Dynamic Failure Assessment Using Bayesian Methodology

by

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Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Chemical Engineering)

SEPTEMBER 2011

Universiti Teknologi PETRONAS

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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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(CHEMICAL ENGINEERING)

Approved by,

(Dr. Risza Rusli)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2011

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.

NURAZURA MOHD YUSOP

ABSTRACT

Quantitative Risk Assessment (QRA) that had been used in the industry before is known to be static and a dynamic risk assessment is form using real time data and Bayesian theorem where the assessment is updated with near misses or accident that had occurred. Research has proven that dynamic approach in risk assessment can predict the incident that occurred in BP Texas refinery. Steps in conducting the dynamic risk assessment are scenario identification, prior function calculation, formation of the likelihood function and posterior function calculation. A calculation tool using Visual Basic (VB) software is develop base on the function and is validated with published data. Result shows that it is possible to develop a tool for this assessment using coding by VBA software. Dynamic failure assessment also manages to prove that risk of failure of component also increasing over time.

ACKNOWLEDGEMENTS

First and foremost, praise to God for His guidance and blessings throughout the entire course of the Final Year Project. I would like to express my deepest appreciation to my supervisor, Dr. Risza Rusli for giving me an opportunity to work on this project and for her guidance throughout the project completion. Million thanks to those who have direct or indirectly involve in completing this project. Finally, deepest gratitude goes to all my fellow colleagues, friends and family who gave me great inspirations and support to complete this project. Your cooperation and kindness is highly appreciated. Thank you.

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ABBREVIATIONS AND NOMENCLATURES

QRA	Quantitative Risk Assessment
LNG	Liquefied Natural Gas
VBA	Visual Basic for Application
FTA	Fault Tree Analysis
ETA	Event Tree Analysis
ASP	Accident Sequence Precursor

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Risk assessment and management is a part of safety and loss prevention approach in the industries (Kalantarnia, 2009) and one of the popular methodologies is Quantitative Risk Assessment (QRA). This methodology is proven effective in managing risk in industries, but it is still lacking in term of risk management that associated with time. The approach is also proven to be static and solely based on one time judgment whereby assessment on the system is done base on data during the design stage. Risk associated with the system as the time pass by is not included and base on this condition, Meel and Sieder (2006) has comes up with an approach to assess a system using dynamic risk assessment using the concept of Bayesian theorem.

1.2 PROBLEM STATEMENT

Quantitave risk assessment (QRA) is an approach in industry for hazard identification and risk assessment purposes. Although this approach is proven effective in managing risk in industries, but this approach is static and solely based on one time judgment whereby risk associated with time is not counted. Dynamic approach on the assessment is then introduced to overcome the problem and was first applied to the nuclear industry as it is among the most hazardous industries. Due to extreme consequences and the protective measures, the accident frequency in the nuclear industry is very low and hence very little accident data is available for risk analysis. Therefore, an approach to use incidents and near misses as updating tools was developed. The detection and diagnosis of uncontrolled faults, often using fault trees, has been an active area of research in chemical facilities. Meel and Seider (2006) have introduced a new approach using Bayesian theorem to update the failure assessment with real time data. Yun, Rogers, and Mannan (2009) have applied this method in conducting risk assessment in LNG Terminal while Kalantarnia, Khan and Hawboldt (2010) have come up with the modeling of BP Texas City refinery accident to verify and test this method. Among all the studies, the concept on the application of dynamic failure assessment only associated with the theory and application where tools or software for calculation that can be applied in industry has never been mentioned.

1.3 OBJECTIVES AND SCOPE OF STUDY

The main objective of the study is to develop dynamic failure assessment tool base on Bayesian Theorem for chemical facilities unit or equipment. The sub-objectives of the study are:

a) To develop tools for calculation of Dynamic Failure Assessment using Bayesian Theorem using Microsoft Excel Visual Basic for Application® (VBA) software.
b) To estimate the dynamic failure probability using the Bayesian theorem.
c) To identify the most likely scenario, type of failures and the end-states associated with the scenario.

Scopes of study covered in this project will be revolving around the probability of failure assessment where dynamic assessment method is proposed. Study and understanding on the risk assessment took placed before focusing on dynamic failure assessment that applied the Bayesian theorem. Tools for calculation of the assessment is developed using Visual Basic software before validating it using available data. Study on unit or equipment and its related safety equipment are carried out before dynamic failure assessment is applied on the system. The summarization of scope of study for this project is shown in figure below.

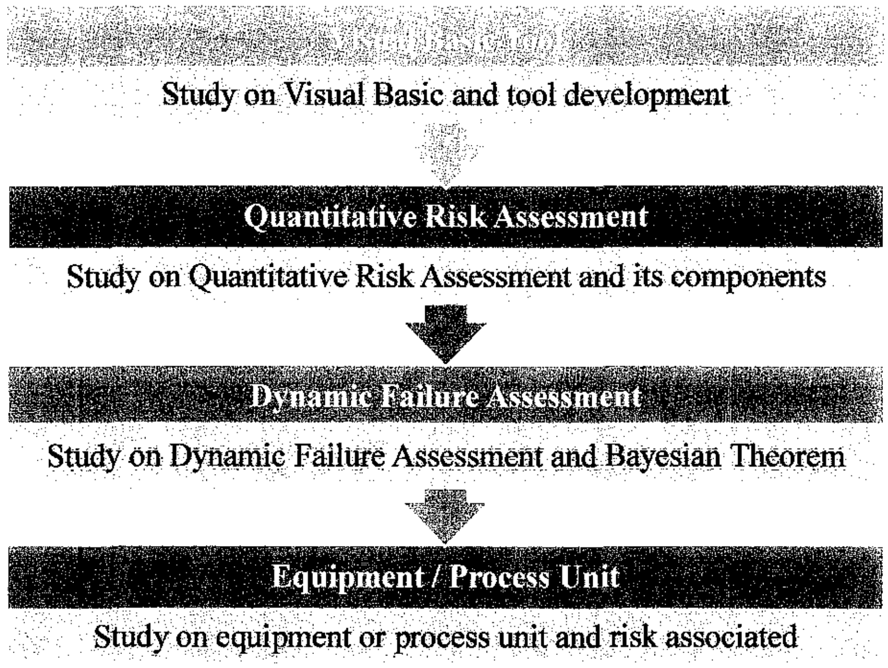


Figure 1.1 Scope of study

CHAPTER 2

LITERATURE REVIEW

2.1 DYNAMIC FAILURE RISK ASSESSMENT

An outstanding safety record is maintained by process industry mainly by assessing risk associated with the facilities and activities in the plant using the approach of estimation based upon their industry experience (Arendt & Lorenzo, 2000). As time passes by and new technology emerged, this approach is no longer feasible due to lack of experience necessary to judge the safety aspects of the new technology. This constraint later led to the development of QRA as a predictive tool for risk management. Risk analysis is usually performed in the form of Quantitative Risk Assessment (QRA) whereby potential hazard is identified and the likelihood of occurrence and its sequences being calculated. Several popular techniques for process industry in QRA are Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) (Khan & Abbasi, 1998).

Azmi & Chan (2009) stated that from observation, QRA is conducted when most of the design tasks have been completed and one of most common mitigation act proposed after QRA is the addition of protective device. The literature also stated that this protective device needs a proper maintenance throughout the plant operation for the purpose of failure detection that also incurs cost of plant operation. A new concept of inherent safety is proposed in the literature to be included as a part of risk assessment to eliminate or reduce the risk as early as the beginning of design stage.

The QRA approach is proven effective in managing risk in industries, but this approach is static and solely based on one time judgment whereby risk associated with time is not counted. Dynamic approach in risk assessment is then introduced to overcome this problem whereby real time data such as near misses and latest incident is taken account into the assessment (Bier & Mosleh, 1990).

Meel and Seider (2006) has introduced the new method in failure assessment where dynamic failure assessment is conducted using Bayesian and joint probability theory and a predictive model of the process also has been developed using this approach (Meel et al., 2007). Bayesian theory is a method of probability that manipulate the conditional probability principles to reason with uncertainties (Kalantarnia et al., 2009).Yun, Rogers, and Mannan (2009) have used this approach while conducting risk assessment analysis on LNG Terminal. Kalantarnia, Khan and Hawboldt (2009) have come up with simple application of this method using the same methodology proposed by Meel and Seider (2006). In this paper, dynamic risk assessment analysis has been applied to a tank that contained hazardous chemicals. New data on failure analysis has been gained as the real time data is introduced to the assessment model.

Kalantarnia (2009) has comes up with a thesis on dynamic risk assessment using precursor data and Bayesian theory where she followed methodology proposed by Meel and Seider (2006) and applied it into two case study which are process facility on oil and gas platform and BP Texas City refinery. Subsequently, Kalantarnia, Khan and Hawboldt (2010) have also produces the modeling of BP Texas city refinery using the same approach. The paper describe the incident and it major causes before further analyze the incident using dynamic failure assessment. The modeling is perform to test and validate the risk model and resulted in the accident was predictable by this tool.

Study and effort on developing a simple tool for plant application of calculation on this method would be great since all literature only highlight the theory and its application. This simple tool can be used in industry and may be upgraded in the future by synchronizing it with plant operation data.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

According to literature by Meel and Seider (2006), dynamic risk assessment that will be used to calculate the failure probability using Bayesian theory can be implemented through four step by step procedures.

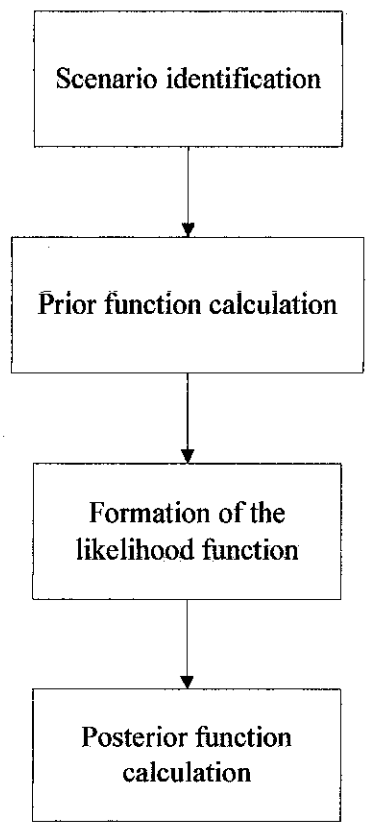


Figure 3.1 Methodology flow chart

Step 1: Scenario identification

During this step, most likely scenarios, types of failures and end-states linked to the incident are identified followed by initiating unusual events and all safety systems installed to the process system that served as protective layers in the case of event occurrence. Event tree analysis is then conducted using all the information obtained that will give a clearer picture on relations between failure and success of each safety system together with it possible end-states.

Step 2: Prior function calculation

All information on the safety barriers and its failure frequencies is then used to form the event tree for the chosen scenario. Basically, the information obtained to form the event tree is the design stage data from plant specific data and expert opinion that later being used to calculate the prior (failure probabilities) of the system.

The prior probabilities for every end state are calculated and result obtained is the static probabilities which the real time data is not counted for. Calculation of every end state is done base on the event tree which yield different value of end state for different event tree.

Step 3: Formation of the likelihood function

Number of near misses and incident occur recorded every year within the study period is also known as accident sequence precursor (ASP) data that usually contain number of process upsets, shutdowns and any form of failures characterized in the event tree. ASP is a real time data that will be used to form the likelihood function.

The most convenient likelihood function selected is the conjugate pair of the prior function where beta and binomial distributions are one of them. Binomial distribution is a perfect match since ASP data are best presented by binomial distribution.

The defined likelihood function is:

$$f(Data|x) = \binom{n}{s} x^s (1-x)^f \text{ (Kalantarnia, 2009)}$$

where $f(Data|x)$ is the likelihood function, n is total no of trials, s is the number of success and f is the number or failures$(n-s)$.

Step 4: Posterior function calculation

Posterior distribution or updated information about end-states of the system can be obtained after calculating the posterior function calculation. Posterior function is formed by combination of failure probability (prior) of the system and likelihood functions using Bayesian theorem. Equation that formulated this function is:

$$f(x|Data) \propto f(Data|x)f(x) \text{ (Kalantarnia, 2009)}$$

where $f(x|Data)$ is the posterior function, $f(Data|x)$ is the likelihood function and $f(x)$ is the prior.

This step has been simplified that mean value posterior for every event is calculated using formula below:

$$Mean\ Value\ Posterior = \frac{a+F}{a+F+b+S} \text{ (Kalantarnia, 2009)}$$

Where a and b is distribution parameter at design stage data, F is no of failure and S is the no of success for equipment safety system.

All the calculation is done using Microsoft Excel Visual Basic for Application® (VBA) that acts as a tool for calculation of dynamic failure probabilities. A user friendly tool for calculation of the probabilities is build using VBA coding that prompt the result after button "Calculate" is clicked. The coding is done based on literature by Jacobson (2007) and Berk and Carey (2007). This tool can ease the process of updating the dynamic failure probabilities for the equipment every year.

The case study for the validation of the tool is based on the literature by Kalantarnia (2009) where a dynamic failure assessment is done on the compressor (offshore process facilities). Based on event tree and data from the literature, the coding is developed. The tool is later validated using data from the same literature.

CHAPTER 4

RESULTS AND DISCUSSION

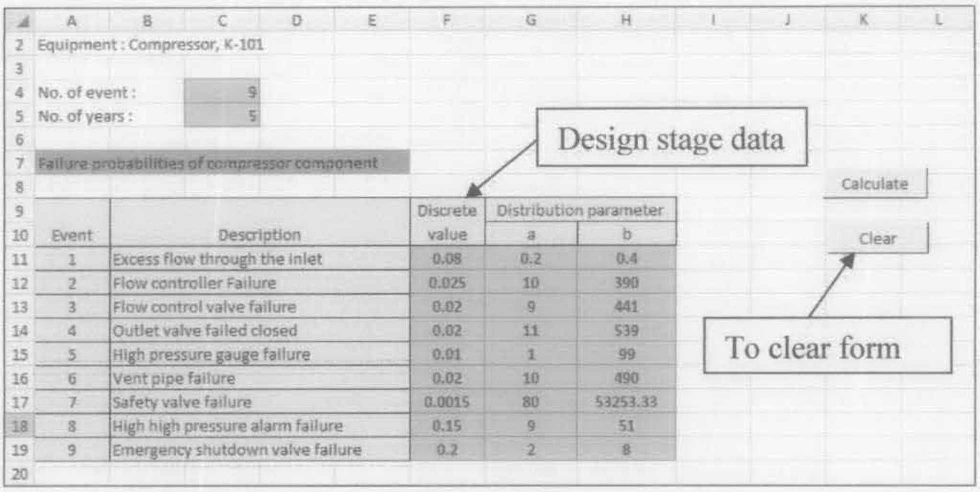
4.1 RESULTS

The result section is divided into two sections which are the result for calculation tool as well as the result for the case study which is the compressor on the offshore facilities.

4.1.1 Calculation Tool

A tool for calculation of posterior probabilities has been developed using Microsoft Excel Visual Basic for Application® (VBA). The tool is meant to be used by plant operator and is designed to be user friendly with simple user interface. The tool is validated using result published in literature by Kalantarnia (2009) where a case study on compressor in the offshore facilities has been chosen.

The tool consists of 3 worksheets where the first sheet serves as interface for user input. The second sheet is the output sheet where result of posterior parameter and mean value posterior calculation are stored and the last sheet prompt the result of the calculation that consist of prior and posterior frequency of all end states of the event. Charts based on the result is predefined and categorized according to types of end state. All the component will be automatically update if the button "Calculate" is clicked whenever new data or update is filled in. The overview of the tools is shown in figure 4.1, figure 4.2, figure 4.3 and figure 4.4. VBA coding for the worksheet is attached in the appendix 1, 2 and 3.



Equipment : Compressor, K-101

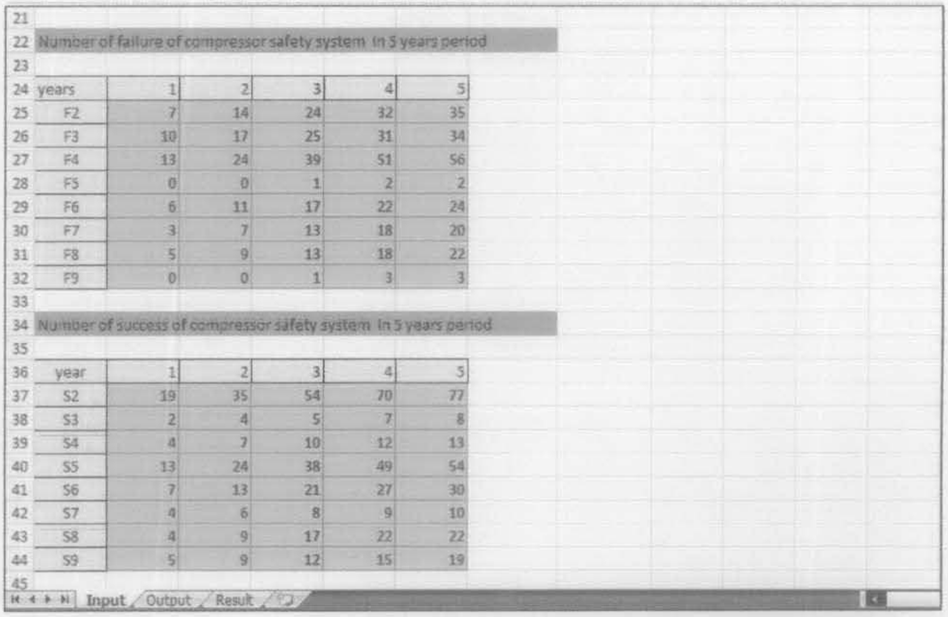
No. of event : 9

No. of years : 5

Failure probabilities of compressor component

Event	Description	Discrete value	Distribution parameter a	b
1	Excess flow through the inlet	0.08	0.2	0.4
2	Flow controller Failure	0.025	10	390
3	Flow control valve failure	0.02	9	441
4	Outlet valve failed closed	0.02	11	539
5	High pressure gauge failure	0.01	1	99
6	Vent pipe failure	0.02	10	490
7	Safety valve failure	0.0015	80	53253.33
8	High high pressure alarm failure	0.15	9	51
9	Emergency shutdown valve failure	0.2	2	8

Figure 4.1 Input worksheet – part 1



Number of failure of compressor safety system in 5 years period

years	1	2	3	4	5
F2	7	14	24	32	35
F3	10	17	25	31	34
F4	13	24	39	51	56
F5	0	0	1	2	2
F6	6	11	17	22	24
F7	3	7	13	18	20
F8	5	9	13	18	22
F9	0	0	1	3	3

Number of success of compressor safety system in 5 years period

year	1	2	3	4	5
S2	19	35	54	70	77
S3	2	4	5	7	8
S4	4	7	10	12	13
S5	13	24	38	49	54
S6	7	13	21	27	30
S7	4	6	8	9	10
S8	4	9	17	22	22
S9	5	9	12	15	19

Figure 4.2 Input worksheet – part 2

Posterior parameter of beta distribution (a+F)

Event \ Year	1	2	3	4	5
2	17	24	34	42	45
3	19	26	34	40	43
4	24	35	50	62	67
5	1	1	2	3	3
6	16	21	27	32	34
7	83	87	93	98	100
8	14	18	22	27	31
9	2	2	3	5	5

Posterior parameter of beta distribution (b+S)

Event \ Year	1	2	3	4	5
2	409	425	444	460	467
3	443	445	446	448	449
4	543	546	549	551	552
5	112	123	137	148	153
6	497	503	511	517	520
7	53257.33	53259.33	53261.33	53262.33	53263.33
8	55	60	68	73	73
9	13	17	20	23	27

Mean Value Posterior

Event \ Year	1	2	3	4	5
2	0.0399	0.0535	0.0711	0.0837	0.0879
3	0.0411	0.0552	0.0708	0.0820	0.0874
4	0.0423	0.0602	0.0835	0.1011	0.1082
5	0.0088	0.0081	0.0144	0.0199	0.0192
6	0.0312	0.0401	0.0502	0.0583	0.0614
7	0.0016	0.0016	0.0017	0.0018	0.0019
8	0.2029	0.2308	0.2444	0.2700	0.2981
9	0.1333	0.1053	0.1304	0.1786	0.1563

Input | Output | Result

Figure 4.3. Output worksheet

End States	Category	Prior Frequency	Posterior Frequency				
			1	2	3	4	5
1	A	9.56E-01	9.21E-01	8.94E-01	8.63E-01	8.41E-01	8.32E-01
2	A	1.91E-02	3.78E-02	4.91E-02	6.03E-02	6.75E-02	7.11E-02
3	A	3.78E-04	1.60E-03	2.99E-03	5.13E-03	7.00E-03	7.93E-03
4	B	4.82E-07	1.99E-06	3.76E-06	6.77E-06	9.40E-06	1.04E-05
5	B	6.81E-08	4.39E-07	1.01E-06	1.90E-06	2.86E-06	3.74E-06
6	C	1.70E-08	6.76E-08	1.19E-07	2.86E-07	6.21E-07	6.93E-07
7	B	6.56E-06	4.12E-05	9.63E-05	2.05E-04	3.17E-04	3.65E-04
8	B	9.27E-07	9.09E-06	2.58E-05	5.77E-05	9.63E-05	1.31E-04
9	C	2.32E-07	1.40E-06	3.04E-06	8.66E-06	2.09E-05	2.42E-05
10	C	3.90E-06	1.48E-05	2.54E-05	7.90E-05	1.51E-04	1.66E-04
11	A	2.45E-02	3.82E-02	5.02E-02	6.52E-02	7.52E-02	7.84E-02
12	A	4.84E-04	1.62E-03	3.06E-03	5.55E-03	7.80E-03	8.74E-03
13	B	6.19E-07	2.01E-06	3.85E-06	7.32E-06	1.05E-05	1.15E-05
14	B	8.73E-08	4.44E-07	1.03E-06	2.06E-06	3.18E-06	4.13E-06
15	C	2.18E-08	6.83E-08	1.21E-07	3.09E-07	6.92E-07	7.64E-07
16	B	8.42E-06	4.16E-05	9.85E-05	2.22E-04	3.53E-04	4.02E-04
17	B	1.19E-06	9.18E-06	2.64E-05	6.24E-05	1.07E-04	1.44E-04
18	C	2.97E-07	1.41E-06	3.11E-06	9.36E-06	2.33E-05	2.67E-05
19	C	5.00E-06	1.49E-05	2.60E-05	8.54E-05	1.68E-04	1.83E-04

Figure 4.4 Result worksheet

4.1.2 Case Study - Compressor

Compressor is a part of process plant on the offshore facilities. The function of the compressor is to increase the pressure of the gas by reducing the volume. The compressor is located in the process area and received gas from separator after it has been separated from the crude oil (Khan et al., 2002). The location of the compressor in the process is shown in figure 4.5 while its safety system is shown in figure 4.6. The possible end state for the event tree of excess flow to the compressor is divided into three which are:

a) End state A – Continue Operation Safely
b) End state B – Process Shutdown
c) End state C – High Pressure Release

According to Khan et al. (2002) the end state C which is high pressure release of the gas may lead to occurrence of jet fire if there is source of ignition available.

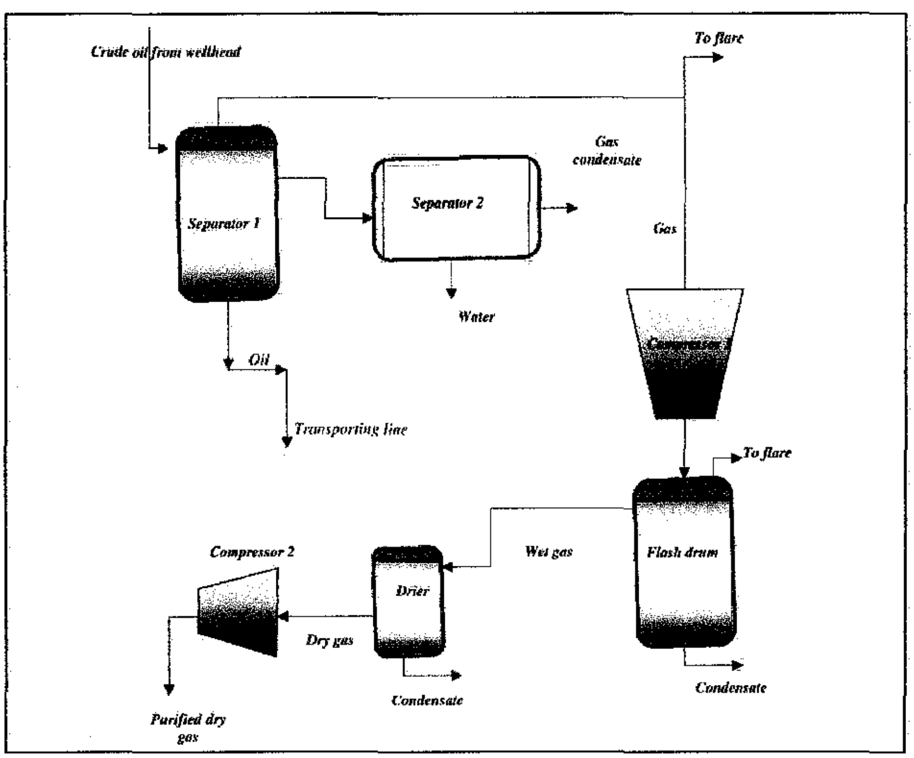


Figure 4.5 Process Flow Diagram for offshore process facilities (Khan et al., 2002)

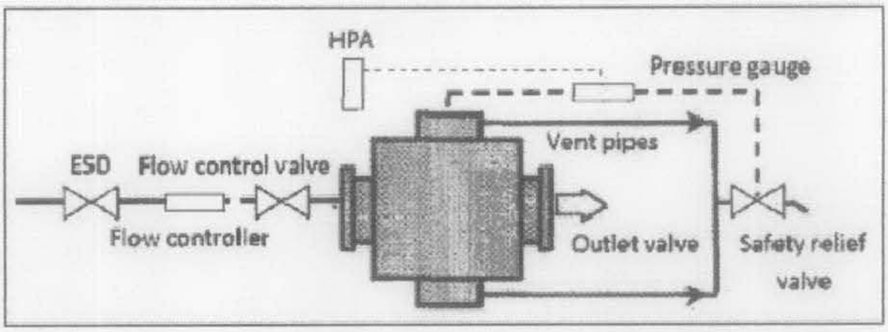


Figure 4.6 Gas compressor and safety system (Kalantarnia, 2009)

The final result calculated using the tool which is the dynamic failure probabilities of the compressor is shown in table below:

Table 4.1. Prior Frequency and Posterior Frequency for Each End State

End States	Category	Prior Frequency	Posterior Frequency				
			1	2	3	4	5
1	A	9.56E-01	9.21E-01	8.94E-01	8.63E-01	8.41E-01	8.32E-01
2	A	1.91E-02	3.78E-02	4.91E-02	6.03E-02	6.75E-02	7.11E-02
3	A	3.78E-04	1.60E-03	2.99E-03	5.13E-03	7.00E-03	7.93E-03
4	B	4.82E-07	1.99E-06	3.76E-06	6.77E-06	9.40E-06	1.04E-05
5	B	6.81E-08	4.39E-07	1.01E-06	1.90E-06	2.86E-06	3.74E-06
6	C	1.70E-08	6.76E-08	1.19E-07	2.86E-07	6.21E-07	6.93E-07
7	B	6.56E-06	4.12E-05	9.63E-05	2.05E-04	3.17E-04	3.65E-04
8	B	9.27E-07	9.09E-06	2.58E-05	5.77E-05	9.63E-05	1.31E-04
9	C	2.32E-07	1.40E-06	3.04E-06	8.66E-06	2.09E-05	2.42E-05
10	C	3.90E-06	1.48E-05	2.54E-05	7.90E-05	1.51E-04	1.66E-04
11	A	2.45E-02	3.82E-02	5.02E-02	6.52E-02	7.52E-02	7.84E-02
12	A	4.84E-04	1.62E-03	3.06E-03	5.55E-03	7.80E-03	8.74E-03
13	B	6.19E-07	2.01E-06	3.85E-06	7.32E-06	1.05E-05	1.15E-05
14	B	8.73E-08	4.44E-07	1.03E-06	2.06E-06	3.18E-06	4.13E-06
15	C	2.18E-08	6.83E-08	1.21E-07	3.09E-07	6.92E-07	7.64E-07
16	B	8.42E-06	4.16E-05	9.85E-05	2.22E-04	3.53E-04	4.02E-04
17	B	1.19E-06	9.18E-06	2.64E-05	6.24E-05	1.07E-04	1.44E-04
18	C	2.97E-07	1.41E-06	3.11E-06	9.36E-06	2.33E-05	2.67E-05
19	C	5.00E-06	1.49E-05	2.60E-05	8.54E-05	1.68E-04	1.83E-04

4.2 DISCUSSION

4.2.1 Calculation Tool

The validation is done to ensure that this tool is working and it is possible to use VBA coding to develop tools calculation of dynamic failure probability. Result yield in the output worksheet which is the posterior parameter for *a* and *b* as well as the mean value posterior is 100% matching the one calculated by Kalantarnia in her thesis. As for posterior probabilities, the result also 100% matching with result published by Kalantarnia.

4.2.2 Case Study – Compressor

The results yields from the tool are represented in graph (figure 4.6, figure 4.7 and figure 4.8) below:

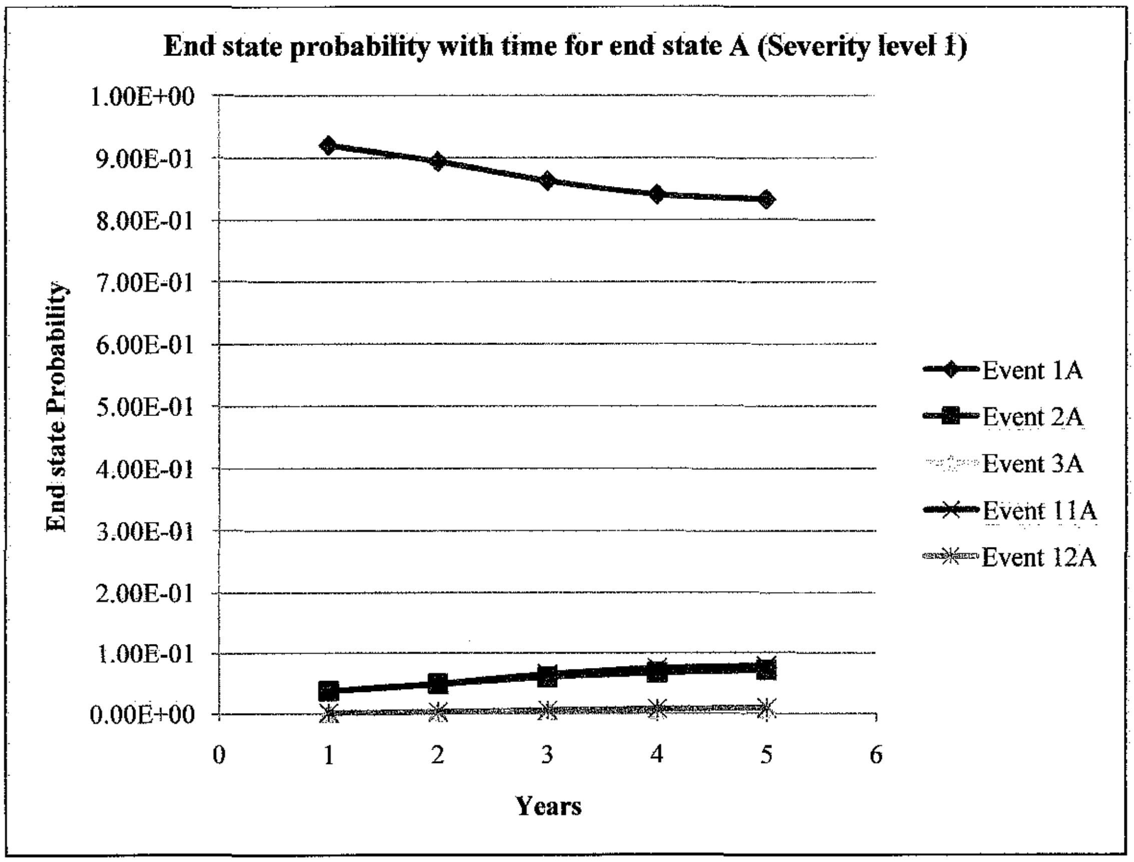


Figure 4.7 End State Probability with Time for End State A

The graph shows the probability of occurrence of end state A is decreasing for event 1A while the others show a slight increase in the probability. Event 1A is the result of success of flow controller and flow control valve of the compressor safety system. It is shown here that the probability of the success is reducing over time and preventative measure must be taken before unwanted incident occurred. As for the rest, the probability of occurrence of event A which allow the operation to continue safely is increasing by time. This may due to maintenance done over the component involved that increase the probability to continue operation safely.

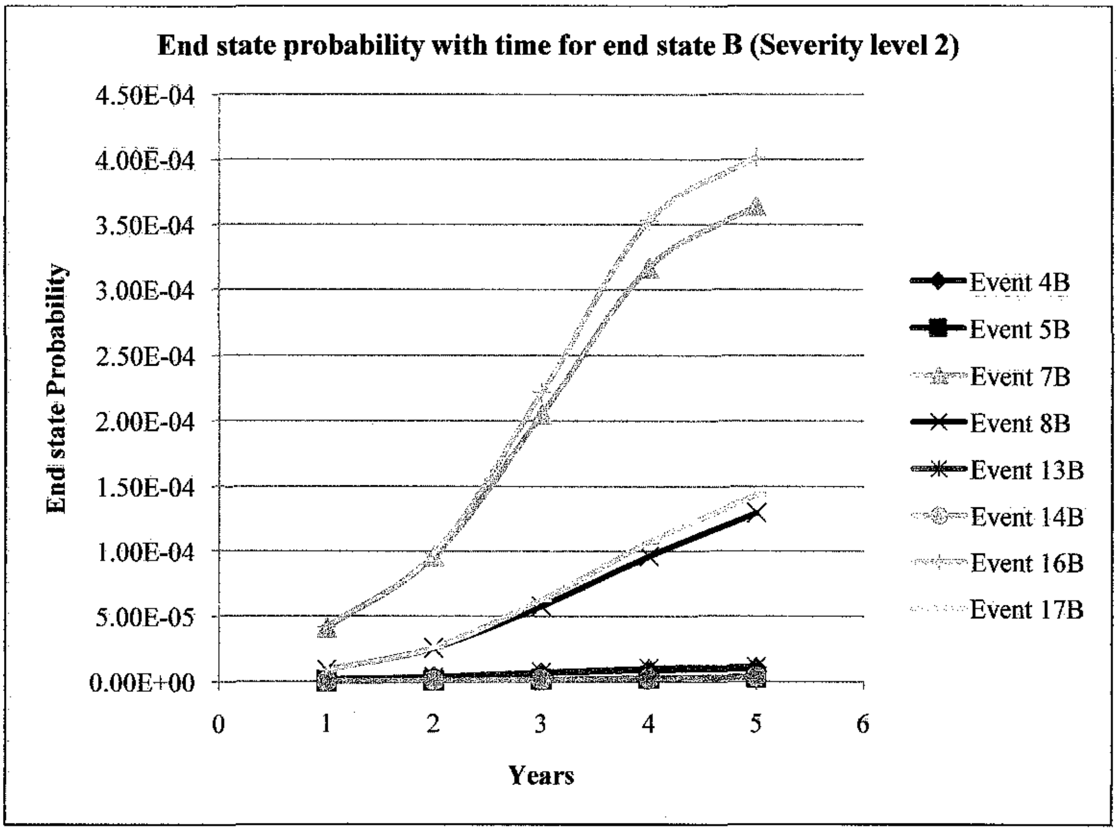


Figure 4.8 End State Probability with Time for End State B

Result has shown that for End state B, all events shows increment in probability over years. The highest probability that contributes towards process shutdown is event 16B and followed by event 7B. Both events are resulted from failure of control valve, outlet valve, vent pipes but success of high pressure alarm that lead to process shutdown. Assessment using dynamic failure probability has shown that probability of occurrence of event that lead to process shutdown in increasing over years. Action can be taken in the form of maintenance to make sure all related safety system are in good measures to prevent process shutdown that can cause losses to productivity.

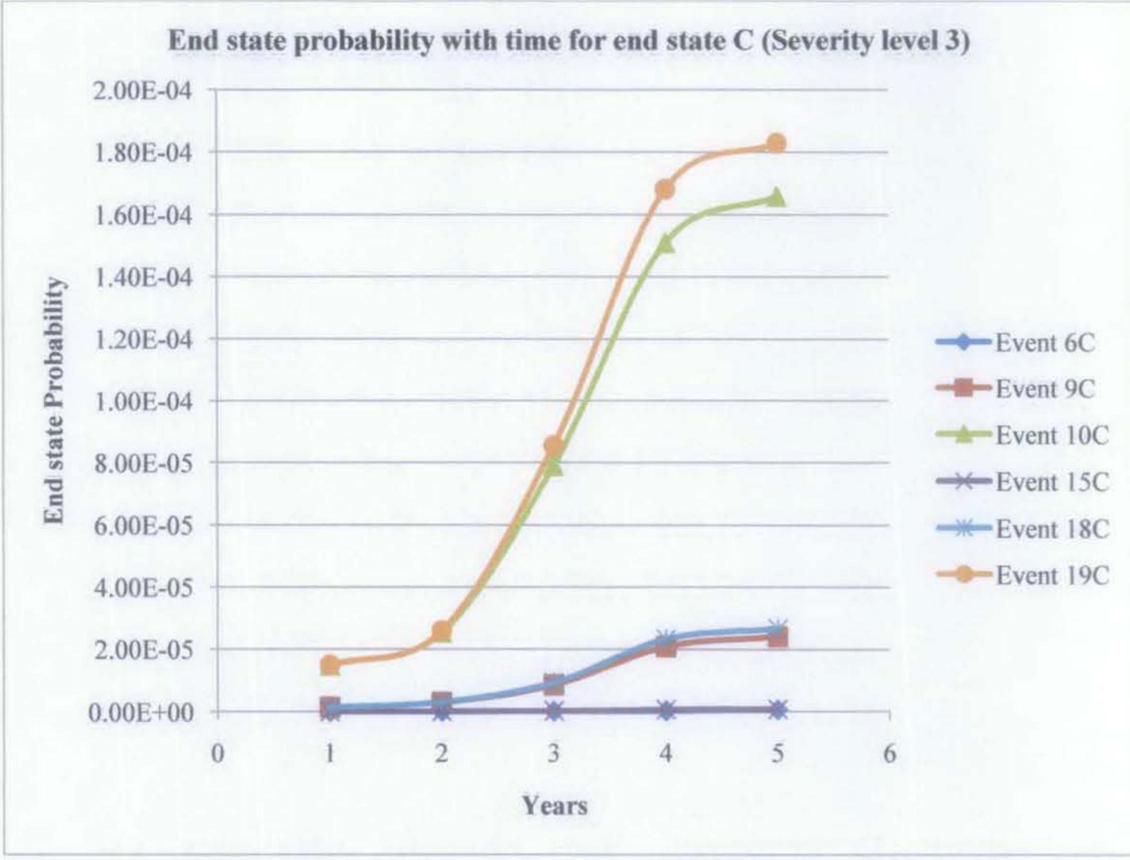


Figure 4.9 End State Probability with Time for End State C

From the graph, it can be observed that all probability is increasing over the years. This is mean that probability of high pressure release of gas is increasing throughout the operation of the compressor. Event 19C has the highest probability followed by event 10C. Both events are resulted from failure of outlet valve and high pressure gauge where once the high pressure gauge is failed, release of high pressure gas will occur. This indicate that both outlet valve and high pressure gauge need extra care in term of maintenance and safety procedure since failure of both can lead to catastrophic disaster such as jet fire. The consequence for all end states can be calculated by multiply the probabilities with dollar value according to severity of the end state.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

After conducting study on the project, it is found that this project is significant due to ability of dynamic risk assessment to estimate failure probability over time. This method can improve the weakness of available method that is static and depending upon one time judgment. The project has achieved all its objectives where the main objectives to develop tools for calculation of Dynamic Failure Assessment using Bayesian Theorem using Microsoft Excel Visual Basic for Application (VBA) software. The tool is proven working and had been validated using published result. This shows that it is possible to develop a tool for this assessment using VBA coding. Dynamic failure assessment on a case study which is compressor on offshore process facilities also has been successfully conducted based on data and event tree from literature.

5.2 RECOMMENDATION

There are several recommendation can be made for further improvement of the project. The recommendations are:

a) To generalize the application of the tools where with extra resource and time, it is possible to improve the limitation of the tool that is specifically for specified event tree.
b) To improve the user interface of the tool and make it possible to integrate the tools with another software in process industry.
c) To expand the case study to cover a unit in a process plant.
d) To include consequence analysis in the study and tool.

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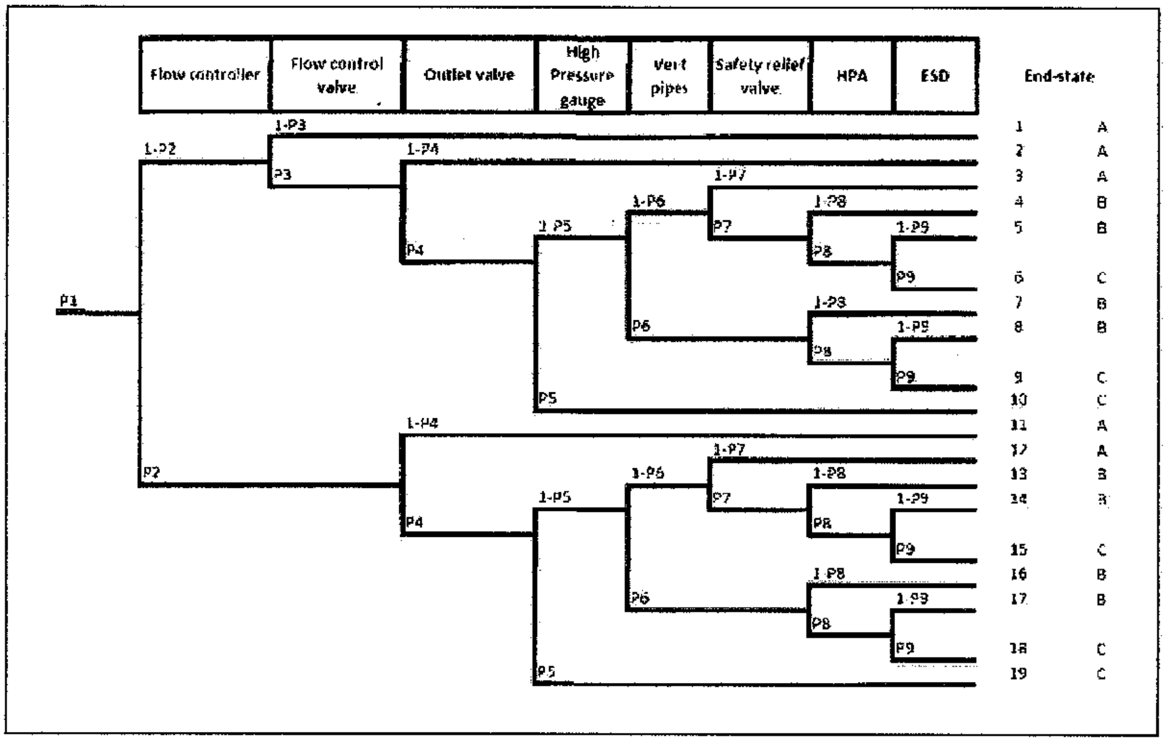
APPENDICES

Appendix A: Event tree for scenario excess flow to compressor (Kalantarnia, 2009)



Appendix B: Project Timeline (Final Year Project I)

No	Detail/Week	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 Defence						■								
4	Proposal Defence								■	■					
5	Project Work Continues										■	■	■		
6	Submission of Interim Draft Report													■	
7	Submission of Interim Report														■

Appendix C: Project Timeline (Final Year Project II)

No	Detail/Week	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 EDX															
5	Submission of Draft Report, Dissertation (Soft Copy) and Technical Paper															
6	Oral Presentation															
7	Submission of Project Dissertation (Hard Copy)															

Work completed   Work Planned

Appendix D: VBA Coding for calculation of posterior parameter and mean value posterior

```
Sub a_F()

Dim x, n, a, b As Double

a = Cells(5, 3)
b = Cells(4, 3) - 1

 For n = 1 To a

   For x = 1 To b

    Sheets("Output").Cells(3 + x, 1 + n) = Cells(11 + x, 7) + Cells(24 + x, 1 + n)


   Next x

Next n


End Sub


Sub b_S()

Dim x, n, a, b As Double

a = Cells(5, 3)
b = Cells(4, 3) - 1

 For n = 1 To a

   For x = 1 To b

    Sheets("Output").Cells(14 + x, 1 + n) = Cells(11 + x, 8) + Cells(36 + x, 1 + n)


   Next x

Next n

End Sub

Sub mean_value_posterior()
Dim x, n, a, b As Double

a = Cells(5, 3)
b = Cells(4, 3) - 1

 For n = 1 To a

   For x = 1 To b

    Sheets("Output").Cells(25 + x, 1 + n) = Sheets("Output").Cells(3 + x, 1 + n) /
(Sheets("Output").Cells(3 + x, 1 + n) + Sheets("Output").Cells(14 + x, 1 + n))


   Next x

Next n

End Sub
```

Appendix E: VBA Coding for calculation of prior frequency

```
'For Prior Frequency

Sub EndState_1()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_1 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value


    EndState_1 = (1 - MVP_2) * (1 - MVP_3)

    Sheets("Result").Range("D4").Value = EndState_1
End Sub

Sub EndState_2()

    Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_2 As
Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_2 = (1 - MVP_2) * (MVP_3) * (1 - MVP_4)

    Sheets("Result").Range("D5").Value = EndState_2

End Sub

Sub EndState_3()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_3 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
```

```
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_3 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * (1 - MVP_7)

    Sheets("Result").Range("D6").Value = EndState_3

End Sub

Sub EndState_4()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_4 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_4 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * (1 -
MVP_8)

    Sheets("Result").Range("D7").Value = EndState_4
End Sub

Sub EndState_5()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_5 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_5 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8
* (1 - MVP_9)

    Sheets("Result").Range("D8").Value = EndState_5
End Sub
```

```
Sub EndState_6()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_6 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_6 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8
* MVP_9

    Sheets("Result").Range("D9").Value = EndState_6
End Sub

Sub EndState_7()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_7 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_7 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * (1 - MVP_8)

    Sheets("Result").Range("D10").Value = EndState_7
End Sub

Sub EndState_8()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_8 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value
```

```
    EndState_8 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * (1 - MVP_9)

    Sheets("Result").Range("D11").Value = EndState_8
End Sub

Sub EndState_9()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_9 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_9 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * MVP_9

    Sheets("Result").Range("D12").Value = EndState_9
End Sub

Sub EndState_10()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_10 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_10 = (1 - MVP_2) * MVP_3 * MVP_4 * MVP_5

    Sheets("Result").Range("D13").Value = EndState_10
End Sub

Sub EndState_11()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_11 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
```

```
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_11 = MVP_2 * (1 - MVP_4)

    Sheets("Result").Range("D14").Value = EndState_11
End Sub

Sub EndState_12()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_12 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_12 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * (1 - MVP_7)

    Sheets("Result").Range("D15").Value = EndState_12
End Sub

Sub EndState_13()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_13 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_13 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * (1 - MVP_8)

    Sheets("Result").Range("D16").Value = EndState_13
End Sub

Sub EndState_14()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_14 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
```

```
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_14 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8 * (1 - MVP_9)

    Sheets("Result").Range("D17").Value = EndState_14
End Sub

Sub EndState_15()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_15 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_15 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8 * MVP_9

    Sheets("Result").Range("D18").Value = EndState_15
End Sub

Sub EndState_16()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_16 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_16 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * (1 - MVP_8)

    Sheets("Result").Range("D19").Value = EndState_16
End Sub

Sub EndState_17()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_17 As Double
```

```
    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_17 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * (1 - MVP_9)

    Sheets("Result").Range("D20").Value = EndState_17
End Sub

Sub EndState_18()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_18 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_18 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * MVP_9

    Sheets("Result").Range("D21").Value = EndState_18
End Sub

Sub EndState_19()
Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9, EndState_19 As Double

    MVP_2 = Sheets("Input").Range("F12").Value
    MVP_3 = Sheets("Input").Range("F13").Value
    MVP_4 = Sheets("Input").Range("F14").Value
    MVP_5 = Sheets("Input").Range("F15").Value
    MVP_6 = Sheets("Input").Range("F16").Value
    MVP_7 = Sheets("Input").Range("F17").Value
    MVP_8 = Sheets("Input").Range("F18").Value
    MVP_9 = Sheets("Input").Range("F19").Value

    EndState_19 = MVP_2 * MVP_4 * MVP_5

    Sheets("Result").Range("D22").Value = EndState_19
End Sub
```

Appendix F: VBA Coding for calculation of posterior frequency

```
Sub EndState_Finale()

    Dim x, n, a, c As Double
    Dim MVP_1, MVP_2, MVP_3, MVP_4, MVP_5, MVP_6, MVP_7, MVP_8, MVP_9 As Double
    Dim EndState_1, EndState_2, EndState_3, EndState_4, EndState_5, EndState_6,
EndState_7, EndState_8 As Double
    Dim EndState_9, EndState_10, EndState_11, EndState_12, EndState_13, EndState_14,
EndState_15, EndState_16 As Double
    Dim EndState_17, EndState_18, EndState_19 As Double

a = Cells(5, 3)



For n = 1 To a

    MVP_2 = Sheets("Output").Cells(26, 1 + n)
    MVP_3 = Sheets("Output").Cells(27, 1 + n)
    MVP_4 = Sheets("Output").Cells(28, 1 + n)
    MVP_5 = Sheets("Output").Cells(29, 1 + n)
    MVP_6 = Sheets("Output").Cells(30, 1 + n)
    MVP_7 = Sheets("Output").Cells(31, 1 + n)
    MVP_8 = Sheets("Output").Cells(32, 1 + n)
    MVP_9 = Sheets("Output").Cells(33, 1 + n)


    EndState_1 = (1 - MVP_2) * (1 - MVP_3)
    EndState_2 = (1 - MVP_2) * (MVP_3) * (1 - MVP_4)
    EndState_3 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * (1 - MVP_7)
    EndState_4 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * (1 -
MVP_8)
    EndState_5 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8
* (1 - MVP_9)
    EndState_6 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8
* MVP_9
    EndState_7 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * (1 - MVP_8)
    EndState_8 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * (1 - MVP_9)
    EndState_9 = (1 - MVP_2) * MVP_3 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * MVP_9
   EndState_10 = (1 - MVP_2) * MVP_3 * MVP_4 * MVP_5
   EndState_11 = MVP_2 * (1 - MVP_4)
   EndState_12 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * (1 - MVP_7)
   EndState_13 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * (1 - MVP_8)
   EndState_14 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8 * (1 - MVP_9)
   EndState_15 = MVP_2 * MVP_4 * (1 - MVP_5) * (1 - MVP_6) * MVP_7 * MVP_8 * MVP_9
   EndState_16 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * (1 - MVP_8)
```

```
EndState_17 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * (1 - MVP_9)
EndState_18 = MVP_2 * MVP_4 * (1 - MVP_5) * MVP_6 * MVP_8 * MVP_9
EndState_19 = MVP_2 * MVP_4 * MVP_5


    Sheets("Result").Cells(4, 4 + n) = EndState_1
    Sheets("Result").Cells(5, 4 + n) = EndState_2
    Sheets("Result").Cells(6, 4 + n) = EndState_3
    Sheets("Result").Cells(7, 4 + n) = EndState_4
    Sheets("Result").Cells(8, 4 + n) = EndState_5
    Sheets("Result").Cells(9, 4 + n) = EndState_6
    Sheets("Result").Cells(10, 4 + n) = EndState_7
    Sheets("Result").Cells(11, 4 + n) = EndState_8
    Sheets("Result").Cells(12, 4 + n) = EndState_9
    Sheets("Result").Cells(13, 4 + n) = EndState_10
    Sheets("Result").Cells(14, 4 + n) = EndState_11
    Sheets("Result").Cells(15, 4 + n) = EndState_12
    Sheets("Result").Cells(16, 4 + n) = EndState_13
    Sheets("Result").Cells(17, 4 + n) = EndState_14
    Sheets("Result").Cells(18, 4 + n) = EndState_15
    Sheets("Result").Cells(19, 4 + n) = EndState_16
    Sheets("Result").Cells(20, 4 + n) = EndState_17
    Sheets("Result").Cells(21, 4 + n) = EndState_18
    Sheets("Result").Cells(22, 4 + n) = EndState_19


Next n


End Sub
```