, 238-253.

Cockshott, J. E. (2005). Probability Bow-Ties: A Transparent Risk Management Tool. *Process Safety and Environmental Protection, 83*(4), 307-316.

Cockshott, J. E. (2005). Probability Bow-Ties: A Transparent Risk Management Tool. *Process Safety and Environmental Protection, 83*(4), 307-316.

Ekanem, Nsimah J., Mosleh, Ali, & Shen, Song-Hua. Phoenix – A model-based Human Reliability Analysis methodology: Qualitative Analysis Procedure. *Reliability Engineering & System Safety*.

Garvey, Paul R. (2009). *Analytical method for risk assessment: a systems engineering persective*. US: Taylor & Francis Group.

Harpe, Spencer E. (2015). How to analyze Likert and other rating scale data. *Currents in Pharmacy Teaching and Learning, 7*(6), 836-850.

Hurst, Nick W. (1998). *Risk Assessment: The Human Dimension*. Thomas Graham House, Science Park, Milton Road, Cambridge: The Royal Society of Chemistry.

Jacinto, Celeste, & Silva, Cristina. (2010). A semi-quantitative assessment of occupational risks using bow-tie representation. *Safety Science, 48*(8), 973-979.

Khakzad, Nima, Khan, Faisal, & Amyotte, Paul. (2012). Dynamic risk analysis using bow-tie approach. *Reliability Engineering & System Safety, 104*, 36-44.

Markowski, Adam S., & Kotynia, Agata. (2011). “Bow-tie” model in layer of protection analysis. *Process Safety and Environmental Protection, 89*(4), 205-213.

Modarres, Mohammad. (2006). *Risk Analysis in Engineering: Technique, Tools, and Trends*. 6000 Broken Sound Parkway NW, Boca Raton: Taylor & Francis.

Sun, Zhiqiang, Li, Zhengyi, Gong, Erling, & Xie, Hongwei. (2012). Estimating Human Error Probability using a modified CREAM. *Reliability Engineering & System Safety, 100*, 28-32.

Wong, W. (2010). *The Risk Management of Safety and Dependability: A Guide for Directors, Managers and Engineers*. Boca Raton, Boston, New York, Washington,DC: Woodhead Publishing Limited.

APPENDICES

Training

	Condition	Usefulness	Adequacy	Average score
Furnace	4.5	4.0	4.0	4.2
Oven	3.7	4.0	3.7	3.8
Centrifuge	4.0	4.0	3.0	3.7
UV-Vis	5.0	5.0	2.0	4.0
Rotary Evaporator	3.0	4.0	3.0	3.3
SEM	4.0	4.0	4.0	4.0
HPLC	3.0	3.0	3.0	3.0
Magnetic Heater	4.0	4.0	4.0	4.0
Solubility Testing	4.0	4.0	4.0	4.0

PPE

	Inspection Frequency	Emphasis	Adequacy	Average score
Furnace	4.5	4.5	4.5	4.5
Oven	4.3	4.3	3.7	4.1
Centrifuge	5.0	5.0	3.0	4.3
UV-Vis	2.0	2.0	4.0	2.7
Rotary Evaporator	4.0	4.0	1.0	3.0
SEM	3.0	4.0	4.0	3.7
HPLC	3.0	3.0	3.0	3.0
Magnetic Heater	3.0	4.0	3.0	3.3
Solubility Testing	3.0	5.0	4.0	4.0

Signs & Language

	Inspection Frequency	Emphasis	Adequacy	Average score
Furnace	3.0	3.0	3.5	3.2
Oven	3.3	3.3	3.7	3.4
Centrifuge	3.0	3.0	3.0	3.0
UV-Vis	5.0	5.0	5.0	5.0
Rotary Evaporator	4.0	4.0	4.0	4.0
SEM	3.0	3.0	3.0	3.0
HPLC	3.0	3.0	3.0	3.0
Magnetic Heater	3.0	3.0	3.0	3.0
Solubility Testing	4.0	4.0	3.0	3.7

SOP

	Inspection Frequency	Emphasis	Adequacy	Average score
Furnace	4.0	4.0	4.0	4.0
Oven	4.0	3.7	4.0	3.9
Centrifuge	4.0	4.0	4.0	4.0
UV-Vis	4.0	4.0	4.0	4.0
Rotary Evaporator	1.0	2.0	3.0	2.0
SEM	3.0	3.0	3.0	3.0
HPLC	3.0	3.0	3.0	3.0
Magnetic Heater	2.0	3.0	3.0	2.7
Solubility Testing	2.0	2.0	2.0	2.0

Intention: Verify that the feed tank valves remain closed until you are ready to run.							
No.	Guide Word	Deviation	Cause	Risk ranking	Consequence	Safe guard	Action
1	No	Valve not closed	Operator distracted/lapse	B2	The mixture may enter without proper mixing, undesired product may effect purity	Signs and label installed to remind operator of sequence of operation and warning	Install flushing stream to flush mixture before operate dryer.
	Less	Valve partially closed	Operator miscalculate condition of valve	C2	Refer to valve not closed	Refer to valve not closed	Refer to valve not closed
2							

Answer instruction:

1. Fill in the blank with the equipment operated
2. Rate question in box by rating from 1-5 (very bad- very good)

Equipment used: ____________________________

Facilities & Equipment

Condition	
Usefulness	
Adequacy	

Training

Instruction clarity	
Impact	
Adequacy	

Personal Protective Equipment (PPE)

Inspection frequency	
Emphasis	
Adequacy	

Signs & Labels

Clarity	
Understanding	
Emphasis	

Standard Operating Procedures (SOP)

Clarity	
Understanding	
Emphasis	