Reliability Block Diagram Assessment of Ethylene Oxide Production Facilities

by
Mohamad Nashakir bin Md Dom

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(Dr Ainul Akmar binti Mokhtar)

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.

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MOHAMAD NASHAKIR BIN MD DOM

ABSTRACT

Reliability block diagram assessment of ethylene oxide production facilities. Having a maintenance plan by referring to the OEM manual is not the optimum time interval. The manual usually created to follow the failure rate of the equipment in a general operating range and condition, and tested independently. Difficulty in having optimal maintenance plan is the accuracy of the data and the equipment modeling. Accuracy in the data usually is very low therefore creating optimum strategy is the best solution. In the study component prioritization is the strategy based on risk. Focused on the developing the reliability block diagram for the ethylene oxide production facilities.

ACKNOWLEDGEMENTS

In the name of Allah, The most Merciful and Compassionate, praise to Allah, He is the Almighty. Eternal blessings and peace upon to the Glory of the Universe, our Beloved Prophet Muhammad (S.A.W.), his family and companions.

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Abbreviations and Nomenclatures

EtO	Ethylene Oxide
RBD	Reliability Block Diagram
FTA	Fault Tree Analysis
OEM	Original Equipment Manufacturer
RBM	Risk Based Maintenance
β	Slope or shape factor of Weibull distribution
η	characteristic life of the component
σ	Mean availability
MTTF	Mean time to failure
RGGG	Reliability graph with general gates
RBDGG	Reliability block diagram with general gates

CHAPTER 1

INTRODUCTION

1. Introduction

Ethylene oxide (EtO) is a flammable, colorless gas at temperatures above 51.3 °F (10.7 °C) that smells like ether at toxic levels. Ethylene oxide mainly used as a chemical intermediate in the manufacture of textiles, detergents, polyurethane foam, antifreeze, solvents, medicinal, adhesives, and other products [4].

1.1. Background study

The manufacturing of EtO consist of ethylene at 95-98% purity and oxygen (air with 95 mole % of oxygen) are mixed in a ratio of 1:10 by weight and passed over a catalyst consisting of silver oxide deposited on an inert carrier such as corundum [3]. Generally an anti catalyst such as ethylene dioxide is added to the ethylene feed to suppress the formation of carbon dioxide. As an alternative, vent gases form the absorber may be recycled to the reactor in a quantity as to keep the ethylene concentration in the feed at 3-5% at pressure of 4-5 atmosphere and temperature of 270-300 ^{o}C. The effluent gases from the reactor are washed with water under pressure in an absorber. The ethylene is absorbed and sent to the absorber to absorb the water.

Common hazards exposures of EtO to human are eye pain and sore throat. More than that, exposure to EtO can cause difficulty in breathing and blurred vision. Exposure can also cause dizziness, nausea, headache, convulsions, blisters and can result in vomiting. Both human and animal studies show that EtO is a carcinogen that may cause leukemia and other cancers. EtO is also linked to spontaneous abortion, genetic damage, nerve damage, peripheral paralysis, muscle weakness, as well as impaired thinking and memory. In liquid form, EtO can cause severe skin irritation upon prolonged or confined contact [3].

Maintenance must be carried out to reduce the equipment failure that may lead to fire and excessive exposure to EtO. Unnecessary plant maintenance is typically related to cost and time, but in handling maintenance related to EtO, workers have to chance to have the exposure with EtO even though personal protective equipment such as goggles, protective clothing and mask are present.

The methodology provided by Khan & Haddara called risk-based maintenance (RBM) combined the reliability of the equipment and risk assessment [8]. How the equipment fail was observed and recorded. The most likely to fail equipments were inspected thoroughly. Then the failure consequences were created from the failure mode. From the data obtained fault tree analysis (FTA) was made and the probability of occurrence was placed in. Subsequently risk was calculated through the failure consequence data and probability from FTA. Later on, the risk was compared to the acceptable criteria developed. Finally, the frequency of the maintenance plan was computed by minimizing the estimated risk [7].

1.2. Problem Statement

Having a maintenance plan by referring to the OEM manual is not always the optimum solution. Usually maintenance manual was created to follow the failure rate of the equipment in a general operating range and weather condition, and that equipments are tested independently. The maintenance schedule should be generated by the plant engineer itself and the OEM manual is only as a reference. Factory that have been running for years at least have the failure data for the last two years to generate maintenance plan. However two years of failure data is sufficient but not enough so the having a longer failure data is better.

The key to have best possible maintenance plan is on the accuracy of the data. Usually the failure data accuracy is very low because some minor failure and trip case are not recorded. Some plant technician does modify data to hide the failure. The best solution provided by Khan and Haddara are implementing optimal maintenance plan [6].

Ethylene oxide (EtO) is a flammable gas and it smells like ether at high concentration. An optimal maintenance is needed to reduce the exposure of maintenance personnel to EtO. The gas has several health issues if exposed to human [3]. EtO needs proper handling because failures and risk to human exposure need to be minimized.

1.3. Objective and Scope of Study

The objective is assessment of ethylene oxide production facilities using reliability block diagram. The result will show the current state of the equipment and the critical components of the system. The sub objective is further assessment on the optimum maintenance interval. Later reinsert the maintenance interval data to the block diagram to identify the revised equipment state.

CHAPTER 2

LITERATURE REVIEW

2. Literature Review

2.1. Reliability Assessment

Reliability is a measure of probability of successful performance of the system to perform the required function over a period of time under stated condition [17]. Most components have the reliability characteristic following the so-called 'bath tub' curve shown in Figure 1. Failures during infant mortality are highly undesirable and are always caused by defects such as material defects, design blunders, errors in assembly, etc. Infant mortality failure decrease rapidly over time. At middle of the curve, normal life failures are normally considered random cases of stress exceeding strength. Most failures occurred during the normal life curve and the failure rate is even throughout the time. Wear-out failure is due to fatigue or depletion of materials such as lubrication depletion in bearings, worn out carbon in motor, rust on electrical contact area, etc. [18]

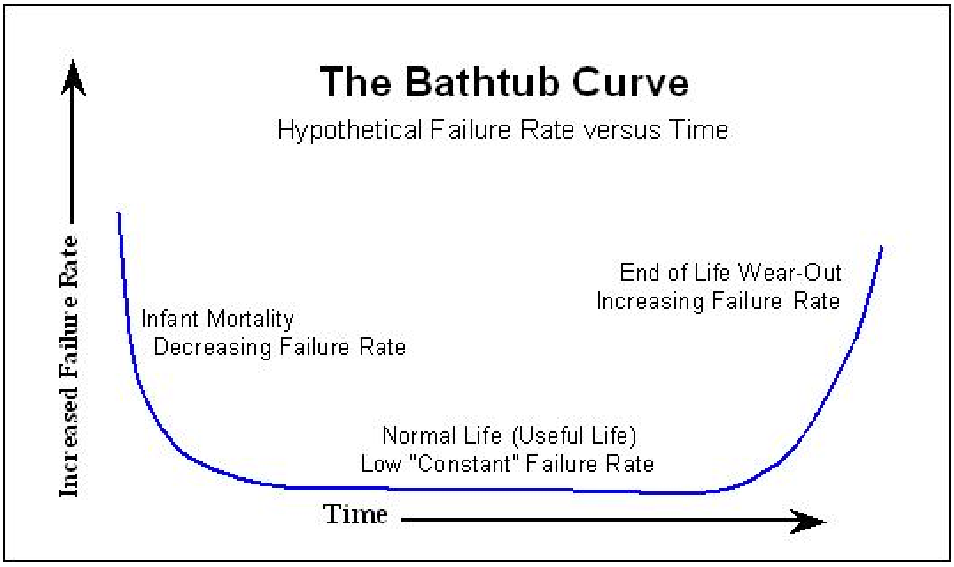

Figure 1: Reliability 'bath tub' curve [17]

The following steps involved in prediction of reliability of a system [14]:

- construction of reliability block diagram (RBD)
- perform failure mode and effect analysis (FMEA)
- determine the operational profile (uptime/downtime)
- derivation of time to failure distribution of each block
- compute the reliability function of each block
- compute the reliability function of the system

Maintainability is the ability of an equipment or system to be restored to the operation state using stated procedures and resources [16]. Corrective maintenance is carried out after failure happened to restore the system to the operating state. Preventive maintenance performed continuously at a time interval governed by trend of the failure by monitoring and diagnostic.

Availability is the probability of a system is in operational condition. for non repairable system availability is the same with reliability of the system. Availability of a system represent by Equation 1 .

$$Availability = \frac{Uptime\ of\ system}{Uptime\ of\ system + Downtime\ of\ system}$$

Equation 1

2.2. Reliability Block Diagram

A Reliability Block Diagram is a method of modeling how components and sub-system failures combine to cause system failure. It is a left right method from the main event at the left and the basic event at the right. The first level in the diagram are major subsystems and it is further broken down into minor subsystem. The block logical diagrams consist of blocks connected in series, parallel, standby or a combination. [19]

The structure depends on the effect of failure on each of the block. Block failure whose cause system failure is connected in series meanwhile block whose will not result in system failure is connected in parallel. The blocks represent a component or a subsystem and the connecting lines represent the failure connection but not necessarily represent physical connection between blocks. It only indicates how the functioning of the components reflects the functioning on the system. Analysis of reliability block diagram able to determine the critical components of the system. [20]

2.3. Khan & Haddara Method

This project refers Khan & Haddara's research on risk based maintenance of ethylene oxide production facilities. Khan & Haddara identified five systems that are critical to the production facilities that are Reaction unit, EO storage unit, Ethylene transportation line, Ethylene EO distillation column, and ethylene reboiler. The hazard rating is shown in Table 1. The research methodology and result were taken as a reference for the model development & comparison. The fault tree developed shown in **Error! Reference source not found.**.

Table 1: Summarized results of hazard identification in ethylene oxide production plant

Units	Chemical of concern	Type of major hazard	Fire and explosion damage index (FEDI)	Toxic damage index (TDI)	Hazard control index (HCI)	SWeHI = maximum (FEDI or TDI)/HCI
Ethylene transportation line	Ethylene	Fire and explosion	440.3	145.5	39.3	11.2 (H)
Reaction unit	Ethylene and ethylene oxide	Fire and explosion	575.4	177.5	35.0	16.5 (HH)
Ethylene oxide distillation column	Ethylene oxide	Fire and explosion	380.5	135.0	33.1	11.5 (H)
Reboiler	Ethylene oxide	Fire and explosion	281.7	106.5	26.8	10.5 (H)
Ethylene oxide storage	Ethylene oxide	Fire and explosion	541.5	165.7	30.9	17.5 (HH)

EH: extremely hazardous; HH: highly hazardous, H: hazardous, MH: moderately hazardous, LH: less hazardous, NH: not hazardous.

2.4. Methodology

The methodology used by Khan & Haddara is as follow [6]:

Module 1: Risk estimation
- Step 1: Failure scenario development for ethylene transportation
- Step 2: Consequence assessment
- Step 3: Fault tree development & analysis
- Step 4: Risk & quantification & estimation

Module 2: Risk evaluation

Step 1: Setting up acceptance criteria

Step 2: Risk comparison against acceptance criteria

Module 3: Maintenance planning

Step 1: Estimation & optimisation of maintenance duration

Step 2: Re-estimation & re-evaluation of risk

The software used by Khan & Haddara's research named PROFAT (PRObabilistic FAult Tree analysis) and it able to develop fault tree, Boolean matrix, finding minimum cutset & optimisation, probability analysis and improvement index estimation. [14]

2.5. Result

The Khan & Haddara's fault tree analysis indicates that component 1, 4,5,6,11,12 have significant contribution towards the failure as in Figure 2 &. Meanwhile components 7 and 13 to 25 have the very low contribution towards failure [6].

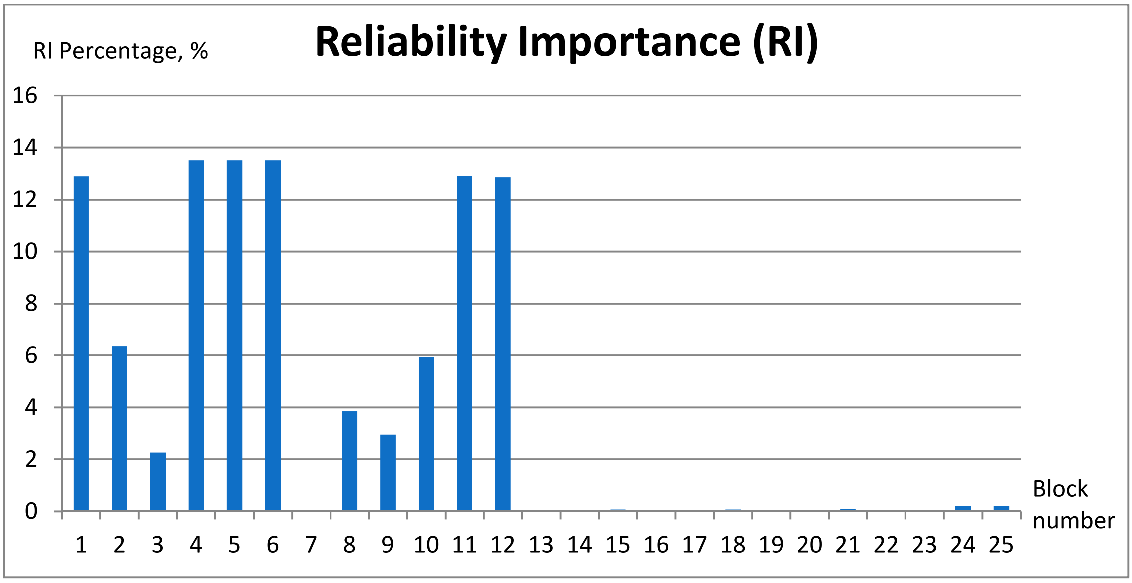

Figure 2: Reliability importance result from fault tree analysis [6]

From the identified critical components in Figure 2, Khan & Haddara generate maintenance interval and the result shown in Table 2. The maintenance is for equipment 1 to 6 and 8 to 12 [6].

Table 2: Preventive maintenance interval [6]

Average individual risk factor before and after add-on safety measures have been decided

Components[a]	Cost ($/improvement in reliability)	Improvement in reliability (x_i)	Revised failure probability (R_{latest})	Preventive maintenance interval (year)
1	15	2.81E−01	0.1704	0.506
2	20	4.18E−01	0.5817	0.0338
3	20	2.06E−01	0.1519	0.514
4	150	2.63E−02	0.1114	0.879
5	150	2.63E−02	0.1114	0.879
6	60	6.66E−02	0.1238	0.756
8	20	2.13E−01	0.1766	0.789
9	30	1.39E−01	0.1605	0.821
10	20	2.64E−01	0.3361	0.568
11	15	2.91E−01	0.1971	0.436
12	15	2.60E−01	0.1025	0.400

2.6. Reliability Importance

It is easy to identify weak or critical components in a simple system such as in a series. For complex systems, mathematical approach is needed to determine the critical component by calculating the importance value of each component in the system. Reliability Importance (I_R) measures the relative importance of each component in a system to the overall reliability of the system. The reliability importance value depends on the reliability and position of the component. The reliability importance, I_{Ri}, of component *i* in a system of *n* components is given by Leemis [13]:

$$I_R(t) = \frac{\delta R_s(t)}{\delta R_i(t)}$$

Equation 2

Where:

- $R_s(t)$ is the system reliability at a certain time, *t*
- $R_i(t)$ is the component reliability at a certain time, *t*

2.7. FTA & RBD difference

Fault tree analysis is a deductive failure analysis which focuses on one particular undesired event and which provides a method for determining causes of this event. The undesired event represents the top event in a fault tree diagram constructed for the system, and generally consists of a complete or catastrophic failure as mentioned above. Fault tree consist of primary events, intermediate event and the gate symbols [12].

A Reliability Block Diagram is a method of modeling how components and sub-system failures combine to cause system failure. The diagram is modeled from left to right and the components is component is connected through series or parallel. It start with an input node and ends with an output node. Blocks in the RBD represent the system component meanwhile the lines describe the connection between components [2].

The most primary difference between FTDs and RBDs is that in an RBD one is working in the success point of view, and thus looks at system successes combinations, while in a fault tree one works in the failure point of view and looks at system failure combinations [10]. Conventionally, fault trees have been used to access fixed probabilities while RBDs may have included time-varying distributions for the success reliability equation and other properties, such as repair/restoration distributions.

Fault trees are built using gates and events (blocks). The two most commonly used gates in a fault tree are the AND and OR gates. As an example, consider two events (or blocks) comprising a Top Event (or a system). If occurrence of either event causes the top event to occur, then these events (blocks) are connected using an OR gate. Alternatively, if both events need to occur to cause the top event to occur, they are connected by an AND gate. As a visualization example, consider the simple case of a system comprised of two components, A and B, and where a failure of either component causes system failure. The system RBD is made up of two blocks in series as shown next:

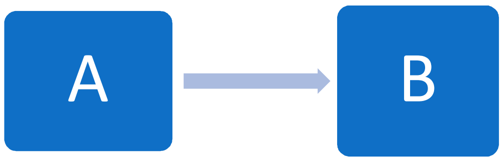

Figure 3: RBD in Series

The fault tree diagram for this system includes two basic events connected to an OR gate (which is the "Top Event"). For the "Top Event" to occur, either A or B must happen. In other words, failure of A OR B causes the system to fail.

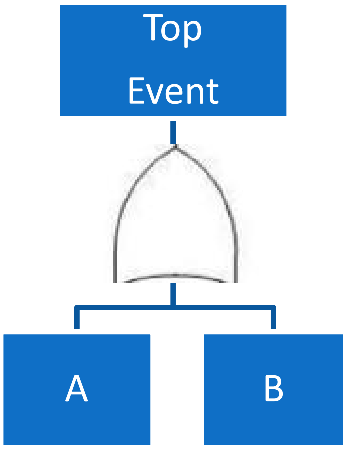

Figure 4: FTA connection by OR gate

2.8. FTA & RBD difference case study

Further discussion on both reliability assessment methods is discussed below. Both of the techniques have their strength and weakness but the main concept is identical. For the comparison failure distribution and corrective distribution of several failure modes data of a system obtained shown below [5].

- Block *1*:
  - Failure Distribution: Normal; $\mu = 1{,}000$; $\sigma = 200$.
  - Corrective Distribution: Normal; $\mu = 6$; $\sigma = 2$.
- Block *2*:
  - Failure Distribution: Weibull; $\beta = 3$; $\eta = 1{,}000$.
  - Corrective Distribution: Weibull; $\beta = 1.5$; $\eta = 20$.
- Block *3*:
  - Failure Distribution: Exponential; $\mu = 100{,}000$.
  - Corrective Distribution: Weibull; $\beta = 1.5$; $\eta = 10$.
- Block *4*:
  - Failure Distribution: Weibull; $\beta = 1.5$; $\eta = 1{,}000$.
  - Corrective Distribution: Weibull; $\beta = 1.5$; $\eta = 100$.
- Block *5*:
  - Failure Distribution: Weibull; $\beta = 1.5$; $\eta = 10{,}000$.
  - Corrective Distribution: Exponential; $\mu = 10$.
- Block *6*:

- Failure Distribution: Exponential; μ = 10,000.
  - Corrective Distribution: Weibull; β = 1.5; η = 20.
- Block *7*:
  - Failure Distribution: Weibull; β = 1.5; η = 5,000.
  - Corrective Distribution: Weibull; β = 1.5; η = 100.
- Block *8*:
  - Failure Distribution: Normal; μ = 5,000; σ = 50.
  - Corrective Distribution: Normal; μ = 10; σ = 2.

Blocks added to the diagram sheet. The failure distribution and corrective distribution as above inserted to the respective blocks. After all blocks have been inserted, the blocks are joined by parallel or series depends on the failure condition. From the completed diagram, simulation for 1000hours is generated and the result is shown below.

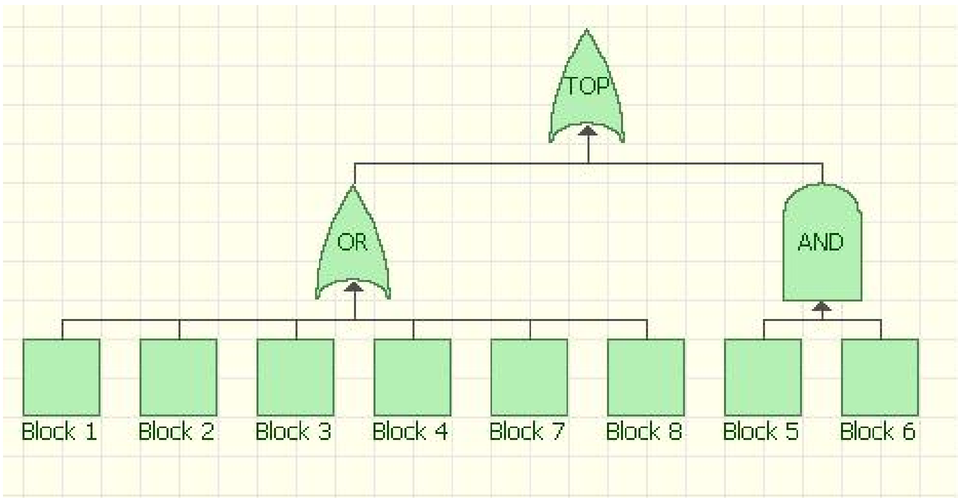

Figure 5: FTA Example

The fault tree analysis as in Figure 5 changed to block diagram as in Figure 6. The result in simulation Table and Table 4 shows that the mean availability for the whole system, mean time to failure, no of failures, uptime and downtime are identical. This result shows that analysis using both method have a similar output.

Table 3: FTA result from simulation

System Overview	
General	
Mean Availability (All Events):	0.9287
Std Deviation (Mean Availability):	0.0751
Mean Availability (w/o PM & Inspection):	0.9287
Point Availability (All Events) at 1000:	0.902
Reliability(1000):	0.147
Expected Number of Failures:	1.323
Std Deviation (Number of Failures):	0.8375
MTTFF:	723.4903
System Uptime/Downtime	
Uptime:	928.6637
CM Downtime:	71.3363
Inspection Downtime:	0
PM Downtime:	0
Total Downtime:	71.3363
System Downing Events	
Number of Failures:	1.323
Number of CMs:	1.323
Number of Inspections:	0
Number of PMs:	0
Total Events:	1.323
Costs	
Total Costs:	0
Throughput	
Total Throughput:	0

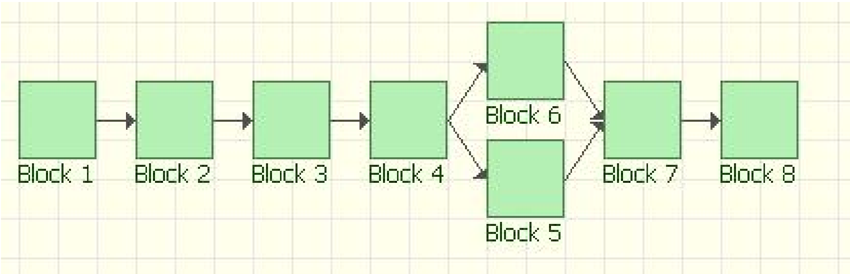

Figure 6: RBD Example

Table 4: RBD result from simulation

System Overview	
General	
Mean Availability (All Events):	0.9323
Std Deviation (Mean Availability):	0.0755
Mean Availability (w/o PM & Inspection):	0.9323
Point Availability (All Events) at 1000:	0.89
Reliability(1000):	0.179
Expected Number of Failures:	1.302
Std Deviation (Number of Failures):	0.8829
MTTFF:	775.8265
System Uptime/Downtime	
Uptime:	932.3089
CM Downtime:	67.6911
Inspection Downtime:	0
PM Downtime:	0
Total Downtime:	67.6911
System Downing Events	
Number of Failures:	1.301
Number of CMs:	1.301
Number of Inspections:	0
Number of PMs:	0
Total Events:	1.301
Costs	
Total Costs:	0
Throughput	
Total Throughput:	0

There are other methods for reliability assessment further than RBD and FTA. Reliability graph with general gates (RGGG) develop by Shin and Seong. Reliability graph with both node and arc failures are transformed to an equivalent graph with only arc failures in RGGG [11]. Main Cheol Kim develop the reliability block diagram with general gates (RBDGG) that able to adopt general gates to the RBD [1].

CHAPTER 3

METHODOLOGY

3. Methodology

To assess ethylene oxide transportation line using reliability block diagram requires several steps. All the process is calculations involving logic thinking and decision making skills.

3.1. Data Collection

The data needed are the individual component failures that have the probability to occur at the ethylene production line. It will be in the form of statistical distribution. The data collected are in Table 5.

3.2. Block Diagram Development

The methodology in the block diagram development is based on the generic RBD. The steps are:

3.2.1. Block diagram creation based on component failure (Figure 7)

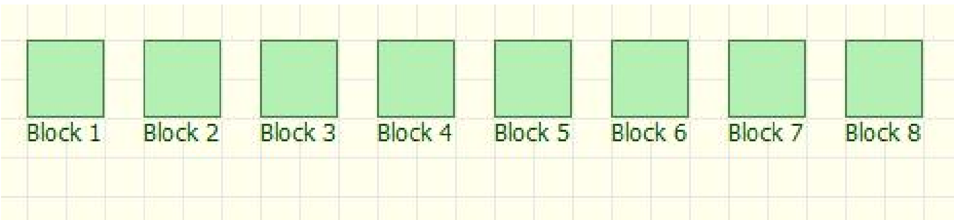

Figure 7: Block diagram created

3.2.2. Failure characteristic input of the block diagram (Figure 8)

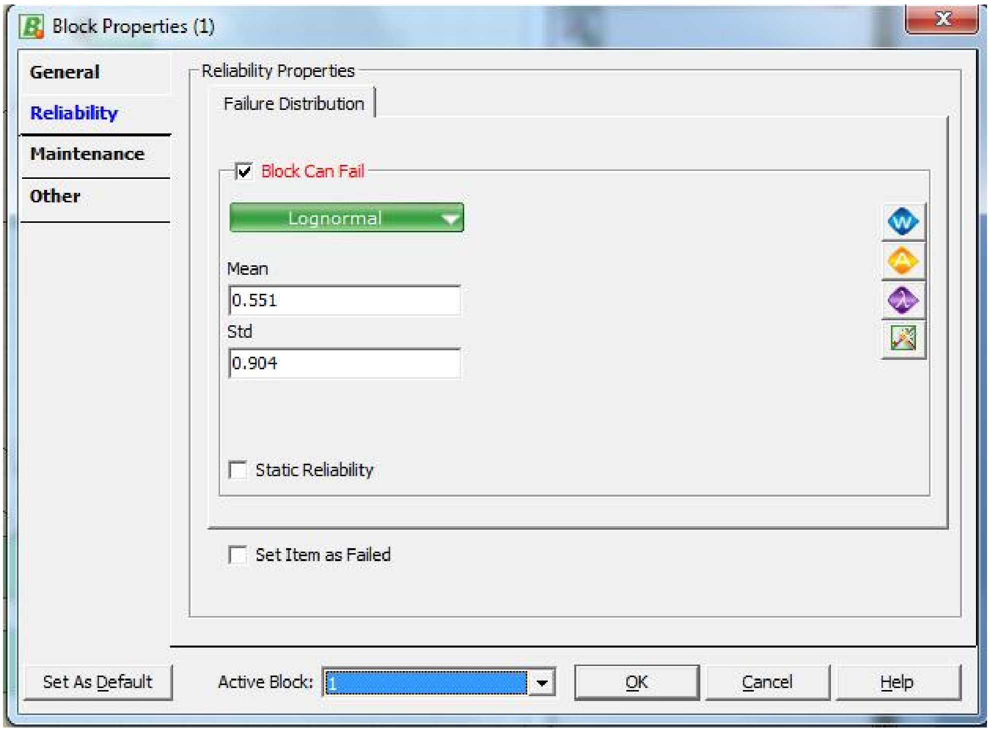

Figure 8: Input data window

3.2.3. Block layout arrangement and link (Figure 9)

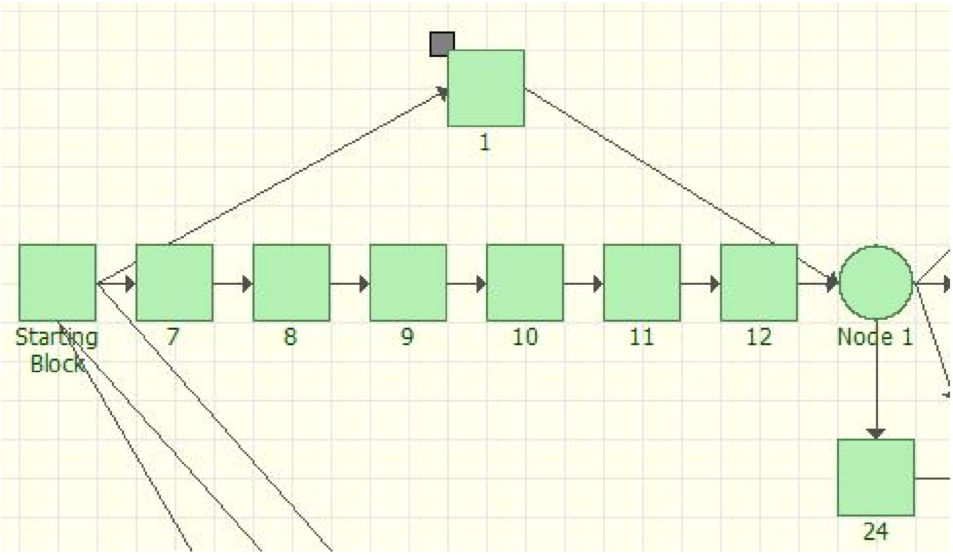

Figure 9: Block modeling area in BlockSim

3.2.4. Simulation based on time =50 year (**Error! Reference source not found.**)

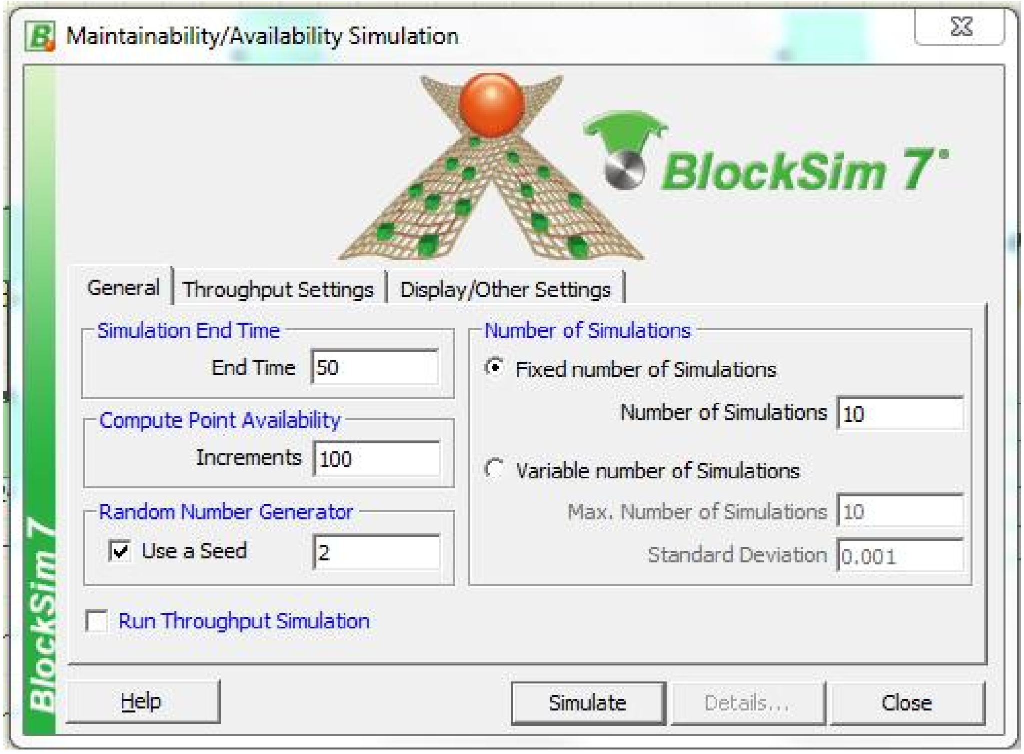

Figure 10: Simulation setting window in BlockSim

3.3. Simulation Result Analysis & Verification

The required outcome from the block diagram is the block reliability importance. Higher reliability importance block have the significant effect to the system failure. Subsequently, those blocks that symbolize component failure are the one maintenance interval need to be optimised. The components that do not contribute to the main event (which is fire and explosion) are not subjected to the preventive maintenance. Instead component are replaced or repaired in case of failure.

3.4. Maintenance Plan Development

Based from the result of the simulation, the critical components are identified. Then these components are subjected to the maintenance planning. Maintenance time, T will be calculated by the Equation 3. The time for maintenance is calculated for every critical components defined in the simulation in **Error! Reference source not found.**. Improvements for reliability for those blocks are set and the revised reliability, R_{latest} are calculated by adding the previous and improvement in reliability. Median time, T_{med} and phi, φ are taken from table 3. The flow chart for the maintenance plan is in Figure 19.

$$T = T_{med} e^{\frac{S(-R_{latest}+1)}{\varphi}}$$

Equation 3

Where:

- T_{med} is the median time
- φ is the normalised probability function
- R_{latest} is the revised reliability
- s is the shape parameter

3.5. Revise Block Diagram

The maintenance time interval created by Equation 3 will be added to the block diagram created earlier. The steps are:

3.5.1. Corrective maintenance

Enable corrective maintenance in the block properties as shown in Figure 11. In this case assume that it takes up to 5 days (0.0137 year) to rectify any failure. However in the real plant condition the repair is up to the types of equipment, how big the failure, spare part availability, when the failure is identified, did the repair is done as soon as the failure is identified?, did the failure is visible if the equipment fail or it is only visible upon inspection?, or did the repair restore the equipment to 100%?

For the corrective maintenance properties crews and spare parts are assumed always available. Equipment that causes the system down is identified and inserted in the block properties. The restoration factor for equipment that is replaced upon repair is set to 1, equipment that is repaired is assumed the restoration factor is 0.7. the corrective maintenance policy is set upon inspection and all the properties is shown in Figure 12.

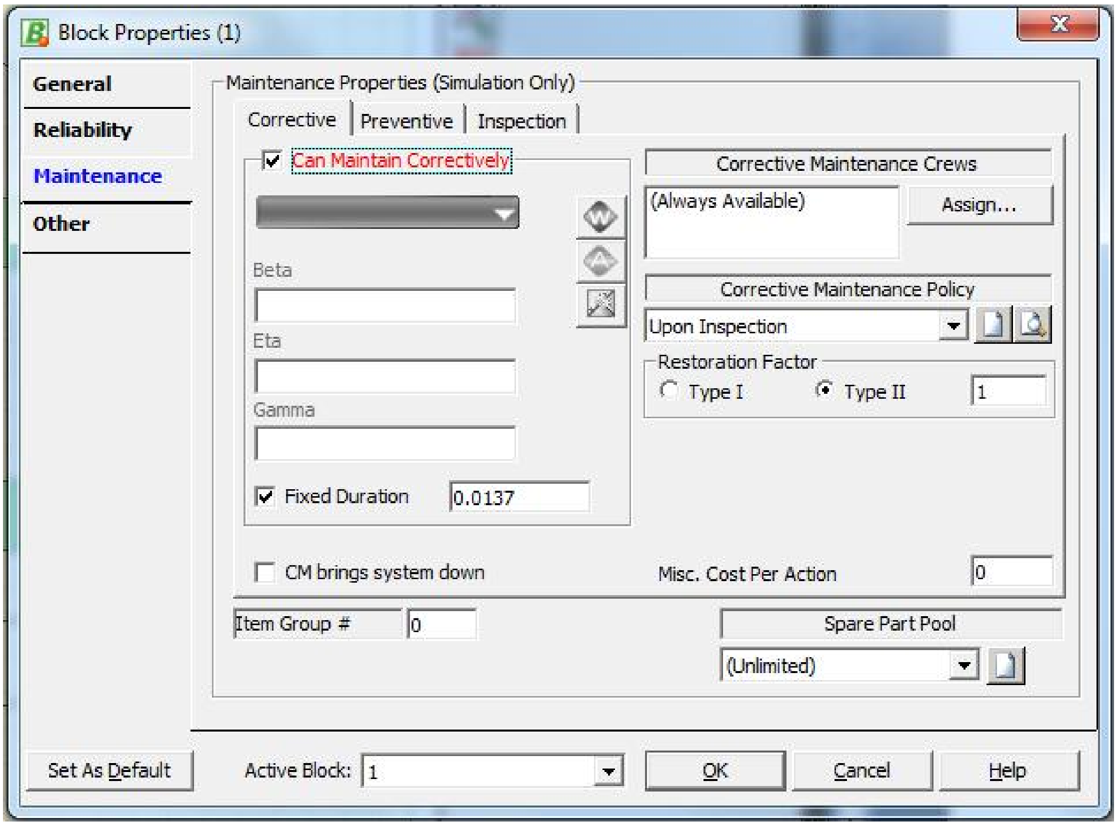

Figure 11: Block properties in BlockSim

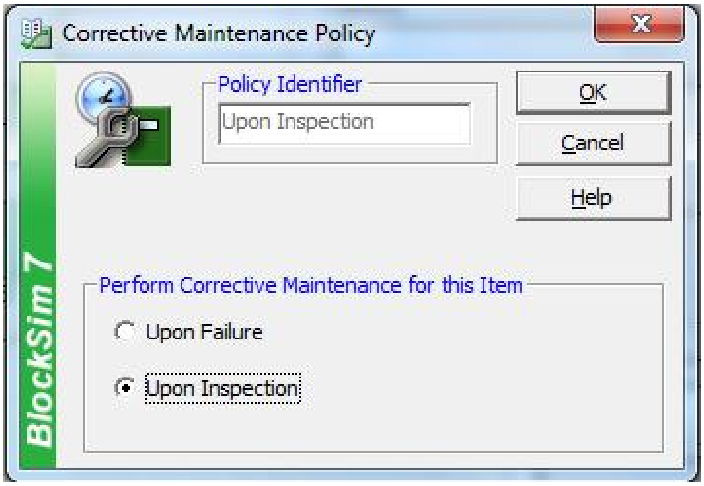

Figure 12: Corrective maintenance policy setting window in BlockSim

3.5.2. Preventive maintenance

Referring to Figure 13, in the preventive maintenance the maintenance duration is assumed to be 2 days (0.0055 year) assuming spare part and maintenance crew are always available. The restoration factor for equipment that is replaced upon repair is set to 1, equipment that is repaired is assumed to be 0.9.

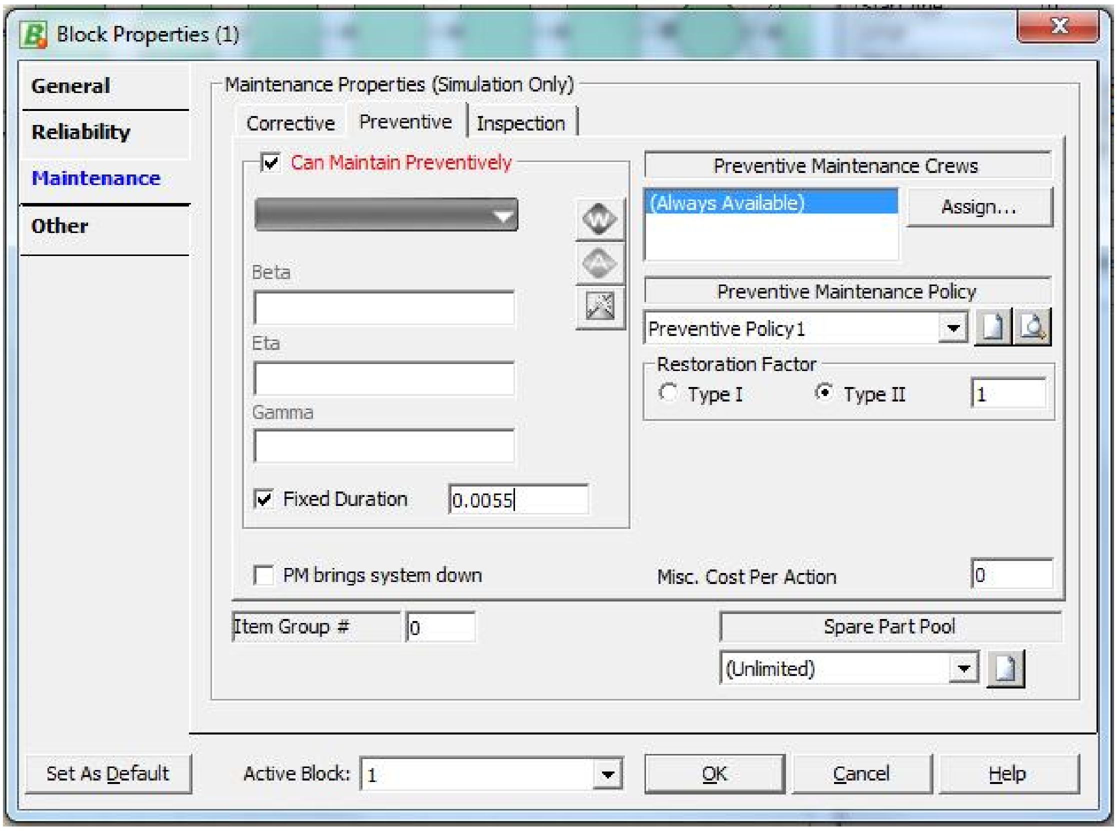

Figure 13: Preventive maintenance setting window in BlockSim

The maintenance interval time that have been calculated by Equation 3 inserted in the fixed time interval based on the item age as shown in Figure 14

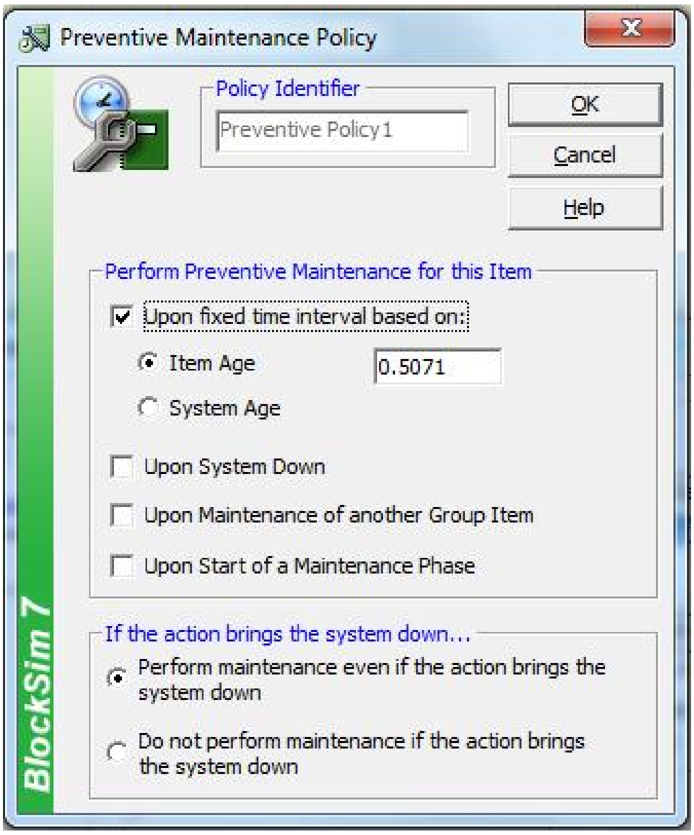

Figure 14: Preventive maintenance policy setting window in BlockSim

3.5.3. Inspection

Inspection is implemented at the same time as preventive maintenance. The inspection time is set to be 1 day (0.0027 year). The required data inserted in Figure 15. The inspection time policy is the same as preventive maintenance policy and will be inserted in Figure 16.

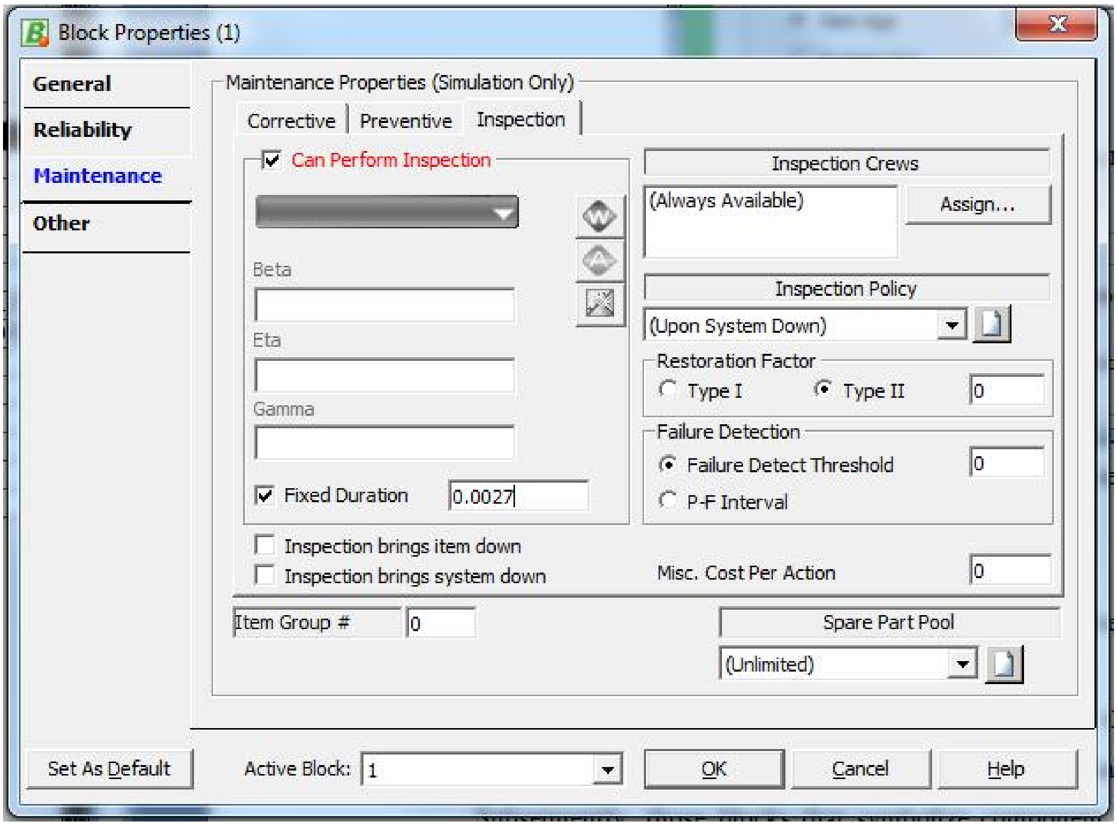

Figure 15: Inspection setting window in BlockSim

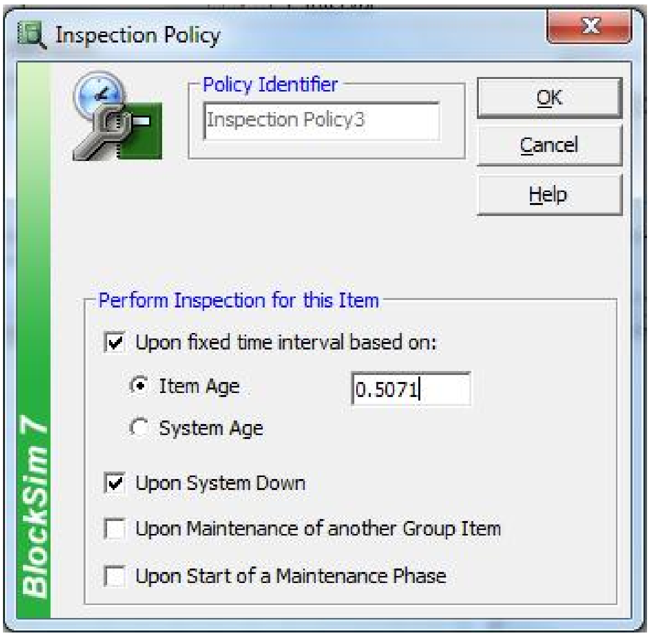

Figure 16: Inspection policy setting window in BlockSim

3.5.4. Simulation based on time =1 year (Figure 17)

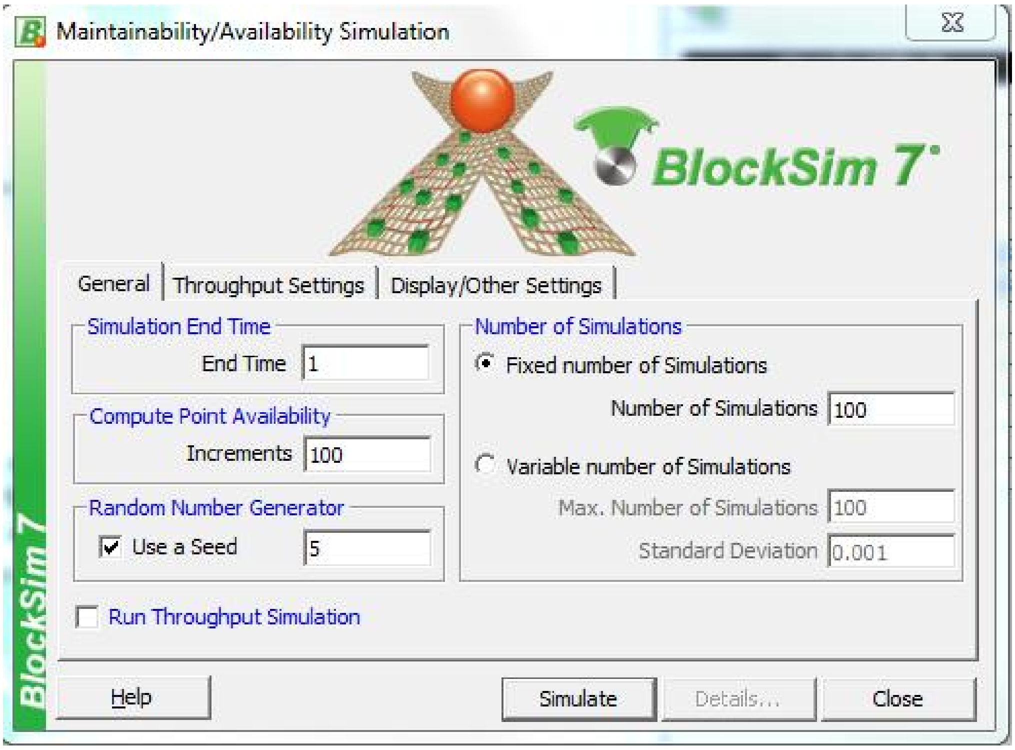

Figure 17: Simulation setting window in BlockSim

3.6. Final result analysis and verification

The required outcome from the final simulation is the reliability of the system. The result will show the how the reliability characteristic over time, time to first system failure, and the criticality of the components after the maintenance plan. The flow chart of revision of the block diagram is shown in Figure 20. For gantt chart refer to appendix C

3.7. Software needed for the model development

- Reliasoft BlockSim 7.0.14 for block diagram development
- Microsoft Excel 2007 for maintenance interval calculation

3.8. Flow Chart

3.8.1. Block diagram

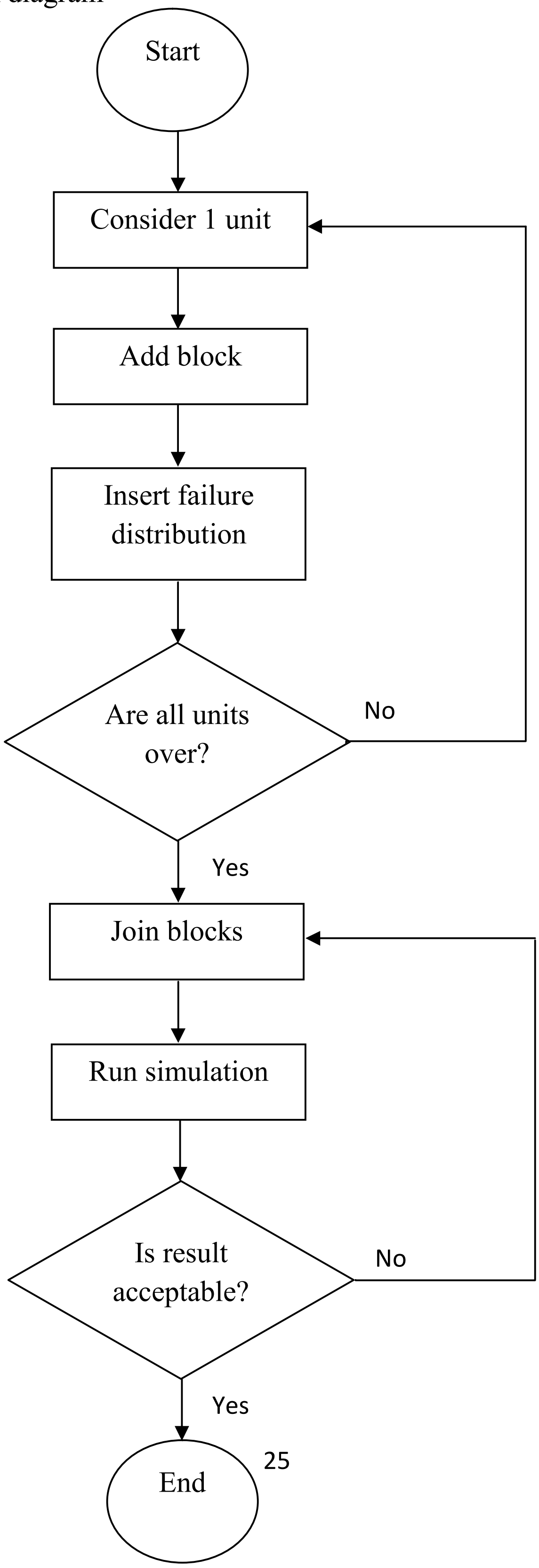

Figure 18: Flowchart for the block diagram development

3.8.2. Maintenance planning

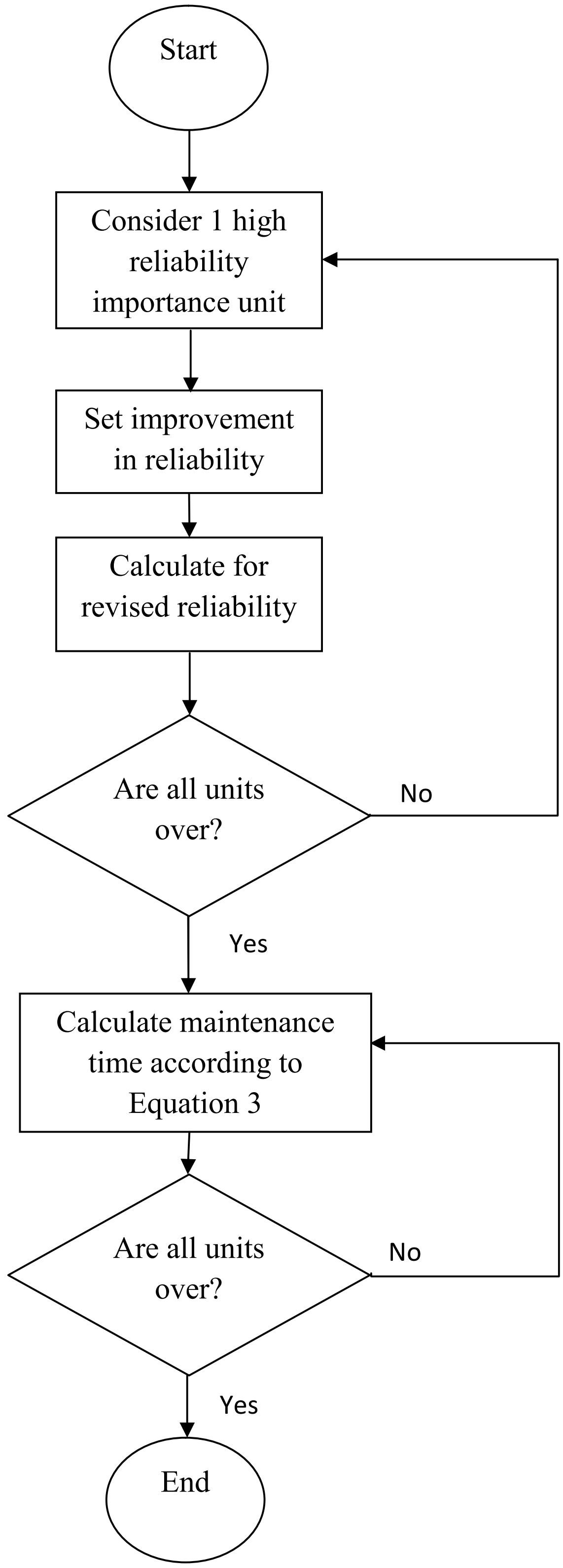

Figure 19: Flowchart for the maintenance planning

3.8.3. Revised block diagram

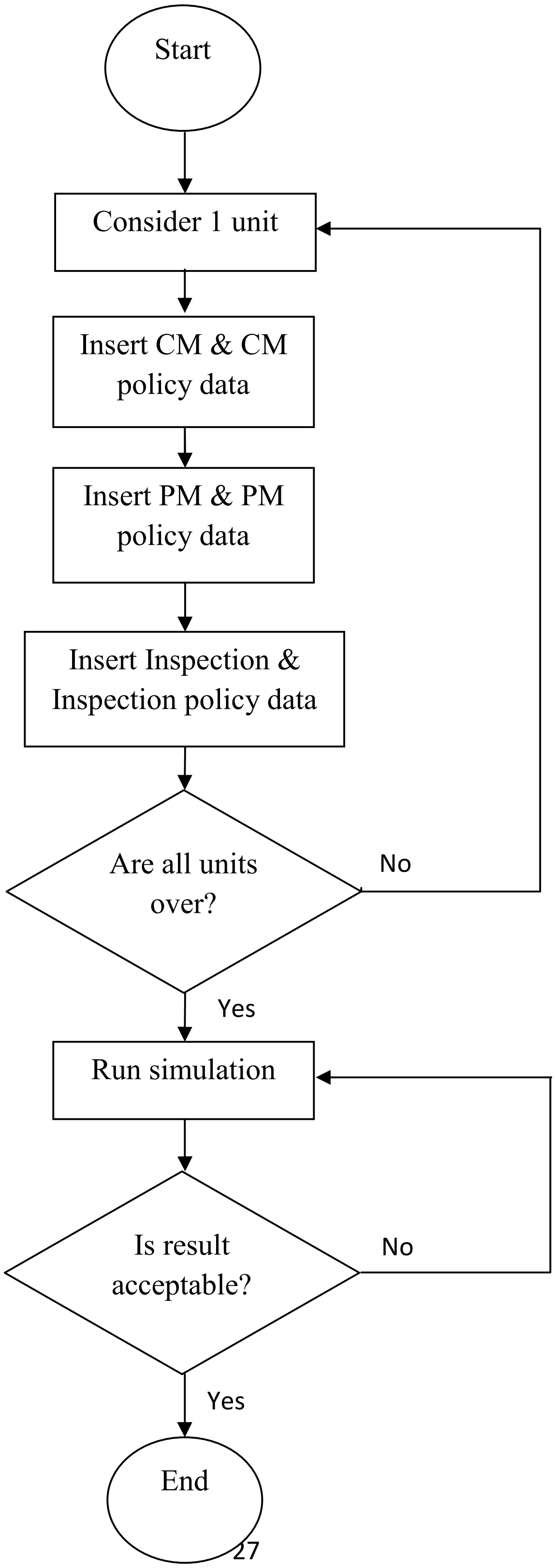

Figure 20: Flowchart for the revision of the block diagram

CHAPTER 4

RESULT & DISCUSSION

4. Result

4.1. Data gathering

The top event for the block diagram was identified as ignition of vapor cloud causing fireball. The contributors to the fire to happen are the ignition source, vapor cloud and oxygen. Oxygen is always available in the air. so how the other two contributor ignition source and vapor cloud are present are the failures that may happen in the plant. A total of 25 basic events identified to the contribution of the failure. The failure data in the form of lognormal distribution is presented in Table 5.

Table 5: Elements of the block diagram

No	Elements	Median time (year)	Shape factor (s)
1	Flammable gas detector fail	1.1043	0.817
2	Gas out of run	0.332	0.088
3	Inert gas release mechanism failed	1.437	1
4	Flame arrestor A failed	2.976	1
5	Flame arrestor B failed	2.976	1
6	Ignition source present	2.402	1
7	Mechanical failure due to corrosion	16.877	1
8	Leak from valves (two valves)	1.325	1
9	Leak from bends (four bends)	1.693	1
10	Leak from joints (10 joints)	0.868	0.557
11	Flow sensor failed	1.022	0.728
12	Pressure sensor failed	1.421	1
13	Pipeline chocked	16.902	1
14	Valve chocked	10.771	1
15	High inlet flow	1.437	1
16	High inlet pressure	1.437	1
17	Pressure controller/trip failed	1.738	1
18	High inlet temperature	0.490	0.191
19	External heat source present	4.997	1
20	Side reaction	2.300	1
21	Temperature controller/trip failed	1.738	1
22	Phase change	4.997	1
23	Valves fails open (two valves)	3.964	1
24	Corrosion	3.535	1
25	Mechanical damage	7.469	1

4.2. First Simulation Result

The elements are arranged in block diagram based on the cause effect criteria. An event can be the cause or effect of another event. A few events occurred together could trigger another event however some event are independent to happen. The developed block diagram is shown in Figure 21.The failure data obtained from [6].

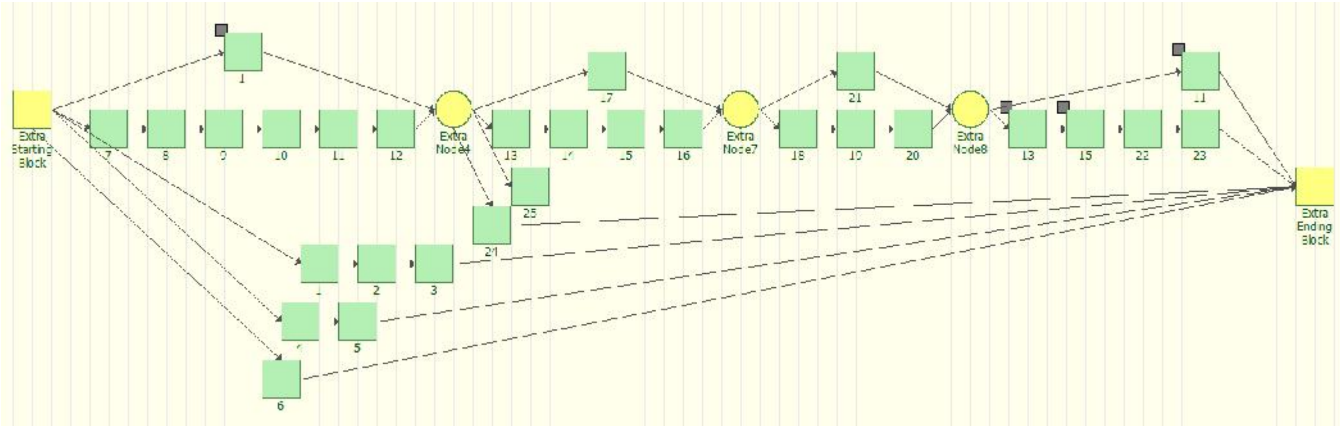

Figure 21: Block diagram for the elements from Table 5

From the block diagram Figure 7, analysis was done and the basic event that contribute the most for the failure are events 1, 4,5 and 6. At one year time, the result of the reliability importance of an event is shown in Figure 22. From 25 elements listed the blocks that have highest chance to fail the system is block 4 and 5, the flame arrestor. However, event 7, 8, 9,10,11,12 contribute a small portion less than 10% to the reliability importance. The other events not mentioned almost do not contribute to the main event. The static reliability importance listed from highest to lowest shown in Figure 23.

Figure 24 shows the individual reliability of the components in the system. Figure 25 shows the state of the system and components with respect to time. From the diagram it shows that the system will fail (fire occurred) at approximately 1.5 years. This condition neglect maintenance just to show how long the system can survive.

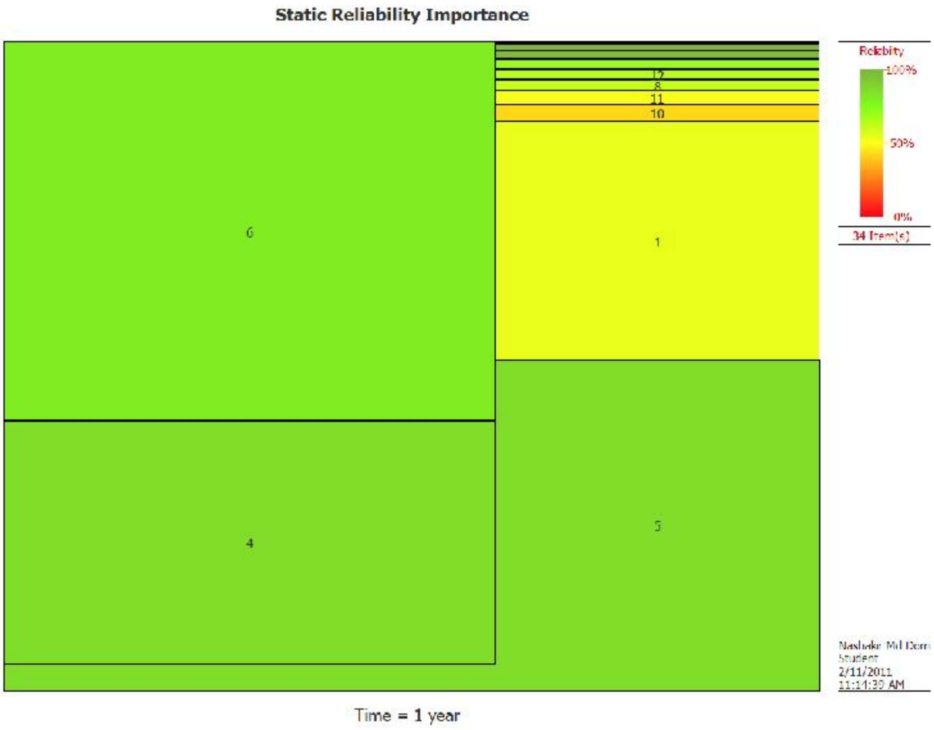

Figure 22: Reliability importance at time =1 year

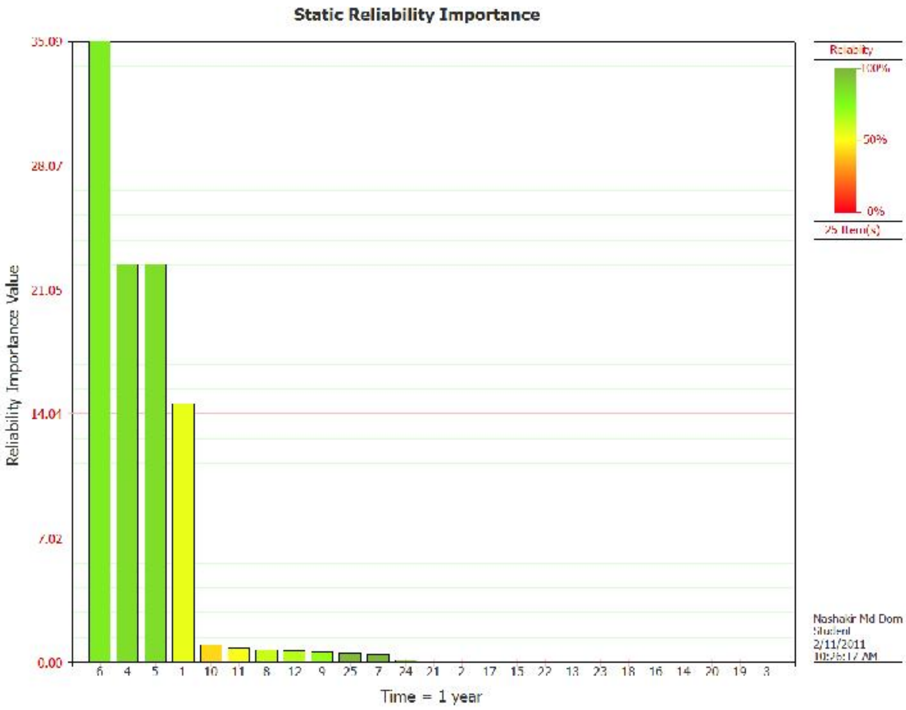

Figure 23: Reliability importance based on magnitude

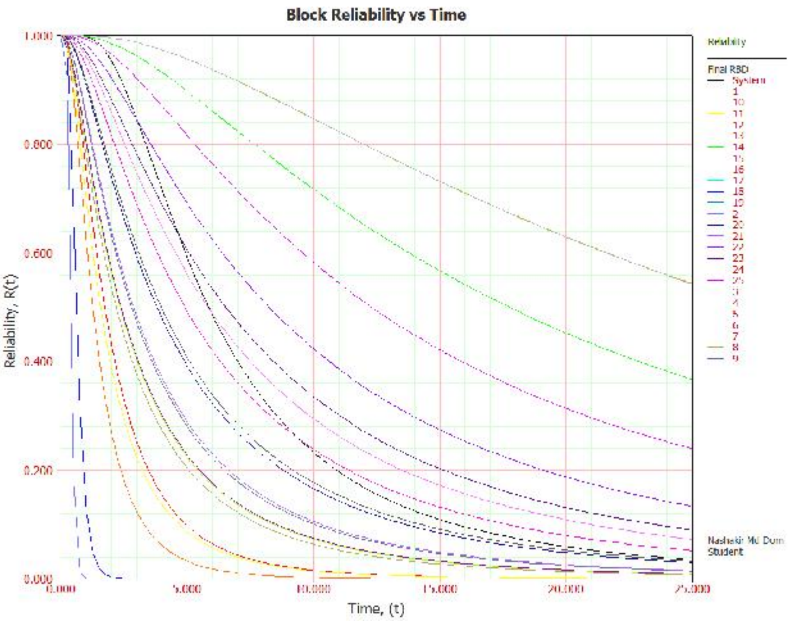

Figure 24: Block individual reliability

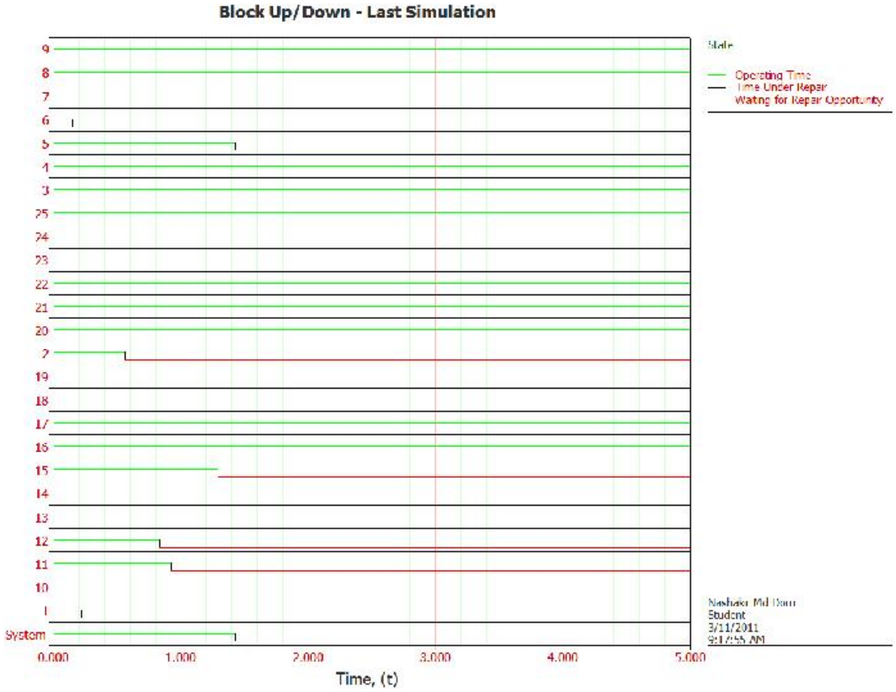

Figure 25: Block up/down simulation

4.3. Maintenance plan development

The maintenance focussed on the 4 item identified in reliability importance in **Figure 23: Reliability importance based on magnitude**Figure 23. The purpose is to prevent the system to fail at all which is to prevent the fire to occur.

Table 6: Maintenance time developed

Component, i	Cost($/improvement in reliability), c_i	Improvement in reliability, x_i	Previous reliability, R_i	Revised reliability, R_{latest}	Shape paremeter, s	Median time, t_{median}	$1 - R_i + x_i$	z value	Preventice maintenance interval (year)
1	15	0.281	0.549	0.830	0.817	1.104	0.170	-0.9526	0.5071
4	150	0.026	0.862	0.889	1	2.976	0.111	-1.2191	0.8794
5	150	0.026	0.862	0.889	1	2.976	0.111	-1.2191	0.8794
6	60	0.067	0.810	0.876	1	2.402	0.124	-1.1562	0.7559

4.4. Block diagram revision

Figure 26 shows system failure did not occur after maintenance have been inserted. This means that failure is prevented from occur after preventive/inspection inserted to component 1, 4, 5 and 6. From the 50 years time interval can be seen that component 6, 5,4 and 1 have several failures and the failures rectified during the next inspection. thats why there are downtime of equipment because the failure of the equipment is not detected until the next equipment functional test on the next inspection.

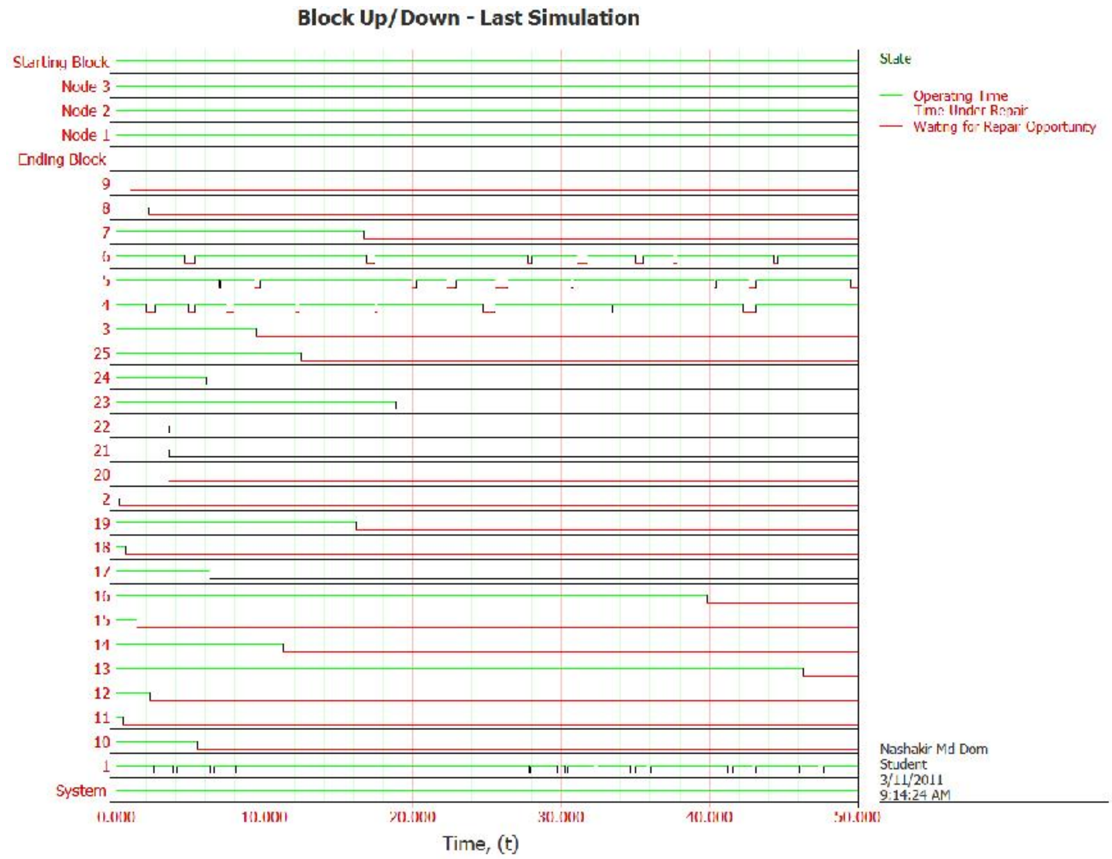

Figure 26: Block up/down with maintenance

4.5. Discussion

The block diagram created in Figure 21 reflects the fault tree developed by Khan & Haddara as in Appendix A.

In static reliability importance as in Figure 22 shows that 4 most critical components that are failure of flammable gas detector , Flame arrestor A , Flame arrestor B and presence of ignition source. These four failures shows that failure of the safety equipment is very critical. Meanwhile Khan & Haddara's critical components are 1,4,5,6, 11 and 12 as in

Appendix B.

In block individual reliability as in Figure 24 shows that most of the equipment reliability will fall lower than 50% after the first 5 year.

In block up/down in Figure 25 shows that the first fire incident expected if there is no maintenance involved are approximately 1.5 years.

By the preventive maintenance/ inspection interval shown in Table 6, Figure 26 proved that the maintenance time worked. The waiting for repair opportunity time is kept minimum.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5. Conclusion & Recommendation

Reliability analysis able to show the current state of a system. Failure of a system rarely the consequence of a single cause, but it is a combination of interactive events. As in the block diagram demonstrate that for a failure to happen, sub failure must occur independently or joint with another failure. The mentioned failure can cause a larger failure.

From the simulation data future failures can be predicted from the failure behavior. It able to prove that did the maintenance implemented really improves the system reliability. The aging equipment in the system can be identified as well as the critical equipment.

The reliability block diagram illustrates clearly the failure that may lead to another failure. If a small failure occurs the more catastrophic failure can be predicted to happen. From that indicator preventive maintenance can be carried out to reduce the probability of the failure to occur.

Usually after the execution of a new maintenance strategy, if the reliability of the system is reassessed the result should shows that the probability of failure decreased. It means that the maintenance strategy is a success but it does not mean that the maintenance policy is optimal. Continuation of reliability evaluation should be carried out.

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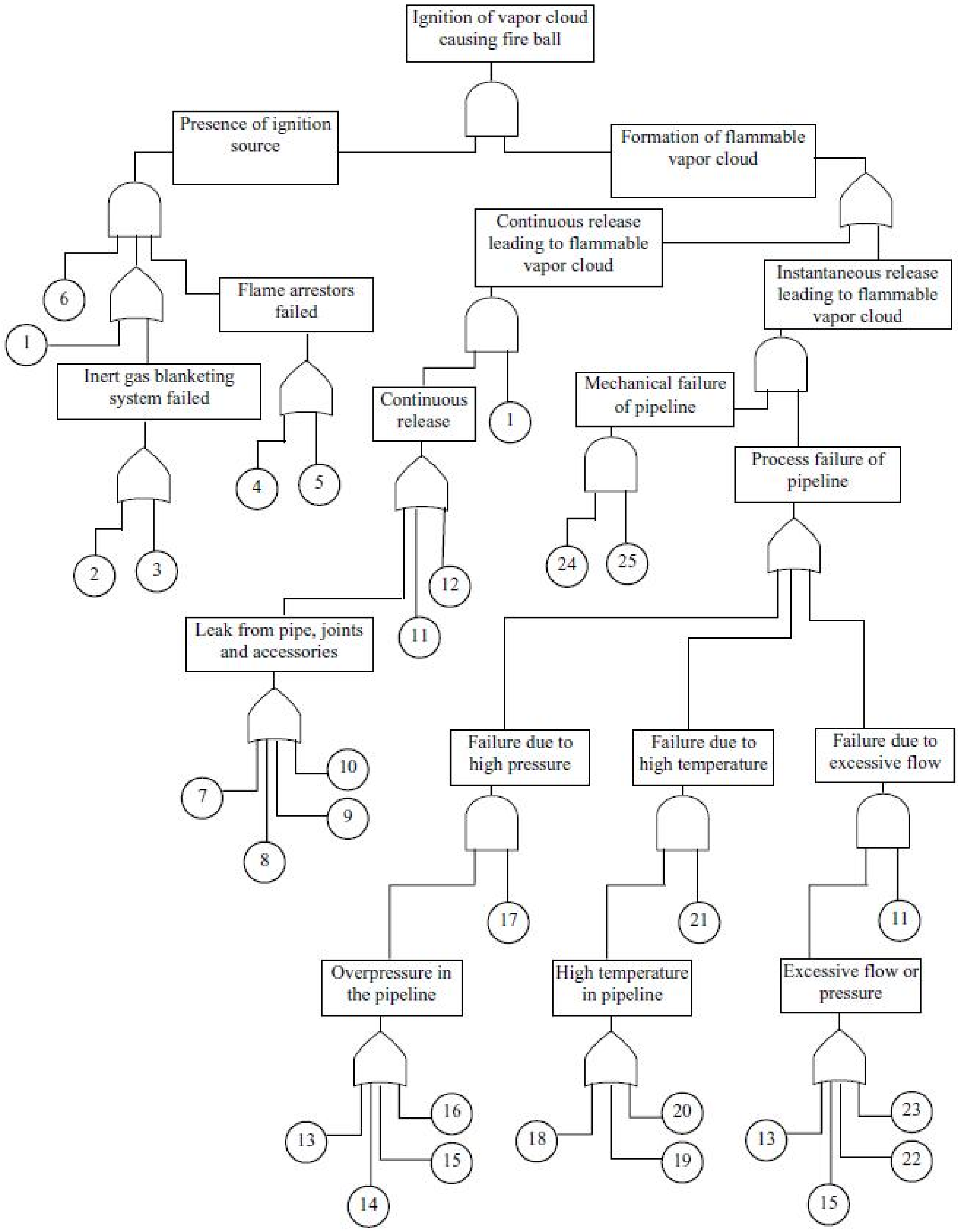
APPENDIX

Appendix A: Fault tree developed by Khan & Haddara



Appendix B: PROFAT result by Khan & Haddara

Results of PROFAT for the most credible accident scenario in the ethylene transportation line

Event not occurring	Probability	Improvement	Improvement index
0	6.0869E−03	0.000E+00	0.000
1	7.2389E−05	2.405E−02	12.902
2	3.1266E−03	1.184E−02	6.350
3	5.0299E−03	4.227E−03	2.267
4	0.0000E+00	2.434E−02	13.057
5	0.0000E+00	2.434E−02	13.057
6	0.0000E+00	2.434E−02	13.057
7	6.0774E−03	3.779E−05	0.020
8	4.2906E−03	7.185E−03	3.853
9	4.7057E−03	5.524E−03	2.962
10	3.3138E−03	1.109E−02	5.948
11	6.7800E−05	2.407E−02	12.911
12	9.6455E−05	2.396E−02	12.850
13	6.0865E−03	1.556E−06	0.000
14	6.0864E−03	1.974E−06	0.001
15	6.0543E−03	1.303E−04	0.069
16	6.0746E−03	4.917E−05	0.026
17	6.0622E−03	9.871E−05	0.052
18	6.0530E−03	1.355E−04	0.072
19	6.0848E−03	8.167E−06	0.004
20	6.0798E−03	2.825E−05	0.015
21	6.0444E−03	1.699E−04	0.091
22	6.0836E−03	1.318E−05	0.007
23	6.0819E−03	2.003E−05	0.010
24	5.9917E−03	3.806E−04	0.204
25	5.9917E−03	3.806E−04	0.204

Appendix C: Gantt chart

Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
Data Collection																
RBD Development																
* Blocks creation																
* Failure data input																
* Blocks layout & relationship																
* Block diagram simulation																
* Result Analysis																
Maintenance plan Development																
* Revision of block reliability																
* Maintenance interval calculation																
RBD Revision																
* Add CM & CM policy																
* Add PM & PM policy																
* Add inspection & inspection policy																
* Block diagram simulation																
* Result Analysis																