TECHNICAL RELIABILITY

Table A.1. Values for mechanical and electrical equipment failures

MECHANICAL AND ELECTRIC EQUIPMENT	FAILURES/YEAR
alternator	0,009-0,08
pumps	
centrifuge	0,09-0,3
boiler	0,9-4
against fire	0,1-1
fuel-oil	0,05-0,4
oil	0,09-0,3
vacuum	0,2
(leak 50%)	
(without transmission 50%)	
air compressor	0,02-0,07
compressors	
centrifugal	1
to piston	4
electric	0,8-2,5
packaging	0,0002-0,008
pneumatic equipment	
conector	0,01
relay	0,2
mechanic filter	0,009-0,02
hand reducer filter of air	0,4-0,8
brake	
friction	0,004-0,03
magnetic	0,02-0,05
(loose 55%)	
(slipping 45%)	
diesel generator	1,0-35
heat exchanger	0,008-0,3
junctions	
pipe	0,004
ring in "O"	0,002-0,004
diesel engine	2,5-50
(air and fuel 23%)	
(injectors 7%)	
(started, battery 1%)	
(refrigeration 23%)	
(stamps and others 16%)	
(mechanical parts in movement 30%)	
electric engine	
c.a	0,01-0,04
c.c	0,003-0,04
pressure vessel	0,00001-0,000001

Table A.1. Continuation

MECHANICAL AND ELECTRIC EQUIPMENT	FAILURES/YEAR
bearing	
balls	0,0008-0,1
rollers	0,004
axials	0,004-0,04
sapphire	0,003
(loose 40%)	
(worn-out 60%)	
sprinkler	0,004
water sistem against fire	0,08-2
mechanic stamp of pump	0,01-0,001
tank pipe	
25 mm diameter	0,00003
50mm diameter	0,000001
150 mm diamater	0,000003
steam turbine	0,3-0,7
mechanic, hidraulic pneumatic valves in normal service conditions	
ball	0,009-0,03
wing nut	0,009-0,2
diaphragm	0,0006-0,09
door	0,01-0,1
needle	0,01
retention	0,02-0,04
relief	0,03-0,08
selenoid	0,01-0,09
(block 5%)	
(external leak 15%)	
(internal leak 60%)	
(glued 20%)	
valve actuators	
intermittent closing	0,04-0,3
opens in air failure	0,0009-0,03
(failure 10%)	
(intermittent 90%)	

Table A.2. Values for electronic components for electronic industry failures

ELECTRONIC COMPONENTS	FAILURES/10(9) HOURS
Electrical power supply	115.000 (aprox 1 per year)
Speaker	9000
Photoelectric cell	15000
Local network	90000 a 200000
Capacitor	
electrolytic	4 a 450
(open circuit 20%)	
(short circuit 80%)	
ceramic	30
(open circuit 1%)	
(short circuit 99%)	
variable	30 a 3500
Connectors	
Circular	90 a 500
Coaxial	100 a 500
PCB	1 a 100
pin	1 a 100
pneumatic	1000000
DIL	0.5
(high resistance 10%)	
(intermittent 20%)	
(open circuit 60%)	
(short circuit 10%)	
Connexions	
Welded by hand with tin	1 to 25
Welded in tin bath	0,5 to 2
Welded	0,5 to 2
Coiled	0,05 to 0,5
Crimped	1 to 3
Power cord	100 to 300
(Break 50%)	
(Without contact 40%)	
(without welded point 10%)	
Diodes	
Si high power	100 to 500
Si low power	10 to 30
Zener	50 to 100
(open circuit 50 %)	
(short circuit 50 %)	
Varactor	1.000
Tiristor	20 to 200

Table A.2. Continuation

ELECTRONIC COMPONENTS	FAILURES/10(9) HOURS
Optical fiber	
Connector	2500 to 8000
Cable/km	100
LED	800 to 1100
Laser	500 to 1000
Si avalanche foto-diode	800
Pin avalanche foto-diode	20
Optocoupler	20 to 100
Power supply	
Converter (c.c./a.c.)	3500 to 25000
Converter (a.c./c.c.)	2500 to 25000
Fuse	100 to 250
(Fail to open 15%)	
(Open 10%)	
(Slow to open 10%)	
Switchs < 600 V	50
Switchs	
Micro	350 to 1100
(High resistance 60%)	
(Do not work 10%)	
(Open 30%)	
Lever	350 to 1000
Key	10 to 25
Button	250 to 1000
(Open 80%)	
(Short Circuit 20%)	
Rotary	50 to 500
(Bow damage 10%)	
(Fail to close 5%)	
(Fail to open 40%)	
(Intermittent Opening 10	
Pilot lamp	5000
Integrated circuits	3
Tape drive	90.000 to 450.000
Sockets	35
From Institute of Chemical Engineers	

Table A.2b. Values for electronic components for consumer electronics

ELECTRONIC COMPONENTS	FAILURES/10(9) HOURS
Speakers	400
Coils and power supply transformers	300
Coils and BF transformers	30
Coils and FI and BF transformers	50
Integrated circuits (< 32 transistors or doors)	3000
Capacitor	4 a 450
Electrilitic	
Aluminium Oxide	500
Tantalum	200
Ceramic	50
Plastic	50
Mica	40
Trimmer	200
Connectors	80
Coiled connections	0.5
Welded connections	5
Quartz	200
Light emitting diodes (LED)	700
Rectifiers and general purpose diodes	200
Voltage regulator diodes	360
Fuse and fuse holder	300
Switches and commutators	250
Pilot lamp	200
Delay lines	30
Single optoaislators	1000
Carbon or metal film resistors	30
Power Resistors	600
Variable Resistors	200
No lineal resistors (Termistors and varistors)	150
Tiristors	500
TV Line Output Transformers	1000
Low power BF Transistors (<= 1 W)	450
Low power FI and BF Transistors (<= 1 W)	540
Power Transistors (> 1 W)	1900
TV image tubes	1000
Courtesy of Enrique Navarro (UPC)	

Table A.3. Devices failures

DEVICES	FAILURES/YEAR
Alarms	
Simple alarm circuit	0,03
Alarm panel	0,4
Alarm siren	0,04 to 0,4
Analyzer	
CO2	1 to 10
Conductivity	0,5 to 5
Dew point	0,8
Oxygen	0,5 to 5
Hydrogen	0,8
pH	0,5 to 5
Gas-liquid chromatograph	30
H2O (in gas)	8
Hardness of water	10
Flow (in fluids)	
Differential pressure	0,5 to 1,5
Variable area	0,3 to 1
Magnetic meter	0,5 to 2
Turbine	0,08 to 0,5
Positive displacement	0,1 to 1
Flow (in solids)	
Load cell	4
Conveyer belt	15
Controler	0,2 to 0,4
Current/pressure converter	0,49
Electro-pneumatic converter	0,02 to 0,07
Fire detector	
ionization	0,03 to 0,06
ultraviolet	0,04 to 0,05
Temperature	0,008 to 0,07
Galvanometer indicator	0,02 to 0,07
(Bleed 30%)	
(Without indication 70%)	
Flow switch	0,03 to 0,3
Control loops	
Presure	1,1 to 1,3
Flow	1,5 to 2,1
Level	2,2 to 2,4
Temperature	1 to 2
Pressure gauge	0,088
Level (liquids)	1,70
Local controler	0,03 to 0,2
Gauge	0,08 to 0,1
Glass level	0,1 to 5
Switch	0,008 to 0,04
pneumatic differential pressure	1,5 to 2
Electronic differential pressure	0,08 to 0,1

Table A.3. Continuation

DEVICES	FAILURES/YEAR
Floater	0,2 to 2
Capacity	0,22
Bubble	0,5 to 1
Conductivity	2,36
Level (Solids)	7
Mainframe computer	**30 a 60**
Mini	0,8 to 6
Micro (CPU)	0,2 to 0,8
Fault tolerance computer	0,002 to 0,00001
Weight – Load Cell	3,5
Pressure	
Manometer	0,1
Pressure switch	0,3
Register	0,22
Pneumatic relay	0,17
Temperature	0,35
Thermocouple	0,1 to 0,5
Resistance probe	0,4
Hg Thermometer	0,03
Vapor pressure bulb	0,4
temperature transducer	0,9
radiation pyrometer	2
Optical pyrometer	10
Control valve	0,2 to 0,9
Solenoid	0,2 to 0,4
Alleviation	0,0022
Piston	0,78
Positioner	0,44
Manual valve	0,13

HUMAN RELIABILITY

Table A.4. Probability of errors made

HEP = Human Error Probability

READING INDICATORS	HEP
analogic indicator	0,003 (0,001-0,01)
digital reading	0,001 (0,005-0,005)
graphic recoder	0,006 (0,002-0,02)
multiple graphic recoder	0,05 (0,01-0,2)
graphics	0,01 (0,005-0,05)
numerical display lamps	0,001 (0,0005-0,005)
faulty instrument without indicators to the operator	0,1 (0,02-0,2)
VERIFICATION OF INDICATORS	**HEP**
digital indicators	0,001 (0,0005-0,005)
analogic indicator with visible graduations	0,001 (0,0005-0,005)
analogic indicators with poorly visible graduations	0,002 (0,001-0,01)
analogic indicators without graduations	0,003 (0,001-0,01)
analogic recoder with visible graduations	0,002 (0,001-0,01)
analogic recoder without graduations	0,006 (0,002-0,02)
condirmation of the change of state of an indicator lamp	despreciable
check for wrong indication lamp (inside a group of lamps)	0,003 (0,001-0,01)
misinterpretation of the indication on the indicator lamps	0,001 (0,0005-0,005)
MANOEUVRES IN VALVES	**HEP**
change or restore a wrong valve from a group of valves with similar appearance	0,005 (0,002-0,02)
change or restore a wrong valve from a group of valves with similar appearance which had been changed before	0,0001 (0,00005-0,001)
change or restore a wrong switch from a group of switches with similar appearance	0,003 (0,001-0,1)
complete the change of position of a valve by pressing a switch until a pilot light indicates that the change has been made	0,003 (0,001-0,1)
to a valve that is blocked the operator mistakenly thinks that the valve is fully open (or closed)	
valves of slider shank	
block > = 3/4 path	0,005 (0,002-0,02)
if there is any position indicator	0,001 (0,0005-0,01)
other valves	
it there is any position indicator	0,001 (0,0005-0,01)
without position indicator	0,01 (0,003-0,1)
MANOEUVRES IN MANUAL CONTROLS	**HEP**
erroneous control selection between identical controllers identified with labels	0,003 (0,001-0,01)
erroneous control selection between functionally grouped controllers	0,001 (0,0005-0,005)
erroneous control selection on the panel with clearly marked lines of chart	0,0005 (0,0001-0,001)
turning the control in the wrong direction, without violating the usual action	0,0005 (0,0001-0,001)
turning the control in the wrong direction in normal surroundings, violating the usual action	0,003 (0,001-0,01)
turning the control in the wrong direction under high stress, violating the usual action	0,5 (0,1-0,9)
place a multiple selector in wrong position	0,001 (0,0001-0,1)
plug in wrongly a connector	0,01 (0,005-0,05)

Table A.5. Probability of errors by default (omission)

HEP = Human Error Probability

TASK	HEP
Procedures with checklist	
<= 10 item	0,001 (0,0005-0,005)
> 10 item	0,003 (0,001-0,01)
erroneously used checks	0,5 (0,1-0,9)
Procedures without checklist	
<= 10 item	0,003 (0,001-0,01)
> 10 item	0,01 (0,005 – 0,05)

Table A.6. Probability of errors in instructions given orally or in arithmetic calculations

HEP = Human Error Probability

TASK	HEP
items not written by the operator	
remember any item among a number of:	
1	0,001 (0,0005-0,005)
2	0,003 (0,001-0,01)
3	0,01 (0,005-0,05)
4	0,03 (0,01-0,1)
5	0,1 (0,05-0,5)
remember any item if the supervisor checks it to see that the task has been performed	negligible
items written by the operator	
remember any item (writing error)	0,001 (0,0005-0,005)
simple arithmetic calculations with or without calculator	0,01 (0,005-0,05)
detection of arithmetic calculations out of range	0,05 (0,01-0,09)

Table A.7. Probability of errors in chosing the right warning between some of them

HEP = Human Error Probability

Number of Warnings	HEP
1	0,0001 (0,00005-0,001
2	0,0006 (0,00006-0,006)
3	0,001 (0,0001-0,01
4	0,002 (0,0002-0,02)
5	0,003 (0,0003-0,03)
6	0,005 (0,0005-0,05)
7	0,009 (0,0009-0,09)
8	0,02 (0,002-0,2)
9	0,03 (0,003-0,3)
10	0,05 (0,005-0,5)
11-15	0,1 (0,01-0,999)
16-20	0,15 (0,015-0,999)
21-40	0,20 (0,02-0,999)
+ 40	0,25 (0,025-0,999)

Table A.8. HEP (human error probability) correction factors according to the stress level

STRESS LEVEL	HEP	UNCERTAINTY ENVIRONMENT
experienced staff		
very low	2 x HEP	2 x table value
optimal	HEP	table value
moderately high		
discrete tasks	2 x HEP	2 x table value
dynamic tasks	5 x HEP	5 x table value
extremely high	0,25	0,03-0,75
novice staff		
very low	2 x HEP	2 x table value
optimal		
discrete tasks	HEP	table value
dynamic tasks	2 x HEP	2 x table value
moderately high		
discrete tasks	4 x HEP	4 x table value
dynamic tasks	10 x HEP	10 x table value
extremely high	0,25	0,03-0,75

Note: stress levels are represented qualitatively in Figure 7.2 and mean:

- Very low: No decisions are required. Periodic reading of indicators.
- Optimal: Reasonable work. Control actions. Decision made in comfortable conditions.
- Moderately high: Fast actions. Mistaken decisions can cause damages or emergency conditions that force the plant to stop.
- Extremely high: Imminent damage of one's own life. Fall of a car down a cliff. Uncontrolled descent of an airplane. Accident at a nuclear power plant due to significant loss of cooling liquid.

FIRE AND EXPLOSION DOW INDEX

Table A.9.1 Dow Chemical material factor

NJ / NF	0	1	2	3	4
0	1	14	24	29	40
1	4	14	24	29	40
2	10	14	24	29	40
3	16	16	24	29	40
4	21	21	24	29	40

Table A.9.2 General Process Hazards (GPH)

GENERAL PROCESS	FACTOR
Exotermic Reactions	
hydrogenation	0,30
Isomerization	0,30
sulfonation	0,30
Neutralization	0,30
Alkylation	0,50
oxidation	
Controlled (without CO2 or H2O)	0,50
With strong oxidizing agents	1,0
halogenation	1,0
condensation	0,5
polymerization	1,0
endothermic reactions	
calcination	0,2
electrolysis	0,2
pyrolysis	0,2
factor multiplier of fuel use as heat source	0,2
Material Handling and Transfer	
Liquid loading and unloading	0,5
centrifuges, reactors or tanks stirred at the process temperature	0,5
gas storage	0,85
storage of liquids	
Flashpoint < = 37,8 ºC	0,85
Flashpoint > 37,8 ºC	0,25
Solid storage	
particle size <= 40 mm	0,65
particle size > 40 mm	0,40
Process units in enclosed areas	
filters and collectors of combustible dust	0,5
Equipment for processing combustible liquids	
Between FP and BP	0,3
Temperature >= BP	0,6
multiplicative factor for quantities >= 4.5 Tm	1,5
inadequate access to emergency equipment	0,35
insufficient drainage	0,50

Table A.9. 3 Special Process Hazards (SPH)

SPECIAL PROCESS	FACTOR
Process Temperature	
Between FP and BP	0,30
Temperature >= BP	0,60
prone to spontaneous combustion	0,75
operation in empty mode	0,50
operations within flammability limits	
Failure of equipment or instruments	0,30
Continuous processes	0,80
operation in the presence of explosive powders or suspending substances	
Particle size	
>175	0,25
Between 150-175	0,50
Between 100-150	**0,75**
Between 75-100	1,25
<= 75	2,0
inert gas multiplier factor	0,5
triggering pressure safety valves	
very viscous material	0,7
compressed gas	1,2
Liquid gas	1,3
Damage to structures a cause low temperatures	
Carbon Steel temperature between -29 ºC and 10 ºC	0,3
Carbon Steel temperature between <29 ºC	0,5
Other materials <= transition temperature	0,2
Amount of combustible material	0,5
Corrosion and erosion	0,1
< 0,5 mm/year	0,2
Between 0,5 and 1 mm/year	0,5
>= 1mm/year	0,5
risk of failure a cause of the material fatigue	0,75
Lost due to leaks	
minor losses due to seals	0,1
regular losses due to seals	0,3
loss of abrasive fluids	0,4
Ovens next to the process	
standard burner	1,0
burner with pressure injection	0,5
Oil thermal fluid exchangers	
amount of oil < 19 m3	
Temperature between FP and BP	0,15
Temperature > BP	0,25
amount of oil between 19 and 38 m3	
Temperature between FP and BP	0,3
Temperature > BP	0,4

Table A.9.3 Continuation

SPECIAL PROCESS	FACTOR
Oil thermal fluid exchangers	
amount of oil between 38 and 95 m3	
Temperature between FP and BP	0,5
Temperature > BP	0,75
amount of oil > = 95 m3	
Temperature between FP and BP	0,75
Temperature > BP	1,15
power of rotating equipment (pumps and compressors)	0,5

Table A.9.4 Degree of risk in Dow scale

IIE VALUE	DOW DEGREE
1 to 60	Light
61 to 96	Fair
97-127	Medium
128-158	Intens
>158	Strong

**** Thanks to Antoni Creus for let me use those tables from his book Fiabilidad y Seguridad (MARCOMBO, 1992)*

HAZARD AND OPERATIONS METHOD

Table A.10 Values used for HAZOP evaluation

CAUSES	FREQUENCY	POWER
Continue	> 10 /year	1
Power supply fail	1/year	0
Human mistake	1/year	0
Strong human mistake	1/10 years	-1
Control system fail	1/10 years	-1
Pump failure	1/100 years	-2
Tank break	1/100.000 years	-5
unfeasibility	1/1.000.000 years	-6

CONSEQUENCES		POWER
Safe		0
Low risk		1
risk with loss of time or low damages		2
High risk or fire		3
Peolpe dead or explosion		4
Tens of deads or catastrophe		5

PROTECTION	RELIABILITY	POWER
None	1.0	1
Operation procedure	0,1	0
Check procedure	0,01	0
Automatic control system	0,01	-1
Alleviation security system	0,001	-1