Presentation

Korean Reliability Assessment & Certification Activities, driven by Government, for Mechanical Components

Reliability Assessment Center

KIMM Korea Institute of Machinery & Materials

Introduction

- –Due to limited technical sources in small and medium size companies, their mechanical components are being undervalued in Korea.
- –The domestic large enterprises make limited profit due to their dependency on a great deal of imported components.
- –The mission statement for "Reliability Assessment Center" founded by Government is to enhance the quality of domestically produced mechanical components and to certify the components by "R" mark for reliability.
- –Three different kinds of tests are performed at "Reliability Assessment Center". *(See Appendix 1)*
- –*Appendix 2* shows the detail of how the component is developed and and the importance of reliability Assessment during development phase.
- –The purpose of "R" mark is to be well known in the world wide markets. *(See Appendix 3)*

Procedure for Reliability Assessment

Step 1

Survey operating conditions of related components in field and determine "Qualification Life" and this qualification life can be adjusted or negotiated between a manufacturer and an end user. *(See Appendix 4)*

- −170,000 km
- −2,000 hours

Step 2

Determine the measures of reliability considering "Sample Size" and importance of related component in field application.

- −B1
- −B5
- −B_{10}
- −(MTBF)
- −MTTF

Step 3

Calculation of test time of laboratory *(See Appendix 5)*

$T_{test} = f\ (L_Q,\ \beta,\ CL,\ N)$

T_{test} : Test Time

L_Q : Qualification Life

β : Shape Parameter of component

CL : Confidence Level

N : Sample Size

Step 4

Find out representative failure mode of related component
(See Appendix 6 & 7)

- FMEA
- FTA
- QFD Level 1
- QFD Level 2

Step 5

Literature survey for shape parameters(β) of related component

(See Appendix 8)

Step 6

Determine sample size (1, 2, 3, 5, 10, 50) considering the following points:

- Price of component
- Number of test bench available
- Possibility of multiple mounting mechanism design of tester

Step 7

Determine confidence level requested by assurance company *(See Appendix 9)*

- Within the range of 80% ~ 95% at least by assurance company

Step 8

Determine failure acceptance rule :

- No failure rule *(See Appendix 10)*
- One failure acceptance rule *(See Appendix 10)*

Step 9

"Accelerated Life Testing Determination" due to limited testing time

(See Appendix 11)

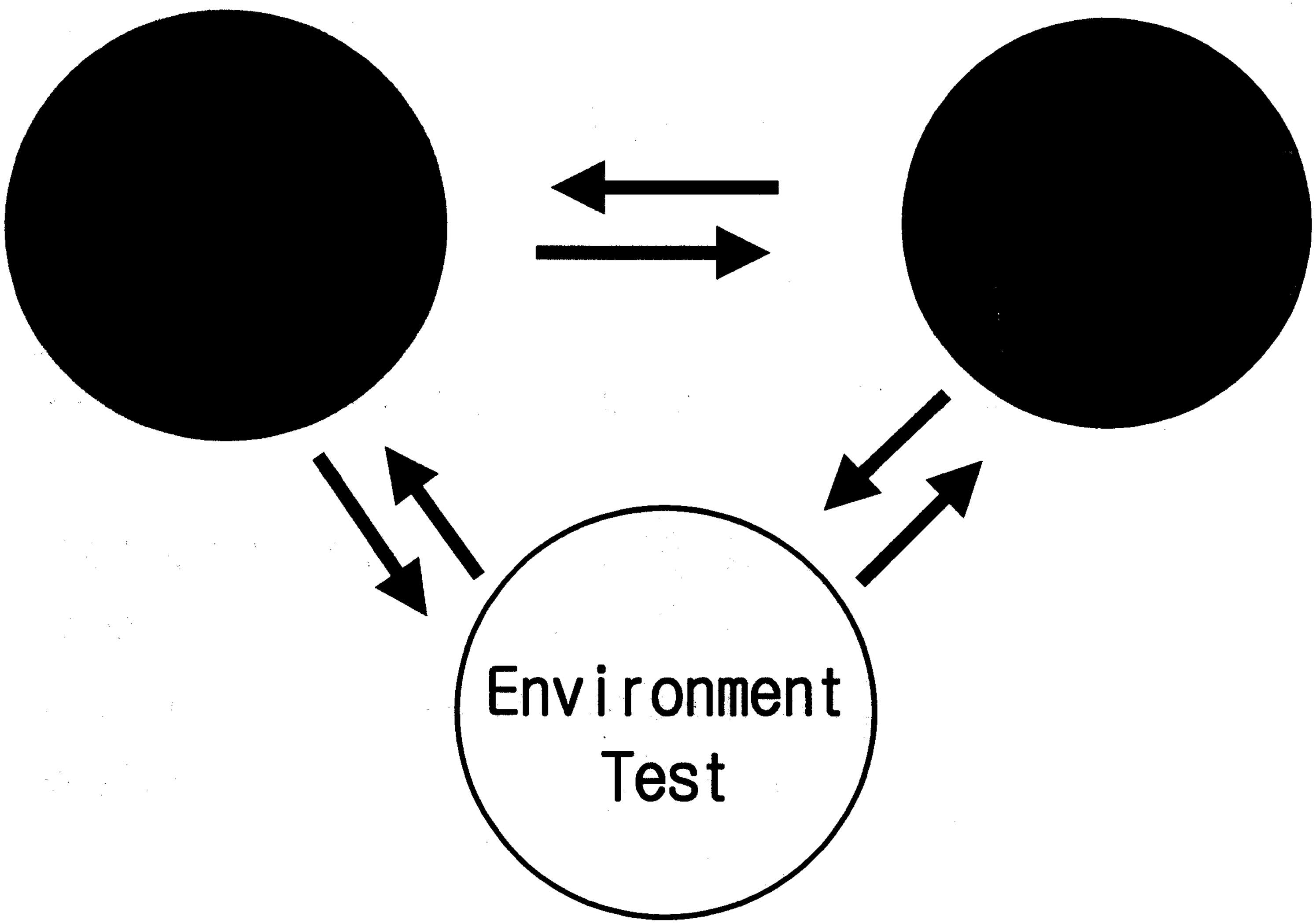
** Refer to *Appendix 12* for the list of reliability analysis from the year 2000 to 2004

Step 10

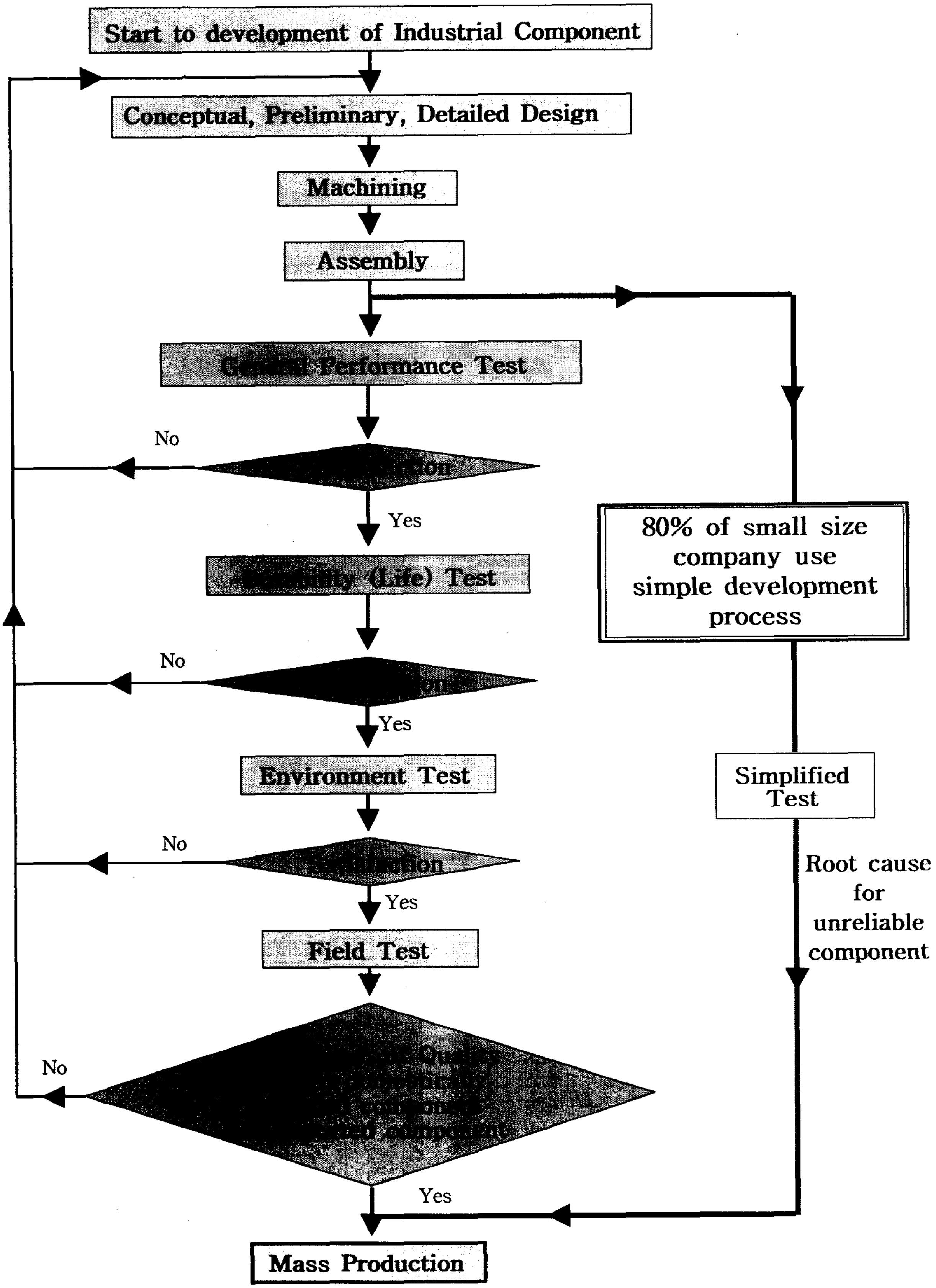
Test effectiveness analysis due to limited test time

(See Appendix 13 & 14)

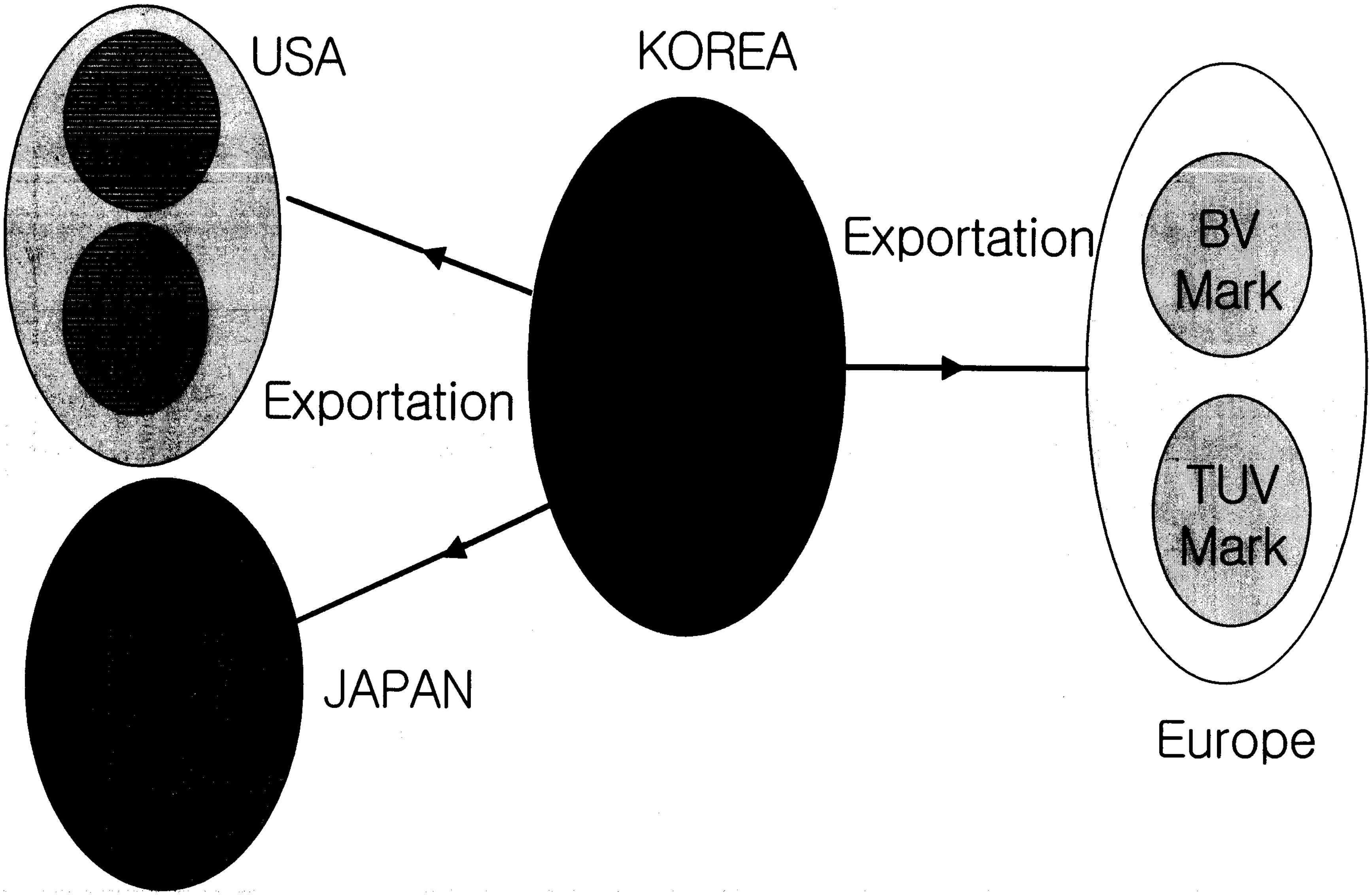
Appendix 1
Reliability Test



... development and Importance ... Assessement



Introduction of Korean reliability Mark(R) to Global Markets



Appendix 4

Supportive Material for the Calculation of Diesel Vehicle Assurance Distance

1) Calculation of Yearly Operation Hours	Distance between work place including Saturdays: 40 km 40km/day×6day/week×5weeks/year =12,000 km Distance on Holidays and Sundays : 120 km (Sundays: 52 weeks one day + Holidays: 13 days) ×120km/day = About 8,000 km

2) Vehicle Operating Distance	10 years 200,000 km (=20,000 km/year ×10 year)

3) The Operating Distance of Small Diesel Vehicle Manual Transmission

Life Guaranteed forSmall Diesel Vehicle Manual Transmission	Equivalent Distance: 200,000 km Operating Distance: 200,000 km (10 years)

Appendix 5 Qualification Life & Test Time

No	Item	Equation
1	**Calculation of Test Time**	$t_n = f\,(qualification\ life,\ \beta,\ n,\ CL)$
2	**Relations between MTTF and B_{10}**	$MTTF = \frac{B_{10} \cdot \Gamma(1+\frac{1}{\beta})}{[-\ln(1-0.1)]^{\frac{1}{\beta}}}$
3	**Scale Parameter θ vs MTTF**	$\theta = \frac{MTTF}{\Gamma(1+\frac{1}{\beta})}$
4	**Acceptance Criteria : $R(t_n)$** **(Probability that n samples are not failed)**	$R(t) = e^{-(\frac{t_n}{\theta})^{\beta}} = (1-CL)^{\frac{1}{n}}$
5	**No failure test time**	$t_n = \theta(\frac{-\mathrm{Ln}(1-CL)}{n})^{\frac{1}{\beta}}$

* MTTF , β_{10} : Qualification Life Time
* β : shape parameter
* CL: Confidence Level
* Γ : Gamma Function
* θ : Scale parameter
* n : sample size
* t_n : Test time

Appendix 6-1

FMMA

(Failure Mode & Mechanism Analysis)

No	Primary Components	Failure Modes	Failure Mechanisms	
1	Metal Housings and Crimp	Hydraulic Fluid Leakage	1-1	Overstress Fracture
			1-2	External Corrosion
			1-3	Cyclic Pressure Fatigue Cracking
2	Coupling Seals	Hydraulic Fluid Leakage	2-1	Excessive pressure and blowout
			2-2	Thermal aging and cracking
			2-3	Chemical degradation from contamination
			2-4	Degradation from lubricant incompatibility
3	Detent Assembly	Jammed	3-1	Contamination
			3-2	Corrosion
4	Poppet Assembly	Leakage	4-1	Wear of valve seat
			4-2	Particle contamination of valve seat
			4-3	Corrosion of valve seat
		Poppet Jammed Open	4-4	Contamination
			4-5	Misalignment
			4-6	Spring fracture due to fatigue failure
		Poppet Jammed Closed	4-7	Contamination
			4-8	Misalignment
5	Hydraulic Hoses	Hydraulic Fluid Leakage	5-1	Excessive pressure and blowout
			5-2	Thermal aging and cracking
			5-3	Chemical degradation from contamination
			5-4	Degradation from lubricant incompatibility
			5-5	Vibration fatigue
			5-6	External wear of braiding and tube
			5-7	Loss of electrical conductivity
			5-8	Cyclic Pressure Fatigue Cracking

Appendix 6-2

FMECA

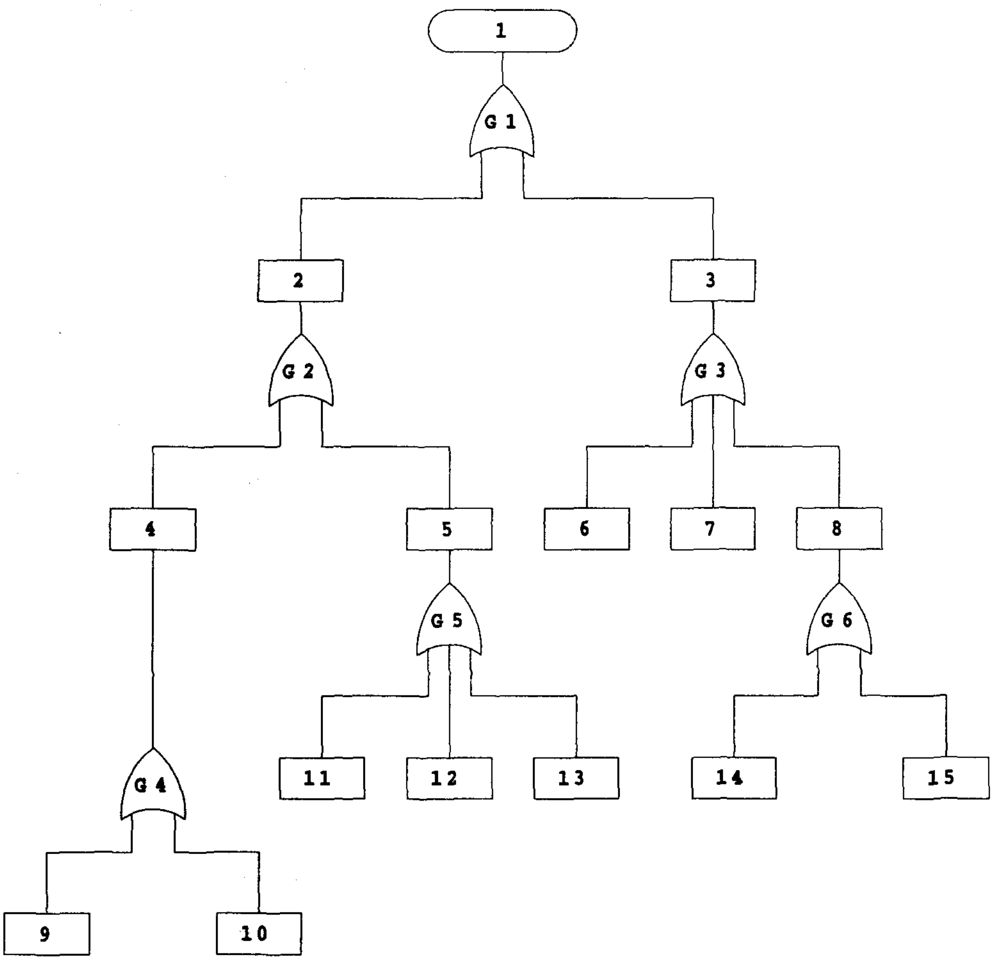
(Failure Mode Effects & Criticality Analysis)

No	Primary Components	Failure Modes	Failure Mechanisms	Effects	Criticality Evaluation		
					Frequency	Severity	Criticality
1	**Metal Housings and Crimp**	Hydraulic Fluid Leakage	Overstress Fracture	Loss of fluid pressure and system failure	2	3	7
			External Corrosion	Coupling difficulty. Leakage.	2	2	5
			Cyclic Pressure Fatigue Cracking	Loss of fluid pressure	2	2	5
2	**Coupling Seals**	Hydraulic Fluid Leakage	Excessive pressure and blowout	Loss of fluid pressure and system failure	2	3	7
			Thermal aging and cracking	Loss of fluid pressure	2	2	5
			Chemical degradation from contamination	Loss of fluid pressure	2	2	5
			Degradation from lubricant incompatibility	Loss of fluid pressure	2	3	7
3	**Detent Assembly**	Jammed	Contamination	Inability to Couple or Uncouple	2	2	5
			Corrosion	Inability to Couple or Uncouple	2	2	5
4	**Poppet Assembly**	Leakage	Wear of valve seat	Leakage uncoupled	2	2	5
			Particle contamination of valve seat	Leakage uncoupled	2	2	5
			Corrosion of valve seat	Leakage uncoupled	2	2	5
		Poppet Jammed Open	Contamination	Leakage uncoupled	2	2	5
			Misalignment	Leakage uncoupled	2	2	5
			Spring fracture due to fatigue failure	Leakage uncoupled	2	2	5
		Poppet Jammed Closed	Contamination	Inability to Couple	2	2	5
			Misalignment	Inability to Couple	2	2	5
5	**Hydraulic Hoses**	Hydraulic Fluid Leakage	Excessive pressure and blowout	Loss of fluid pressure and system failure	2	3	7
			Thermal aging and cracking	Loss of fluid pressure and system failure	2	2	5
			Chemical degradation from contamination	Leakage and pressure loss	2	3	7
			Degradation from lubricant incompatibility	Leakage and pressure loss	2	2	5
			Vibration fatigue	Leakage and pressure loss	2	3	7
			External wear of braiding and tube	Leakage and pressure loss	3	2	7
			Loss of electrical conductivity	Open current condition	1	3	5
			Cyclic Pressure Fatigue Cracking	Loss of fluid pressure and system failure	2	3	7

Appendix 6-3

F T A

(Fault Tree Analysis)



1. Hydraulic Hose Failure
2. Leakage
3. External Failure
4. Hose Blowout
5. Fitting Failure
6. Hose Bend
7. Expanding of Inner rubber
8. Flexibleness Rigidity
9. Rubber Damage
10. Construction of wire reinforcement
11. Degradation of clamp joint
12. Degradation of swaging
13. Damage of screw part
14. Rubber hardening

Appendix 6-4

Quality Function Deployment Level I (Requirements vs. Failure Mode/Mechanism Matrix)

Major Component	Metal Housing and Crimp			Coupling Seals				Detent Assembly		Poppet Assembly						Hose							
										Leakage			Open/Closed										
Requirements \ Failure Mechanisms	Overstress Fracture	External Corrosion	Cyclic Pressure Fatigue Cracking	Excessive pressure and blowout	Thermal aging and cracking	Chemical degradation	Lubricant incompatibility	Contamination	Corrosion	Wear	Particle contamination	Corrosion of valve	Contamination	Misalignment	Spring fatigue	Blowout	Thermal aging	Chemical degradation	Lubricant incompatibility	Vibration fatigue	External wear	Loss of electrical conductivity	Cyclic Pressure Fatigue
Cyclic Pressure Durability	●		○	●												●							○
Dimensional Stability																○		▲	▲				
Tight Bending Radius																●							●
Oil Compatibility				▲		○	○									▲		○	○				
Extended Operational Life	▲	●	○	▲	○	●	▲		○	○	▲	○	▲		○	▲	○	▲	▲	○	○	●	○
Severe Environmental Durability		○	●	▲	○	▲	▲		○			○				●	○	▲	▲	○			●
Electrical Conductivity	●	○	●																		●	○	
High Strength Tubing																○	○	●	●	●			○
Wear Resistant Braiding																					○	○	
Corrosion Resistant Fittings		○							○			○											
Easy Connect/Disconnect								○	○	○	○	○	○	○									
Low Leak Rate	○	●	○	○	○	●	●	▲		●		▲		●	●	○	○	●	●	○	○		○
Importance Ranking	22	37	37	23	27	22	20	12	36	23	12	39	12	14	14	48	36	28	28	32	32	23	46

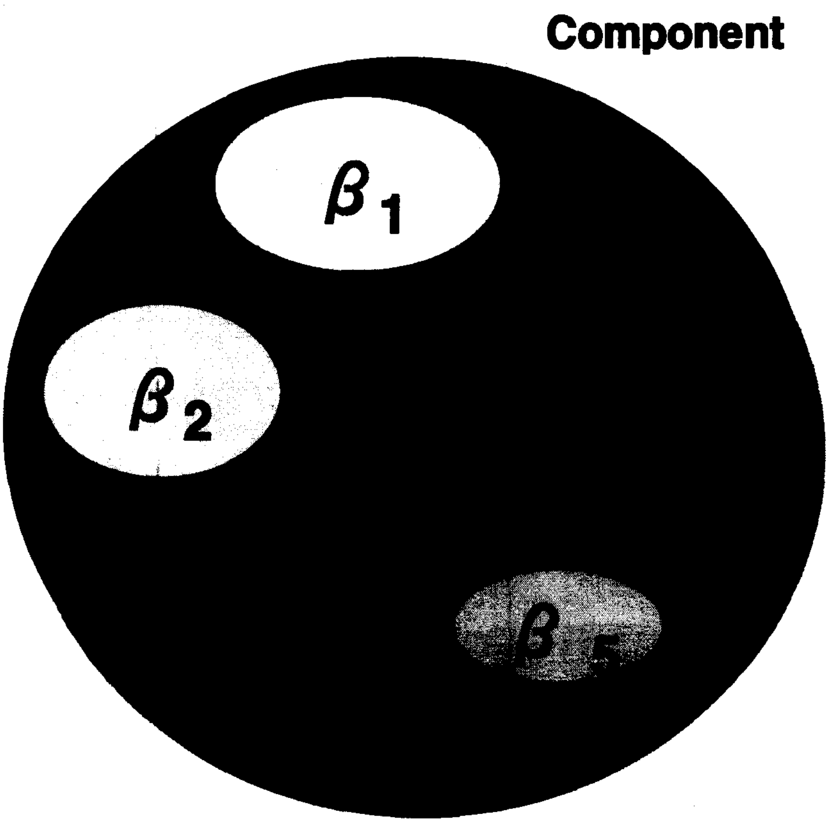
Appendix 6-5

Quality Function Deployment Level II

(Failure Mechanism vs. Standard Test Matrix)

No	Component		Failure Mechanism	Importance Ranking	Dimensional Check	Proof Test	Length Change	Burst Test	Cold Bend	Oil Resistance	Ozone Resistance	Impulse Test (Unaged)	Impulse Test (Aged)	Leakage	Conductivity	Vacuum	Cubical Expansion
					Standard Tests												
1	***Metal Housings and Crimps***		Overstress Fracture	22	●	○		○				▲	▲	○			
			External Corrosion	37													
			Cyclic Pressure Fatigue Cracking	37	●	●		●				○	○	●			
2	***Coupling Seals***		Excessive pressure and blowout	23	●	○		○				▲	▲	○			
			Thermal aging and cracking	27				▲		●	●	●	○	●			
			Chemical degradation from contamination	22						○	●						
			Degradation from lubricant incompatibility	20				▲		○		▲	▲				
3	***Detent Assembly***		Contamination	12													
			Corrosion	36							▲						
4	***Poppet***	***Leakage***	Wear of valve seat	23													
			Particle contamination of valve seat	12													
			Corrosion of valve seat	39							▲						
		Open	Contamination	12													
			Misalignment	14													
			Spring fracture due to fatigue failure	14													
		Closed	Contamination	12													
			Misalignment	14													
5	***Hoses***		Excessive pressure and blowout	48	●	○	●	○	○			▲	▲	○		▲	▲
			Thermal aging and cracking	36		▲	▲	▲	▲	●		●	○			▲	▲
			Chemical degradation from contamination	28			▲			○	●					●	●
			Degradation from lubricant incompatibility	28		▲	▲	▲	▲	○	●	▲	●			●	●
			Vibration Fatigue	32			▲		▲			▲	▲				
			External Wear	32	▲			●									
			Loss Conductivity	23											○		
			Cyclic Pressure Fatigue Cracking	46	▲	●	▲	●	▲			○	○	●			
6	***Test Effectiveness Score***				746	1444	750	1745	858	1197	750	1581	1889	1387	207	532	532
					9	4	8	2	7	6	8	3	1	5	11	10	10

Appendix 7 Component Failure Mode & Representative Accelerated Life Test Model



Shape Parameter	Stress Factor	Accelerated Life test Model
β_1	Temperature	- Arrhenius Model - Eyring Model
β_2	Non thermal Stress (Voltage, Load, Pressure, etc)	- Inverse Power Law Model
β_3	Accumulated Fatigue	- Miner Rule
β_4	Temperature & Humidity	- Temperature-Humidity Model (Transformed model of Eyring Model)
β_5	Temperature & Non thermal Stress	- Temperature-Nonthermal Model (Combined models of Arrhenius Mode and Inverse Power Law Model)

Appendix 8

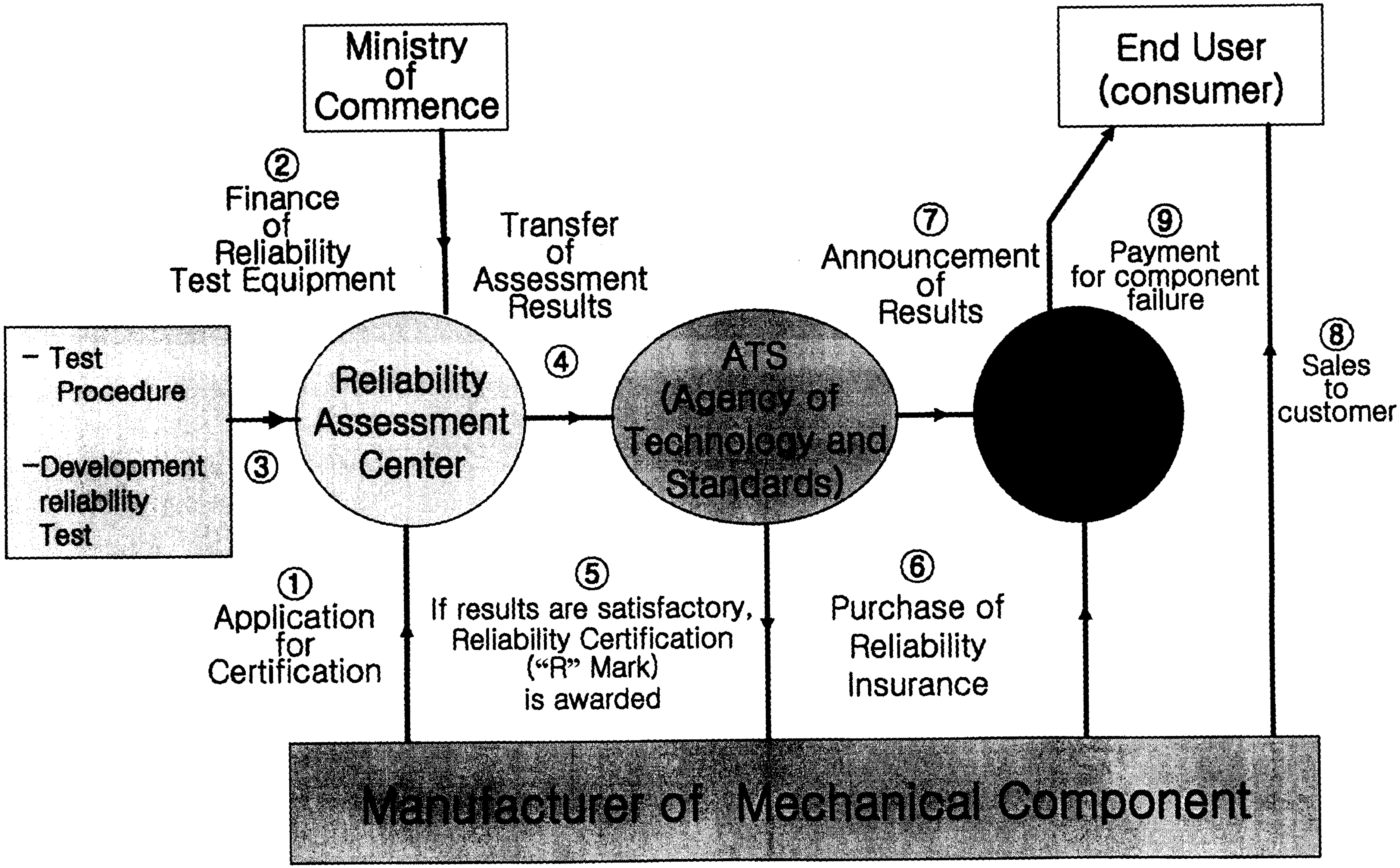
Welbull Shape Parameter

Relibility Standards Items depending on Types and Applications	Item	Beta Values (Weibull Shape Factor)			Eta Values (Weibull Characteristic Life--hours)		
		Low	Typical	High	Low	Typical	High
	Ball bearing	0.7	**1.3**	3.5	14,000	**40,000**	250,000
	Roller bearings	0.7	**1.3**	3.5	9,000	**50,000**	125,000
	Sleeve bearing	0.7	**1**	3	10,000	**50,000**	143,000
	Belts, drive	0.5	**1.2**	2.8	9,000	**30,000**	91,000
	Bellows, hydraulic	0.5	**1.3**	3	14,000	**50,000**	100,000
	Bolts	0.5	**3**	10	125,000	**300,000**	100,000,000
Industrial Air Breake	Clutches, friction	0.5	**1.4**	3	67,000	**100,000**	500,000
	Clutches, magnetic	0.8	**1**	1.6	100,000	**150,000**	333,000
	Couplings	0.8	**2**	6	25,000	**75,000**	333,000
	Couplings, gear	0.8	**2.5**	4	25,000	**75,000**	1,250,000
Hydraulic Actuator for Aircraft Landing Gear	Cylinders, hydraulic	1	**2**	3.8	9,000,000	**900,000**	200,000,000
	Diaphragm, metal	0.5	**3**	6	50,000	**65,000**	500,000
	Diaphragm, rubber	0.5	**1.1**	1.4	50,000	**60,000**	300,000
	Gaskets, hydraulics	0.5	**1.1**	1.4	700,000	**75,000**	3,300,000
	Filter, oil	0.5	**1.1**	1.4	20,000	**25,000**	125,000
Manual Transmission for Small Size Diesel Vehicle	Gears	0.5	**2**	6	33,000	**75,000**	500,000
High Capacity Hydrodynamic Clutch	Impellers, pumps	0.5	**2.5**	6	125,000	**150,000**	1,400,000
	Joints, mechanical	0.5	**1.2**	6	1,400,000	**150,000**	10,000,000
	Knife edges, fulcrum	0.5	**1**	6	1,700,000	**2,000,000**	16,700,000
	Liner, recip. comp. cyl.	0.5	**1.8**	3	20,000	**50,000**	300,000
	Nuts	0.5	**1.1**	1.4	14,000	**50,000**	500,000
	"O"-rings, elastomeric	0.5	**1.1**	1.4	5,000	**20,000**	33,000
	Packings, recip. comp. rod	0.5	**1.1**	1.4	5,000	**20,000**	33,000
	Pins	0.5	**1.4**	5	17,000	**50,000**	170,000
	Pivots	0.5	**1.4**	5	300,000	**400,000**	1,400,000
	Pistons, engines	0.5	**1.4**	3	20,000	**75,000**	170,000
	Pumps, lubricators	0.5	**1.1**	1.4	13,000	**50,000**	125,000
	Seals, mechanical	0.8	**1.4**	4	3,000	**25,000**	50,000
	Shafts, cent. pumps	0.8	**1.2**	3	50,000	**50,000**	300,000
	Springs	0.5	**1.1**	3	14,000	**25,000**	5,000,000
	Vibration mounts	0.5	**1.1**	2.2	17,000	**50,000**	200,000
	Wear rings, cent. pumps	0.5	**1.1**	4	10,000	**50,000**	90,000
Electro-hydraulic Proportional Pressure Reducing Valve	Valves, recip comp.	0.5	**1.4**	4	3,000	**40,000**	80,000

Relibility Standards Items depending on Types and Applications	Item	Beta Values (Weibull Shape Factor)			Eta Values (Weibull Characteristic Life--hours)		
		Low	Typical	High	Low	Typical	High
	Machinery Equipment						
	Circuit breakers	0.5	**1.5**	3	67,000	**100,000**	1,400,000
	Compressors, centrifugal	0.5	**1.9**	3	20,000	**60,000**	120,000
	Compressor blades	0.5	**2.5**	3	400,000	**800,000**	1,500,000
	Compressor vanes	0.5	**3**	4	500,000	**1,000,000**	2,000,000
	Diaphgram couplings	0.5	**2**	4	125,000	**300,000**	600,000
	Gas turb. comp. blades/vanes	1.2	**2.5**	6.6	10,000	**250,000**	300,000
	Gas turb. blades/vanes	0.9	**1.6**	2.7	10,000	**125,000**	160,000
	Motors, AC	0.5	**1.2**	3	1,000	**100,000**	200,000
	Motors, DC	0.5	**1.2**	3	100	**50,000**	100,000
	Pumps, centrifugal	0.5	**1.2**	3	1,000	**35,000**	125,000
	Steam turbines	0.5	**1.7**	3	11,000	**65,000**	170,000
	Steam turbine blades	0.5	**2.5**	3	400,000	**800,000**	1,500,000
	Steam turbine vanes	0.5	**3**	3	500,000	**900,000**	1,800,000
	Transformers	0.5	**1.1**	3	14,000	**200,000**	14,200,000
	Instrumentation						
	Controllers, pneumatic	0.5	**1.1**	2	1,000	**25,000**	1,000,000
	Controllers, solid state	0.5	**0.7**	1.1	20,000	**100,000**	200,000
	Control valves	0.5	**1**	2	14,000	**100,000**	333,000
	Motorized valves	0.5	**1.1**	3	17,000	**25,000**	1,000,000
	Solenoid valves	0.5	**1.1**	3	50,000	**75,000**	1,000,000
	Transducers	0.5	**1**	3	11,000	**20,000**	90,000
	Transmitters	0.5	**1**	2	100,000	**150,000**	1,100,000
	Temperature indicators	0.5	**1**	2	140,000	**150,000**	3,300,000
	Pressure indicators	0.5	**1.2**	3	110,000	**125,000**	3,300,000
	Flow instrumentation	0.5	**1**	3	100,000	**125,000**	10,000,000
	Level instrumentation	0.5	**1**	3	14,000	**25,000**	500,000
	Electro-mechanical parts	0.5	**1**	3	13,000	**25,000**	1,000,000
	Static Equipment						
Shell & Tube Type Oil Coolers for Industrial	Boilers, condensers	0.5	**1.2**	3	11,000	**50,000**	3,300,000
	Pressure vessels	0.5	**1.5**	6	1,250,000	**2,000,000**	33,000,000
	Filters, strainers	0.5	**1**	3	5,000,000	**5,000,000**	200,000,000
	Check valves	0.5	**1**	3	100,000	**100,000**	1,250,000
	Relief valves	0.5	**1**	3	100,000	**100,000**	1,000,000
	Service Liquids						
	Coolants	0.5	**1.1**	2	11,000	**15,000**	33,000
	Lubricants, screw compr.	0.5	**1.1**	3	11,000	**15,000**	40,000
	Lube oils, mineral	0.5	**1.1**	3	3,000	**10,000**	25,000
	Lube oils, synthetic	0.5	**1.1**	3	33,000	**50,000**	250,000
	Greases	0.5	**1.1**	3	7,000	**10,000**	33,000

Appendix 9

General Structure of National Reliability Assessment Process



Appendix 10

1. No failure Acceptance Rule

Requirement	Equation
B10 life	$t = B_{100p} \cdot \left[\frac{\ln(1 - C_L)}{n ln(1 - p)} \right]^{\frac{1}{\beta}}$
MTTF	$t = \frac{MTTF}{\Gamma(1 + \frac{1}{\beta})} [- \frac{\ln(1 - C_L)}{n}]^{\frac{1}{\beta}}$

* Acceptance Rule : If all the samples n show no failure during testing time t, the tested component will pass on the reliability qualification test.

* Equation for no failure testing time

where t : testing time

C_L : confidence level

p : percent number, p=0.1 for B10 life

Γ : Gammer function

β : shape parameter of Weibull distribution

n : sample size

2. One failure Acceptance Rule

*Acceptance Rule : If one sample fails during no failure testing time t and if the failure mode is not critical one to the component functions, then we give a chance to additional test to the remainder component (n-1). And all the (n-1) samples show no failure during additional testing time t', then the tested component will pass on the reliability qualification test.

* Equation for additional testing time t' for (n-1) samples

$$t' = \frac{c - t_1 - (n-1)t}{n-1}$$

where t' : additional testing time for (n-1) samples

c : testing time for n samples in case one sample is allowed to fail.

t_1 : failure time of one sample during no failure time test

t : no failure testing time for sample n

Appendix 11 "Reliability Test Time" & "Necessity of Accelerated Test"

Period / Activity	1 Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Development of Assessment Test procedure (Standard)	■	■	■									
Development of Testing System for Assessment				■	■	■	■					
Reliability Test								■	■			
Prepare Report										■	■	
Presentation of Experiment Result to Government												■

Appendix 12

Component List for Reliability Assessment

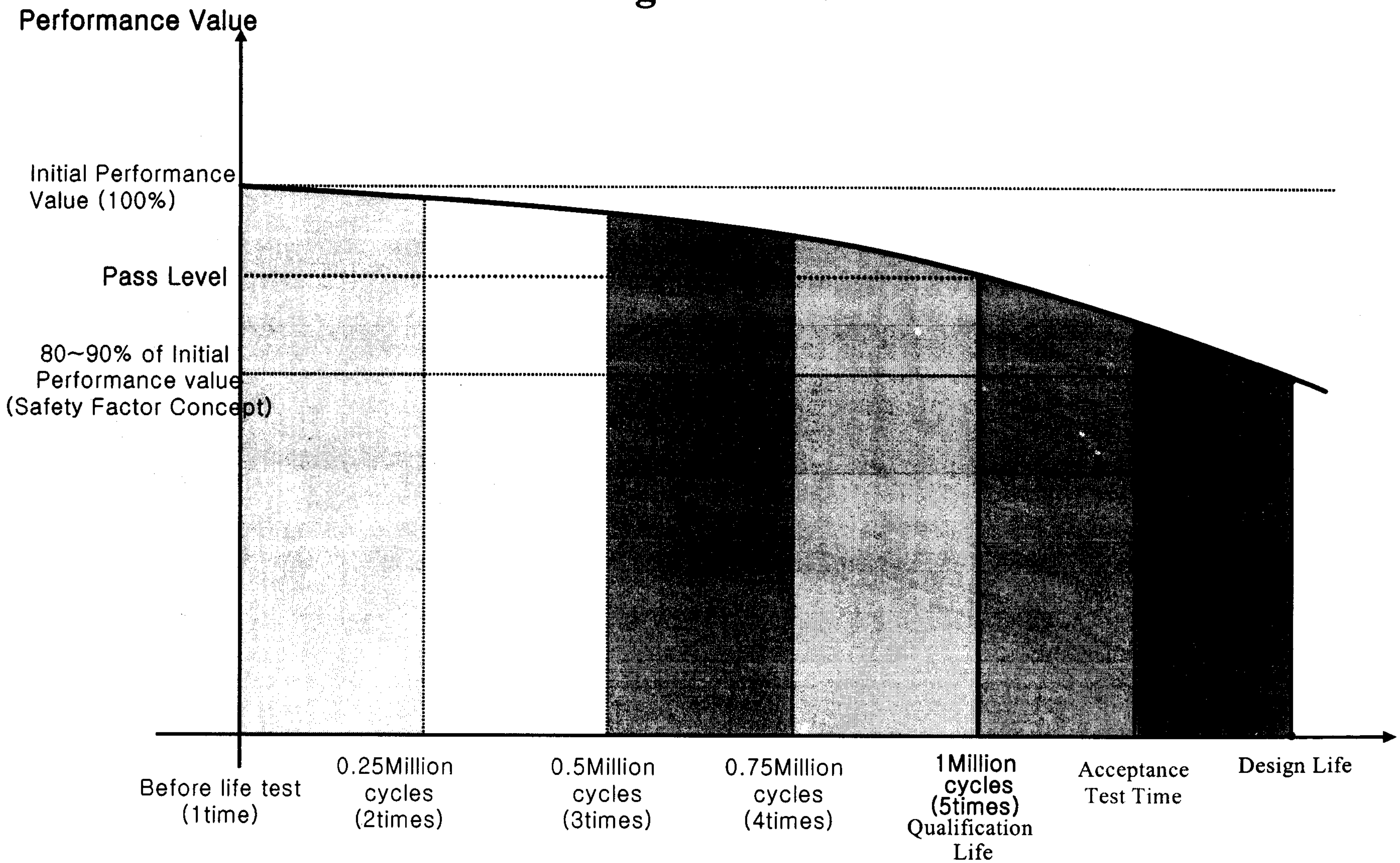
Year	No	Items
2000	1	Hydraulic Cylinder
	2	Pneumatic Cylinder
2001	1	Hydraulic Valve
	2	Pneumatic Valve
	3	Rubber Type Anti-Vibration Mount
	4	Transmission
	5	Gear Box
	6	Oil Pump
	7	Hydraulic Motors
	8	Ultrasonic Components
	9	Clutches
2002	1	Bearing
	2	Brake for Industries
	3	Flexible Hose & Fitting
	4	Seal & Packing
	5	Mechanical Springs
	6	Spindle Shaft Unit
	7	Proportional Valves
	8	Breaker
	9	Diesel Engines
	10	Oil Cooler
2003	1	High Pressure Injection Pump
	2	Track Drive Unit
	3	High Pressure Control Valve
	4	Hydrostatic Transmission
	5	Swing Drive Unit
	6	Tandem Pump
	7	Accumulator
	8	Industrial Continuously Variable Speed Changer
	9	Servo Actuator
	10	Lubricator
	11	Servo Valve
	12	Multiple control Valve
	13	Compressed Air Pressure Regulator
	14	Hydraulic Filter

Appendix 12

Component List for Reliability Assessment

year	No	Items
2004	1	Compressor
	2	Centrifugal Pump
	3	Mechanical Seal
	4	Axle
	5	Industrial Solenoid
	6	Pressure Transducer
	7	Coupling
	8	Load Cell
	9	Heat Exchanger
	10	Industrial Nozzle
	11	Industrial Damper
	12	Rotary Actuator
	13	Chuck
	14	Industrial Lift
	15	Industrial Propeller Shaft
	16	Vacuum Pump
	17	Linear Motor
	18	Ball Screw
	19	Aerial Ladder

Appendix 13 Degradation Characteristics of Performance during Life Test



Appendix 14

Determination of Test Items for Performance Degradation

No	Component	Test Item	Priority by Importance for QFD Level 2	Determination of test items for Performance degradation
1	Bearing	① Precision test ② Rigidity certification test ③ Friction certification test ④ Adhesion test ⑤ High temperature oil test ⑥ Low temperature test ⑦ Contamination test ⑧ Vibration & Noise test ⑨ Wear test	① Rigidity certification test ② Vibration & Noise test ③ Lubrication test ④ Environmental test ⑤ Wear test ⑥ Flame test ⑦ Grease Leakage test ⑧ Low temperature torque test ⑨ Water washing test	① Rigidity certification test ② Friction certification test
2	Brake	① Warming up test ② Leakage test ③ Brake performance test ④ Pressure proof test ⑤ Brake strength test ⑥ Residual drag test ⑦ Surface temperature test ⑧ Parking brake performance test ⑨ Self-adjustor test ⑩ Parking brake strength test ⑪ Vibration test ⑫ Corrosion test ⑬ Under water test ⑭ High & Low temperature test	① Brake performance test ② Brake strength test ③ Parking brake performance test ④ Parking brake strength test ⑤ Surface temperature test ⑥ Leakage test ⑦ High & Low temperature test ⑧ Pressure proof test ⑨ Residual drag test ⑩ Corrosion test ⑪ Vibration test ⑫ Under water test ⑬ Warming up test ⑭ Self-adjustor test	① Brake performance test ② Parking brake performance test
3	Mechanical Spring	① Load test ② Spring constant test ③ Permanent set test ④ High temperature resistant test ⑤ Low temperature test ⑥ Humidity test ⑦ Salt spray test	① Spring constant test ② Load test ③ Permanent set test ④ Humidity test ⑤ Salt spray test ⑥ Low temperature test ⑦ High temperature resistant test	① Spring constant test ② Load test
4	Flexible Hose & Fitting	① Length variation test ② Internal pressure test ③ Low temperature bending test ④ Low temperature internal pressure test ⑤ Ozon aging test ⑥ Burst test ⑦ Impulse pressure test ⑧ Rubber modulus expansion test ⑨ Temperature resistance test	① Burst test ② Impulse pressure test ③ Internal pressure test ④ Low temperature bending test ⑤ Length variation test ⑥ Internal fluidity test ⑦ Vacumm test ⑧ Rubber modulus expansion test ⑨ Temperature resistance test	① Length variation test ② Internal pressure test