CHAPTER 8

APPENDICES

APPENDIX 1 (Section 3.3)

HAZID CHECK LIST

Category	Guideword	Expanders
		(Examples of guide word application – not exclusive)
External & Environmental Hazards		
Natural and Environmental Hazards	Climate Extremes	Temperature, waves, wind, dust, flooding, sandstorms, ice, blizzards
	Lightning	
	Earthquakes	
	Erosion	Ground slide, coastal, riverine
	Subsidence	Ground structure, foundations, reservoir depletion
Created (Man- made) Hazards	Security Hazards	Internal and external security threats
	Terrorist Activity	Riots, civil disturbance, strikes, military action, political unrest
Effect of the Facility on the Surroundings	Geographical - Infrastructure	Plant location, plant layout, pipeline routing, area minimization
	Proximity to Population	
	Adjacent Land Use	Crop burning, airfields, accommodation camps
	Proximity to Transport Corridors	Shipping lanes, air routes, roads, etc.
	Environmental Issues	Previous land use, vulnerable fauna and flora, visual impact
	Social Issues	Local population, local attitude, social/cultural areas of significance
Infrastructure	Normal Communications	Road links, air links, water links
	Communications for Contingency planning	
	Supply Support	Consumables/spares holding
Environmental Damage	Continuous Plant Discharges to Air	Flares, vents, fugitive emissions, energy efficiency
	Continuous Plant Discharges to Water	Target / legislative requirements, drainage facilities, oil / water separation
	Continuous Plant Discharges to Soil	Drainage, chemical storage
	Emergency/upset Discharges	Flares, vents, drainage
	Contaminated Ground	Previous use or events
	Facility Impact	Area minimization, pipeline routing, environmental impact assessment
	Waste Disposal Options	
	Timing of Construction	Seasons, periods of environmental significance
Facility Hazards		

Control Methods / Philosophy	Manning/operations Philosophy	Effect on design, effect on locality (Manned, unmanned, visited)
	Operations Concept	1 train, x-trains, simplification
	Maintenance Philosophy	Plant/train/equipment item, heavy lifting, access, override, bypass, commonality of equipment, transport
Category	**Guideword**	**Expanders** **(Examples of guide word application - not exclusive)**
	Control Philosophy	Appropriate technology, (DCS / local panels)
	Manning Levels	Accommodation, travel and support requirements. Consistency with operations and maintenance, etc. philosophies
	Emergency Response	Isolation, ESD philosophy, blowdown, flaring requirements
	Concurrent Operations	Production, maintenance requirements
	Start-up Shutdown	Modular or plant wide
Fire and Explosion Hazards	Stored Flammables	Improper storage, operator error (release), defect, impact, fire (mitigation measures include: substitute nonflammable, minimize and separate inventory)
	Sources of Ignition	Electricity, flares, sparks, hot surfaces (mitigation measures include: identify, remove, separate)
	Equipment Layout	Confinement, escalation following release of explosive or flammable fluid (operator error, defect, impact process control failure, corrosion), module layout/proximity, orientation of equipment, predominant wind direction (mitigation measures include: reduce degree of confinement, spacing based on consequence assessment, escalation barriers)
	Fire Protection and Response	Active/passive insulation, fire / gas detection, blow down / relief system philosophy, firefighting facilities
	Operator Protection	Means of escape, PPE, communications, emergency response, plant evacuation
Process Hazards	Inventory	Excess hazardous material (mitigation measures include: minimise hazardous inventory, alternate processes and utility systems)
	Release of inventory	Excessive process stress, impact (penetration by foreign object), process control failure, structural failure, erosion or corrosion (mitigation measures include: recognise and minimise process hazards during design, inherently safe plant, containment and recovery measures)
	Over Pressure	Offsite sources, process blockage, thermal expansion, connection of process to utility systems, chemical reaction
		Atmospheric conditions, blowdown, fire, hot surfaces, chemical reaction

Category	Guideword	Expanders (Examples of guide word application - not exclusive)
	Over/under Temperature	
	Excess / Zero Level	Overfill storage tanks, loss of function in separation vessels, blow by to downstream vessels
	Wrong Composition / Phase	Offsite contamination, failure of separation process, build-up of wrong phase (sand, hydrates, etc.), toxic substances
Utility Systems	Firewater Systems	
	Fuel Gas	
	Heating Medium	
	Diesel Fuel	
	Power Supply	
	Steam	
	Drains	
	Inert Gas	
	Waste Storage and Treatment	
Category	**Guideword**	**Expanders** (Examples of guide word application - not exclusive)
	Chemical/fuel Storage	
	Potable Water	
	Sewerage	
Maintenance Hazards	Access Requirements	
	Override Necessity	
	Bypasses Required	
	Commonality of Equipment	
	Heavy Lifting Requirements	
	Transport	
Construction/ Existing Facilities	Tie-ins (shutdown requirements) Concurrent Operations	
	Reuse of Material	
	Common Equipment Capacity	
	Interface – Shutdown / blowdown / ESD	
	Skid Dimensions (weight handling/equipment (congestion)	
	Soil Contamination (existing facilities)	
	Mobilization/ demobilization	
Health Hazards		
Health Hazards	Disease Hazards	Endemic diseases, infection, malarial mosquitoes, hygiene - personal and / or catering, contaminated water or foodstuff, social, e.g. AIDS, VD, etc. stagnant water, poor living conditions
	Asphyxiation hazards	Asphyxiating atmospheres, failure to use appropriate PPE, vessel entry, working in

		confined spaces, smoke, exhaust
	Carcinogenic	Chemicals in use
	Toxic	Hazardous atmosphere, asphyxiating atmosphere, chemicals in use
	Physical	Noise, radiation (ionizing, e.g. radioactive scale or non-ionizing, e.g. flares, UV, sunlight), ergonomics
	Mental	Shift patterns
	Working Hazards	Diving, working in water, working at heights, hazardous equipment, hazardous surfaces, electricity
	Transport	Excessive journeys, extreme weather, quality of roads (mitigation measures include: effective journey management)
Project Implementation Issues		
Contracting Strategy	Prevailing influence	Stability and contractual conditions, contractor selection constraints
	Legislation	Governmental contracting requirements
	External Standards	Additional engineering and construction standards
Category	**Guideword**	**Expanders** **(Examples of guide word application – not exclusive)**
	External Environmental Constraints	Governmental environmental requirements
Hazards Recognition and Management	Hazard Studies HSE Case Hazards and Effects Register	HAZOP, SAFOP, QRA, PHR, EIA, HRA, etc.
	Project Controls	Quality assurance (change control, interdepartmental involvement and interfaces)
Contingency Planning	Geographical Infrastructure	Plant location, plant layout
	Recovery Measures	Medical support, firefighting support, spill leak / clean-up support, security / military support, evacuation
Competency	Level of Indigenous Training	Quality of local workforce and contractors
	Training Requirements	
	Level of Technology	

APPENDIX 2 (Section 3.4.3)
HAZOP worksheet sample

Facility Details: NG gathering station and pipeline net work	**Operating T (min/nor/max)**	**50 deg C**		Pipeline sizes
Contractor job no	**Design T & P**	Pressure: 200 Kpa to 6700 kpa Temperature: 50 to 15 deg C Flow 2800 m3/D	**P& ID** PFS	
	Node Description: Early Tie-in provision for routing the sour gas through the Slug catcher from the Compressor to the new booster compressors		**HAZOP Date:**	**Node: 1 of 4** No. of Node actions = 4 **Total HAZOP actions = 35**

Deviation		**Causes** How?	**Consequences**	**Protection**	**Recommendations**	**Action**		
Parameter	**Guideword**	Is it credible?	Can barriers fail? Does it matter?	What protection is in pre-HAZOP design?	Maximize closed recommendations	**By who?**	**Priority** 1,2,3	**No.** seq.
Flow	No	1. Production stopped due to power failure (Upstream)	1.1 No Hazardous consequence. 1.2 Loss of production	1 None but communication failure signal is available at station.				

Flow	No	2. Downstream of MSV manual isolation valve closed	2. Potential over Pressurization of the MSV and flow line.	1 All the valves d/s in the loop are locked open. 2 The protection will be provided at the well head for the individual flow lines.	Provide the High pressure protection	Project engine er	2
Flow	No	3. Station is tripped.	3.1 No Hazardous consequence 3.2 Loss of production	Station 1 trips and station 2A facilities available.			
Flow	No	4. Failure of the beam Pump when only one pump is hooked up to the MSV.	4.1 No Hazardous consequence. 4.2 Loss of production	None but Pump stop indication is available at stations			
Flow	No	5. Flow line rupture by third party when only one pump is hooked up to the MSV.	5.1. HSE impact 5.2 Loss of Production	None			
Flow	Reverse	2. Reverse flow from MSV to well in case the well in shut.	No Hazardous consequence	Check valves are provided.			

APPENDIX 3 : Typical Flow Diagarm of Natrual Gas gathering station and pipeline (Section 3.6)

HR Power Station

300 GM sm3/d Gas Consumption

Entry Spec
60 ppm H2S Max
P 3 bit barg

HR Gas Pre Treatment

ECGL

60 barg — Existing Pipeline

Station

New Gas Export Pipeline to Birba

6", 600#, 23 km Pipeline

60 barg

Pressure Re-duction System

20 barg

VITE

MM A, Gaham, Thakod

Pressure 75 bar g
H2S: 3500 ppm
Cricondentherm: 12 °C

Sour & Dry Gas Header:
Capacity: 300,000 sm3/day

Water Content 115 mg/m3
1400 ppmv H2S out

Gas Conditioning Unit Train – 1
Capacity: 150,000 sm3/day

Combined Dehydration and Desaulfuring Unit

Water Content 3500 ppm H2S in

Cricondentherm 12°C Supply
Return
Cricondentherm 85°C

Refrigeration Unit

Water Content 115 mg/m3

Gas Conditioning Unit Train – 2
Capacity: 150,000 sm3/day

1400 ppmv H2S in
Water Content 4500 mg/m3

Combined Dehydration and Desaulfuring Unit

Cricondentherm 85°C Supply
Return
Cricondentherm 12°C

Refrigeration Unit

Discharge Header:
Capacity: 300,000 sm3/day
Pressure : 75 bar g

Suction Header:
Capacity: 300,000 sm3/day
Pressure : 5 bar g

Booster Compressor
Capacity: 150,000 sm3/day

Booster Compressor
Capacity: 150,000 sm3/day

Booster Compressor
Capacity: 150,000 sm3/day

Gas Supply

K-2426

Gases from K 2412

Future Source

APPENDIX: 4 (Section 4.7.2)

4.1 a) FAULT TREE ANALYSIS OF TYPICAL NATURAL GAS GATHERING STATION GAS LEAK
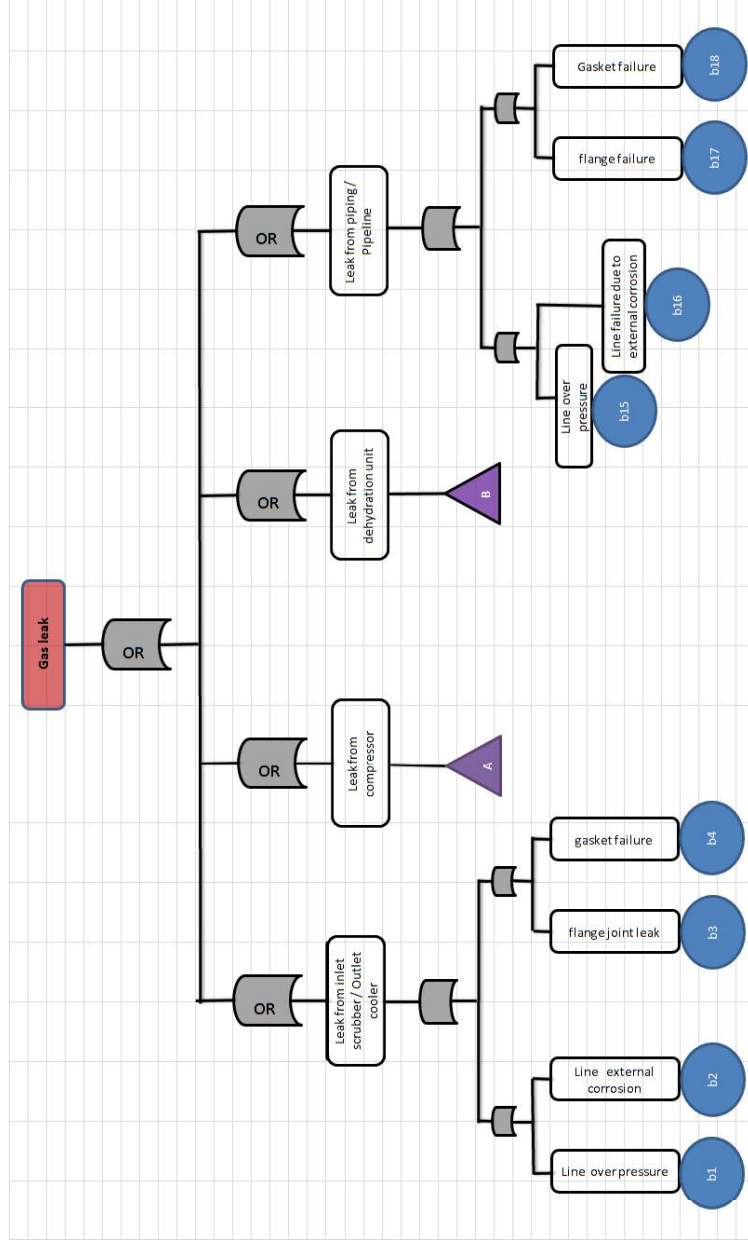
The intermediate events such as leak from compressor (A) and leak from dehydration unit is shown in Figure: 4.1 b and Figure 4.1 c.

4.1 b FAULT TREE ANALYSIS OF LEAK FROM COMPRESSOR
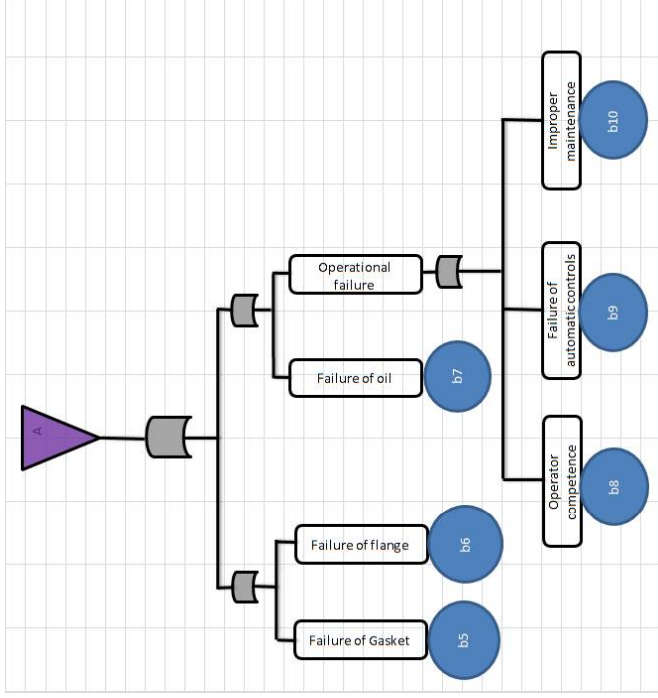
The causes of failure of flange joints, gasket, coolant oil and operational error are contribute to the intermediate element of compressor leak is established.

4.1 C FAULT TREE ANALYSIS OF LEAK FROM VAPOURISER UNIT

APPENDIX 5 (Section 4.7.3)

5.1 a) Typical Event Tree Analysis for natural gas pipeline Leakage

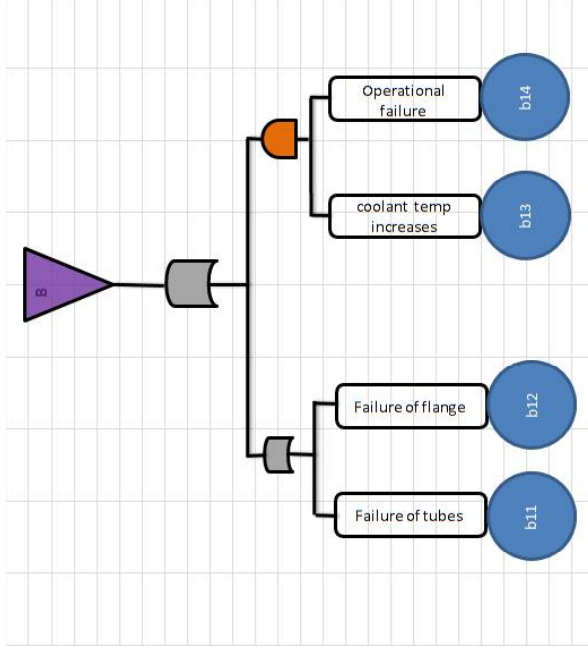| Immediate ignition at site	Confinement	Delayed Ignition	Outcome Cases		Events / year
0.5 / Year — Natural Gas Leakage					
0.1 Yes	0.4 Yes		VCE	C1	2.000.E-02
		0.8 Yes	Flash Fire	C2	2.400.E-02
	0.6 No	0.2 No	Dispersion	C3	6.000.E-03
0.9 No	0.4 yes	0.8 Yes	VCE	C4	1.440.E-01
		0.2 No	Confined cloud	C5	3.200.E-02
	0.6 No	0.8 Yes	Flash Fire	C6	2.160.E-01
		0.2 No	Dispersion	C7	5.400.E-02

5.1 b) Typical event tree analysis for natural gas pipeline Leakage

Immediate Ignition	Wind towards Residential	Wind Speed	Delayed Ignition	Confined	Outcome cases	Frequency
				0.4	BLEVE	4.000.E-05
				0.6	JET FIRE	6.000.E-05
				0.4	VCE	1.071.E-04
			0.85			
			0.5	0.6	FLASH FIRE	1.607.E-04
			0.15		DISPERSION	4.725.E-05
		0.7	0.5		DISPERSION	3.150.E-04
0.1	0.9	0.3			DISPERSION	2.700.E-04

0.001

LPG Leakage
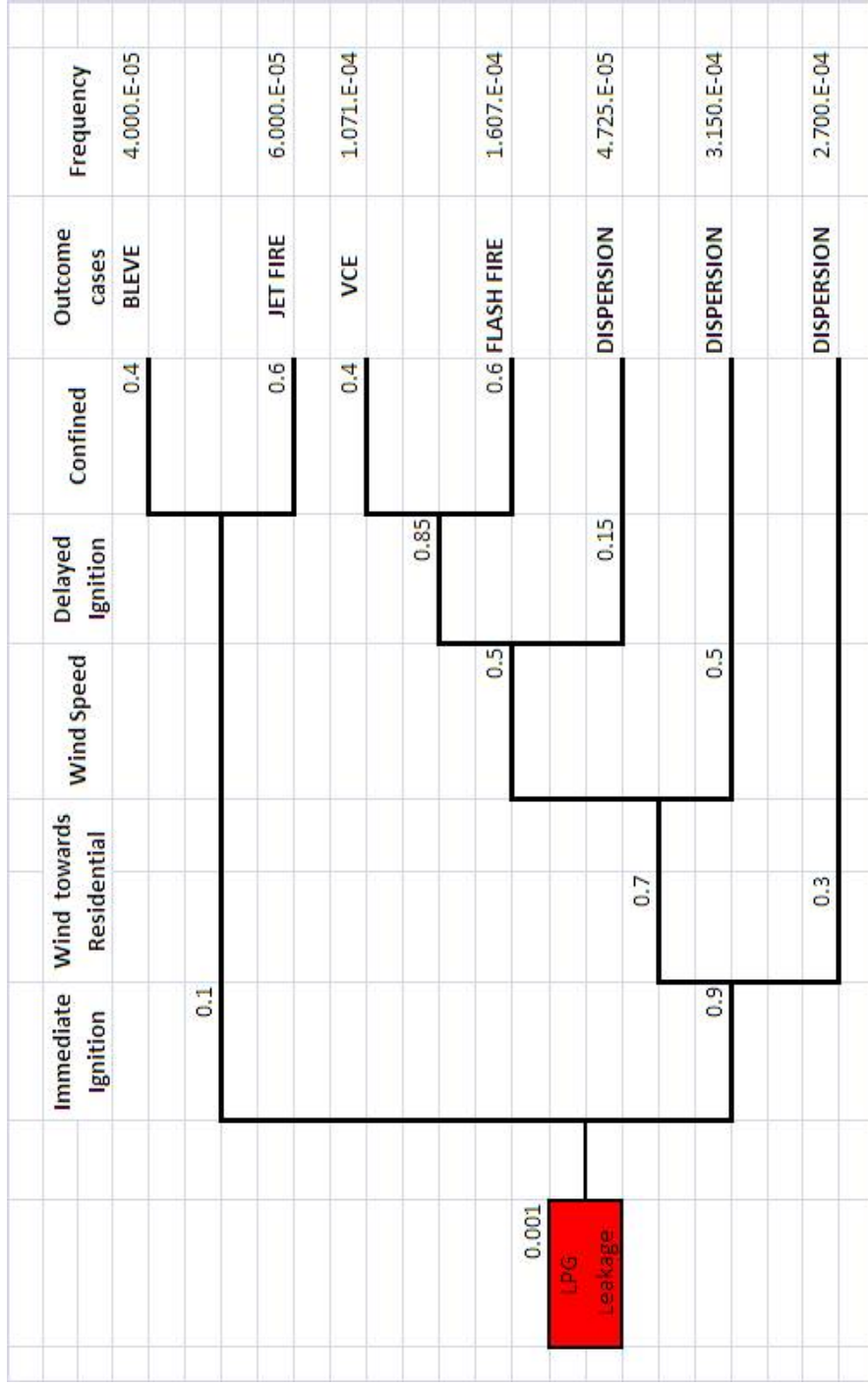
APPENDIX 6 (Section 4.10.1)

Generic failure frequency for natural gas gathering station equipment's and component's based on OGP

S.No	Equipment Name	Type	0 to 3 mm (2mm)	(3 to 10 mm)7mm	(10 to 50 mm)22mm	(50 to 150 mm)70mm	150mm or more than 150 mm
1	1st stage suction scrubber	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
2	Booster compressor 1st stage	Compressor	6.70E-03	2.60E-03	1.00E-03	1.90E-04	1.10E-04
3	Booster compressor 2nd stage	Compressor	6.70E-03	2.60E-03	1.00E-03	1.90E-04	1.10E-04
4	Booster compressor 3rd stage	Compressor	6.70E-03	2.60E-03	1.00E-03	1.90E-04	1.10E-04
5	Booster compressor 4th stage	Compressor	6.70E-03	2.60E-03	1.00E-03	1.90E-04	1.10E-04
6	1st stage cooler	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
7	2nd stage suction scrubber	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
8	2nd stage cooler	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
9	3rd stage suction scrubber	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
10	3rd stage cooler	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04

No.	Equipment	Type					
11	4th stage suction scrubber	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
12	4th stage cooler	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
13	Dehydration. Inlet Gas KOD	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
14	Glycol contractor-Top	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
15	Glycol contractor-Bottom	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
16	Cold recover exchanger	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
17	Chiller	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
18	LT Separator	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
19	Glycol Regenerator	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
20	Glycol flash vessel	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
21	Glycol Exchanger	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
22	Glycol booster pump	Pump	5.10E-03	1.80E-03	5.90E-04	9.70E-05	4.80E-05
23	Glycol Transfer pump	Pump	5.10E-03	1.80E-03	5.90E-04	9.70E-05	4.80E-05
24	Glycol cooler	Heat exchanger	2.20E-03	1.10E-03	5.60E-04	1.40E-04	1.20E-04
25	Tie in up to flares	Piping	4.10E-05	1.70E-05	7.40E-05	7.60E-05	0.00E+00
26	Pipeline from station 1 to 2	Pipeline	2.30E-04	3.30E-04	1.50E-04	2.90E-04	2.90E-04
27	Condensate separator	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04
28	Scrapper receiver	Process vessel	9.60E-04	5.60E-04	3.50E-04	1.10E-04	1.70E-04

APPENDIX 7 (Section 4.10.2)

Frequency estimation using parts count approach method for natural gas gathering station

S.No	Equipment Name	Type	0 to 3 mm (2mm)	(3 to 10 mm)7mm	(10 to 50 mm)22mm	(50 to 150 mm)70mm	150mm or more than 150 mm
1	1st stage suction scrubber	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
2	Booster compressor 1st stage	Compressor	1.340E-02	5.20E-03	2.00E-03	3.80E-04	2.20E-04
3	Booster compressor 2nd stage	Compressor	1.340E-02	5.20E-03	2.00E-03	3.80E-04	2.20E-04
4	Booster compressor 3rd stage	Compressor	1.340E-02	5.20E-03	2.00E-03	3.80E-04	2.20E-04
5	Booster compressor 4th stage	Compressor	1.340E-02	5.20E-03	2.00E-03	3.80E-04	2.20E-04
6	1st stage cooler	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
7	2nd stage suction scrubber	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
8	2nd stage cooler	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
9	3rd stage suction scrubber	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
10	3rd stage cooler	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
11	4th stage suction scrubber	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
12	4th stage cooler	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04

13	Dehydration. Inlet Gas KOD	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
14	Glycol contractor-Top	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
15	Glycol contractor-Bottom	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
16	Cold recover exchanger	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
17	Chiller	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
18	LT Separator	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
19	Glycol Regenerator	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
20	Glycol flash vessel	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
21	Glycol Exchanger	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
22	Glycol booster pump	Pump	6.171E-03	2.18E-03	7.14E-04	1.17E-04	5.81E-05
23	Glycol Transfer pump	Pump	6.171E-03	2.18E-03	7.14E-04	1.17E-04	5.81E-05
24	Glycol cooler	Heat exchanger	7.700E-03	3.85E-03	1.96E-03	4.90E-04	4.20E-04
25	Tie in up to flares	Piping	3.280E-05	1.36E-05	5.92E-05	6.08E-05	0.00E+00
26	Pipeline from station 1 to 2	Pipeline	2.13E-08	2.13E-08	7.00E-08	3.12E-08	1.74E-05
27	Condensate separator	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04
28	Scrapper receiver	Process vessel	4.320E-03	2.52E-03	1.58E-03	4.95E-04	7.65E-04

APPENDIX 8: (Section 4.11.2)

Plant specific equipment data as per site specific conditions.

S.No	Equipment type	Number of Failure	Operating period in hr. / year
1	Process vessel	51	1450000
2	Compressor	40	752000
3	Heat exchanger	124	19900000
4	Glycol Pump	39	445000
5	Pump	39	445000
6	Road tanker	47	17100
7	Piping	6	388000000
8	Pipeline	104	5960000
9	Flange	327	3368520
11	Valve	439	1827600
12	Filters	48	12495

APPENDIX 9: (Sec 4.11.2)

Example Calculation for Process vessel

Generic data from ORDEA / OGP is assumed for calculating failure rate frequency.

Mean value = 1.4e-04

Standard deviation = 4.24e-05

Using equation 1 and 2, calculate shape parameter and scale parameter in gamma distribution. As we have assumed generic data as gamma distribution.

α_{prior} = 1.96e-8

β_{prior} = 1.282e-5

Plant specific data

The failure cases and period of failure observed during the time is considered from filed specific data refer data in annexure table.

No of failure cases observed = 51

The period observed failure = 1447200

Using equation 3 and calculate the failure rate specific to the facility location.

λ= Failure rate = 3.59e-05

Using equation 4 and 5 calculate the posterior parameter of α_{Post} and β_{post}.

α_{post} = 51

β_{post} = 1525074.771

Hence using equation 6 calculate the mean value of posterior frequency.

Posterior frequency = 3.34e-5

Similarly the calculation is made for all the process equipments are selected for this study. The following tables show the Bayesian spread sheets which give details about the assessment of generic data with plant specific data and provide update assessment.
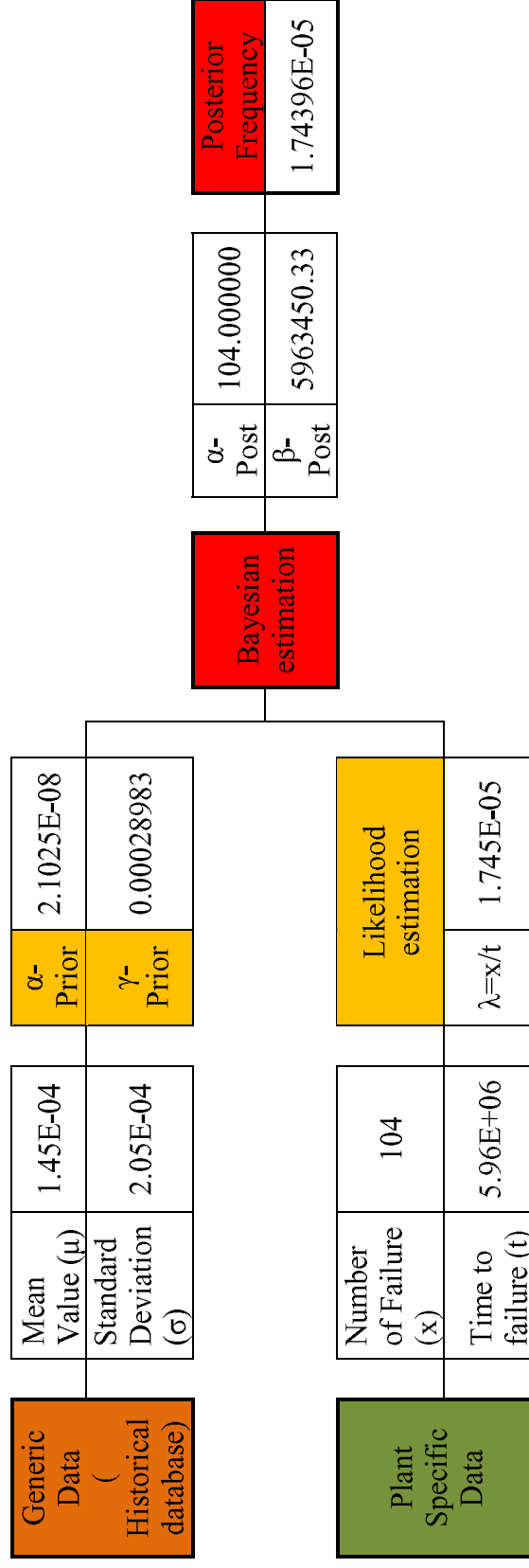
APPENDIX: 10 (Section 4.11.2)

Bayesian network method of NG frequency estimation

S.No	Equipment	Name	2mm	7mm	22mm	70mm	150mm	Field Failure data	Bayesian estimation
1	V-24281	1st stage suction scrubber	0.00413	0.00153	0.00163	0.00011	0.00017	3.52405E-05	3.34431E-05
2	k-2463	Booster compressor 1st stage	0.0121	0.00241	0.00176	0.00019	0.00011	5.31915E-05	5.00704E-05
3	k-2463	Booster compressor 2nd stage	0.0121	0.00241	0.00176	0.00019	0.00011	5.31915E-05	5.00704E-05
4	k-2463	Booster compressor 3rd stage	0.0121	0.00241	0.00176	0.00019	0.00011	5.31915E-05	5.00704E-05
5	k-2463	Booster compressor 4th stage	0.0121	0.00241	0.00176	0.00019	0.00011	5.31915E-05	5.00704E-05
6	E-24101	1st stage cooler	0.00712	0.00194	0.00183	0.00014	0.00012	6.24402E-06	6.04613E-06
7	E-24284	2nd stage suction scrubber	0.00413	0.00153	0.00163	0.00011	0.00017	3.52405E-05	3.34431E-05
8	E-24104	2nd stage cooler	0.00712	0.00194	0.00183	0.00014	0.00012	6.24402E-06	6.04613E-06
9	V-24287	3rd stage suction scrubber	0.00413	0.00153	0.00163	0.00011	0.00017	3.52405E-05	3.34431E-05
10	V-24107	3rd stage cooler	0.00712	0.00194	0.00183	0.00014	0.00012	6.24402E-06	6.04613E-06
11	V-24290	4th stage suction scrubber	0.00413	0.00153	0.00163	0.00011	0.00017	3.52405E-05	3.34431E-05
12	E-24110	4th stage cooler	0.00712	0.00194	0.00183	0.00014	0.00012	6.24402E-06	6.04613E-06

#	Tag	Name							
13	V-24193	Dehydration. Inlet Gas KOD	0.00335	0.0012	0.00133	0.00011	0.00017	3.52405E-05	3.34431E-05
14	C-2455	Glycol contractor-Top	0.00312	0.000991	0.00107	0.00011	0.00017	3.52405E-05	3.34431E-05
15	C-2455	Glycol contractor-Bottom	0.00293	0.00121	0.00112	0.00011	0.00017	3.52405E-05	3.34431E-05
16	E-24121	Cold recover exchanger	0.00217	0.00065	0.000633	0.00014	0.00012	6.24402E-06	6.04613E-06
17	E-24123	Chiller	0.00254	0.000883	0.000819	0.00014	0.00012	6.24402E-06	6.04613E-06
18	V-24203	LT Separator	0.00217	0.000958	0.00106	0.00011	0.00017	3.52405E-05	3.34431E-05
19	V-24204	Glycol Regenerator	0.00824	0.00351	0.00396	0.00014	0.00012	6.24402E-06	6.04613E-06
20	V-24199	Glycol flash vessel	0.00468	0.00186	0.00196	0.00011	0.00017	3.52405E-05	3.34431E-05
21	E-24117	Glycol Exchanger	0.00255	0.000836	0.000825	0.00014	0.00012	6.24402E-06	6.04613E-06
22	P-24183	Glycol booster pump	0.00617	0.00182	0.00161	0.000097	0.000048	8.76739E-05	7.71939E-05
23	P-24181	Glycol Transfer pump	0.00886	0.00302	0.00293	0.000097	0.000048	8.76739E-05	7.71939E-05
24	E-24119	Glycol cooler	0.00406	0.0014	0.00115	0.00014	0.00012	6.24402E-06	6.04613E-06
25	24225-01	Tie in up to flares	2.55E-05	3.32E-06	4.85E-06	0.000076	0.000008	1.54639E-08	1.41011E-08
26	PL_01	Pipeline from station 1 to 2	2.13E-08	2.13E-08	7E-08	0.00029	0.00029	1.74531E-05	1.73876E-05
27	V-36224	Condensate separator	0.00253	0.00092	0.00107	0.00011	0.00017	3.52405E-05	3.34431E-05
28	A-36145	Scrapper receiver	0.00308	0.000901	0.00138	0.00011	0.00017	3.52405E-05	3.34431E-05

APPENDIX: 11 (Section 4.11.2)

10.1 Estimation Spread sheet of initiating failure Frequency for Pipeline (Example 1)

Generic Data (Historical database)

Mean Value (μ)	1.45E-04
Standard Deviation (σ)	2.05E-04

α-Prior	2.1025E-08
γ-Prior	0.00028983

Plant Specific Data

Number of Failure (x)	104
Time to failure (t)	5.96E+06

Likelihood estimation

$\lambda = x/t$	1.745E-05

Bayesian estimation

α-Post	104.000000
β-Post	5963450.33

Posterior Frequency

1.74396E-05

10.2 Estimation Spread sheet of initiating failure Frequency for Flange Joint (Example 2)

| Generic Data (Historical data base) | Mean Value (μ) | 2.89E-07 |
| | Standard Deviation (σ) | 3.66E-07 |

| α-Prior | 8.329E-14 |
| γ-Prior | 4.642E-07 |

| Plant Specific Data | Number of Failure (x) | 51 |
| | Time to failure (t) | 1447200 |

| Likelihood estimation | λ=x/t | 3.524E-05 |

| Bayesian estimation | α-Post | 51.000000 |
| | β-Post | 3601638.771 |

| Posterior Frequency | 1.41602E-05 |
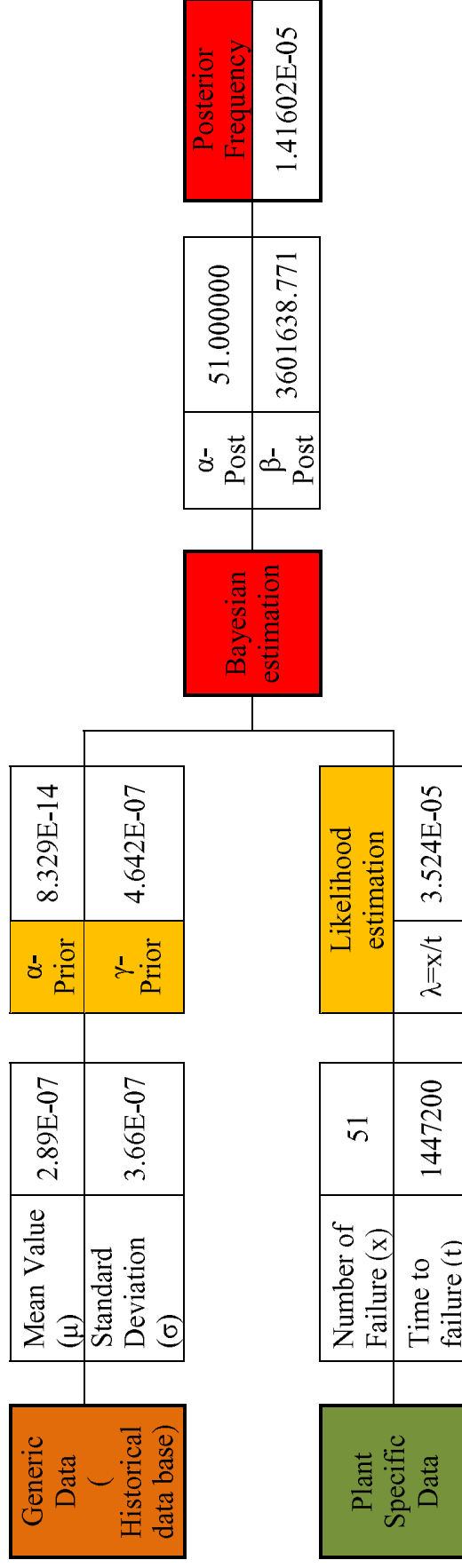
10.3 Estimation Spread sheet of initiating failure Frequency for Process vessel (Example 3)

Generic Data (Historical data base)		
Mean Value (μ)	1.4E-04	
Standard Deviation (σ)	4.24E-5	

α- Prior	1.96E-8
γ- Prior	1.28E-5

Plant Specific Data		
Number of Failure (x)	51	
Time to failure (t)	1447200	

Likelihood estimation	
λ=x/t	3.59E-05

Bayesian estimation	
α- Post	51.000000
β- Post	1525074.689

Posterior Frequency	
3.34E-5	
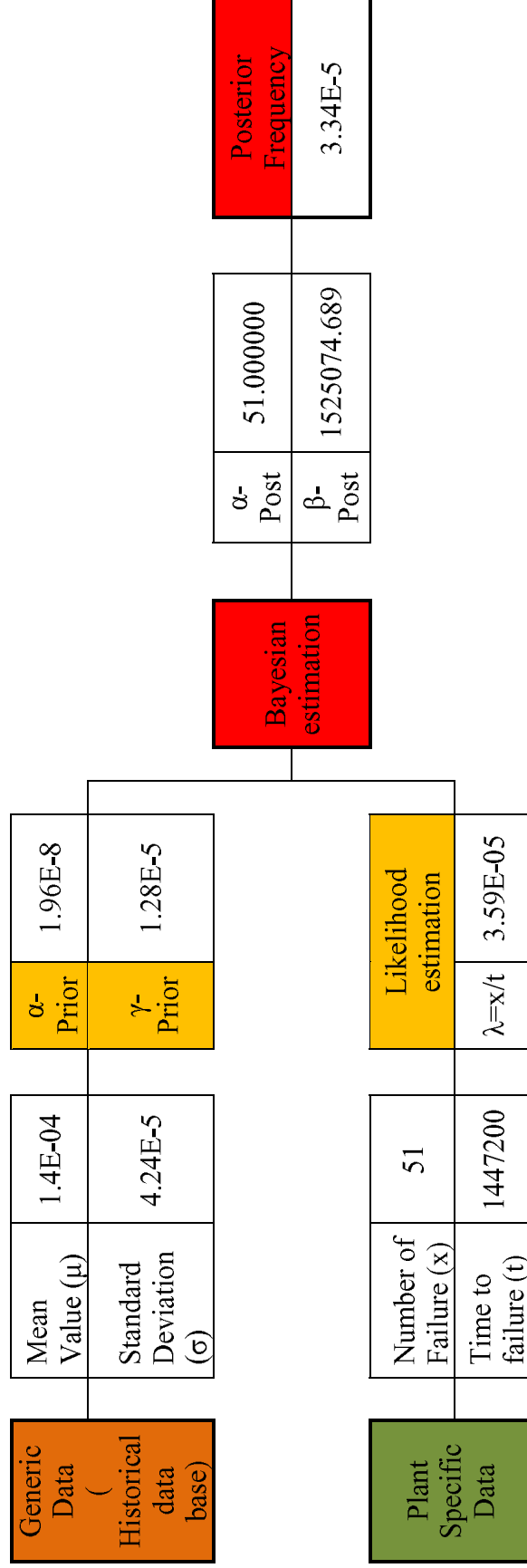
10.4 Estimation Spread sheet of initiating failure Frequency for Road tanker (Example 4)

| Generic Data (Historical data base) | Mean Value (μ) | 4.30E-06 | | α-Prior | 1.849E-11 |
| | Standard Deviation (σ) | 2.30E-06 | | γ-Prior | 1.2302E-06 |

| | | | | Bayesian estimation | | α-Post | 89.000000 |
| | | | | | | β-Post | 7339554.44 |

| Plant Specific Data | Number of Failure (x) | 89 | | Likelihood estimation | |
| | Time to failure (t) | 6526700 | | λ=x/t | 1.3636E-05 |

| Posterior Frequency-Mean | 1.21261E-05 |
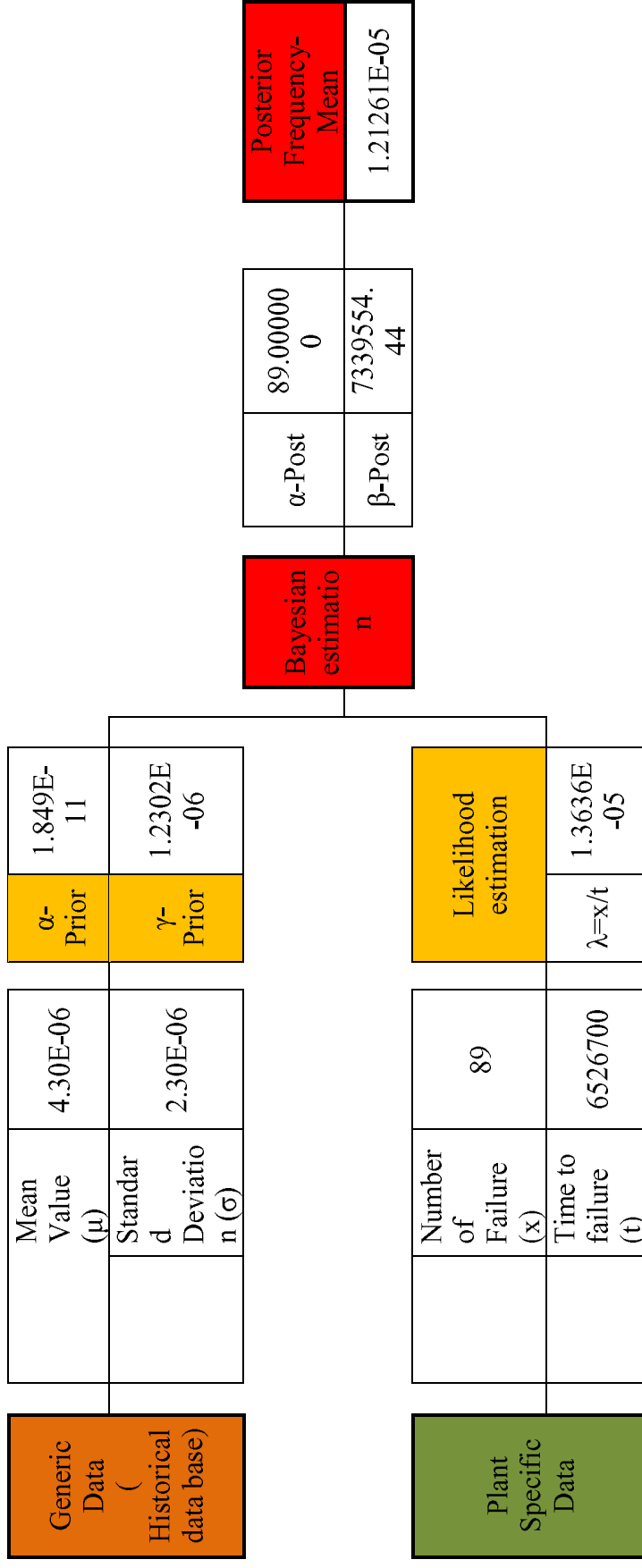
10.5 Estimation Spread sheet of initiating failure Frequency for Pressure Relief valve (Example 5)

Generic Data (Historical data base)		
Mean Value (μ)	6.79E-06	
Standard Deviation (σ)	1.08E-06	
α-Prior	4.6104E-11	
γ-Prior	1.7115E-07	

Plant Specific Data		
Number of Failure (x)	14	
Time to failure (t)	182760	
Likelihood estimation		
$\lambda = x/t$	7.6603E-05	

Bayesian estimation	
α-Post	14.000000
β-Post	6025711.11

Posterior Frequency
2.32338E-06
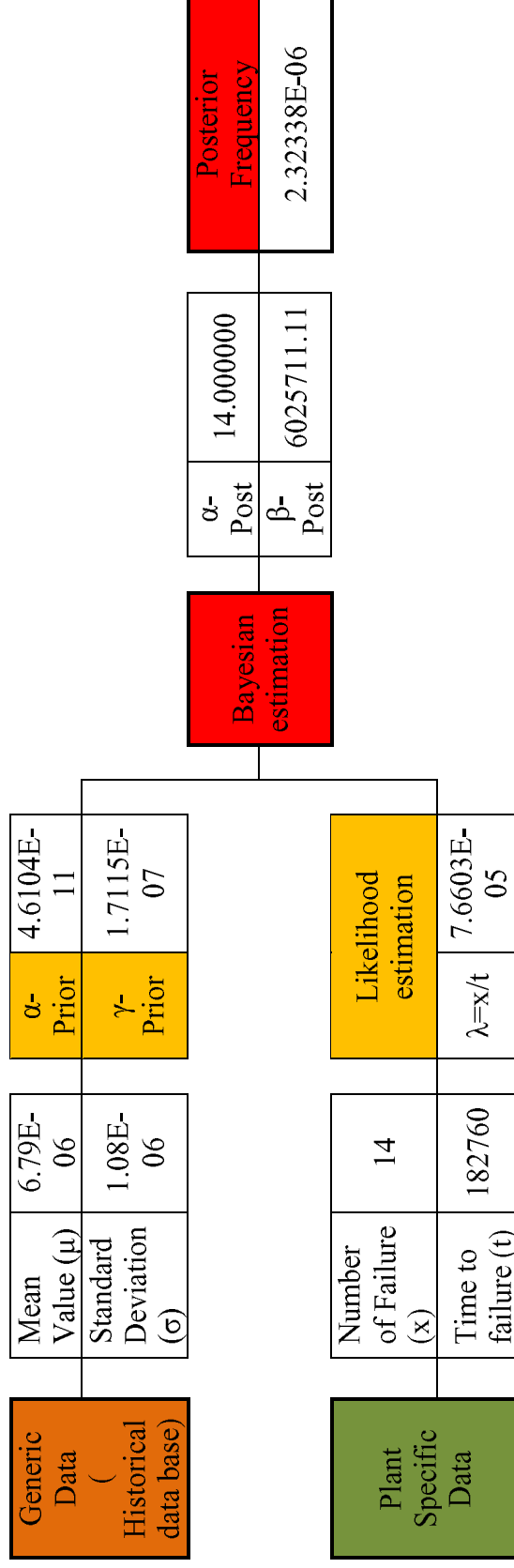
APPENDIX: 12 (Section 4.12)

Frequency comparison with generic Parts Count Approach Method and Bayesian parts count approach method

S.No	Equipment Name	Generic with PCAM	Bayesian with PCAM
1	1st stage suction scrubber	1.50E-04	1.70E-04
2	Booster compressor 1st stage	1.00E-04	1.10E-04
3	1st stage cooler	2.12E-05	1.20E-04
4	2nd stage suction scrubber	1.50E-04	1.70E-04
5	Dehydration Inlet Gas KOD	1.50E-04	1.70E-04
6	Glycol contractor-Top	1.50E-04	1.70E-04
7	Glycol contractor-Bottom	1.50E-04	1.70E-04
8	Cold recover exchanger	2.12E-05	1.20E-04
9	Chiller	2.12E-05	1.20E-04
10	LT Separator	1.50E-04	1.70E-04
11	Glycol Regenerator	2.12E-05	1.20E-04
12	Glycol flash vessel	1.50E-04	1.70E-04
13	Glycol Exchanger	2.12E-05	1.20E-04
14	Glycol booster pump	9.34E-05	4.80E-05
15	Glycol cooler	2.12E-05	1.20E-04
16	Tie in up to flares	1.13E-08	7.60E-05
17	Pipeline from station 1 to 2	1.39E-05	2.90E-04
18	Condensate separator	1.50E-04	1.70E-04
19	Scrapper receiver	1.50E-04	1.70E-04

APPENDIX: 13

PAPERS PUBLISHED / UNDER REVIEW

S. No	Paper Title	Journal Details
1	Risk assessment study for LPG Storage and handling system of heat treatment plant	International Journal of Emerging Technology and Advanced Engineering, (ISSN 2250-2459 Volume 5, Issue 7, July 2015
2	Consequence analysis of hydrogen storage tank facility: a case study approach by using PHAST	International Journal of Applied Engineering Research and Development. Vol. 5 Issue 3, August 2015, 1-10
3	Study of hazard identification techniques adopted by oil and gas industries for risk assessment	International Journal of Management, Information Technology and Engineering, ISSN (P): 2348-0513, ISSN (E): 2454-471X, Vol. 3, Issue 10, Oct 2015, 117-126
4	Fire, Explosion and Dispersion Modelling of Automatic LPG Distribution System of High Rise Building Apartment.	IJSTE-International Journal of science technology and engineering. Volume 2, Issue 4, 276-283, October 2015.
5	Risk Assessment – Tool to Minimize the Accidents.	Journal of Pollution Research 31 (1), 77-82, 2014
6	Risk assessment of natural gas gathering station and associated pipeline.	International Journal of Theoretical and Applied Mechanics. ISSN 0973-6085, 12, 2 (2017), 225-240 Research India Publications.