CHAPTER 2

FMECA of a Scraper Winch

The FMECA for this simple piece of equipment is many pages long! This is typical for this type of study. Only a sample of the tabulation is given here. Definitions for Severity and Probability of Occurrence are given below. Recommendations proceeding from the FMECA are given after the tabulation.

Effect Severity

For Effect Severity, a scale of 1 to 5 was used. The Effect Severity was rated on how the specific failure will influence the main purpose of the winch, being drum rotation to wind up the scraper rope in order to pull the scraper.

1 – Low Probability for the drums to not be able to rotate after the failure has occurred.

2 – Medium to Low Probability for the drums to not be able to rotate after the failure has occurred.

3 – Medium Probability for the drums to not be able to rotate after the failure has occurred.

4 – Medium to High Probability for the drums to not be able to rotate after the failure has occurred.

5 – High Probability for the drums to not be able to rotate after the failure has occurred.

Occurrence Probability

For Occurrence Probability, a scale of 1 to 5 was also used.

1 – Low Probability of the failure occurring.

2 – Medium to Low Probability of the failure occurring.

3 – Medium Probability of the failure occurring.

4 – Medium to High Probability of the failure occurring.

5 – High Probability of the failure occurring.

Recommendations from the FMECA

Design features to improve reliability as identified by following the FMECA process include:

1. To minimise gearbox damage, the gearbox is a sealed unit.

2. To minimise the probability of the motor pinion coming loose, the motor shaft is tapered and so is the pinion bore and key. There is also a lock washer and lock nut to secure the motor pinion.

3. To withstand greater loads and minimise bearing damage, duplex bearings and oil seals are fitted for the clutch gear bearings and the main shaft bearings.

4. The pedestal bearing is easily accessible for the replacement thereof.

5. Between the drums a curved flat bar section is provided to prevent the rope from coiling between the drums.

6. Modern winch motors are purposely designed and built to operate at large slip angles.

7. Pressed sleeves are fitted to the shafts to locate the gears and bearings.

8. All interference fit components are factory pressed with a 100 ton press.

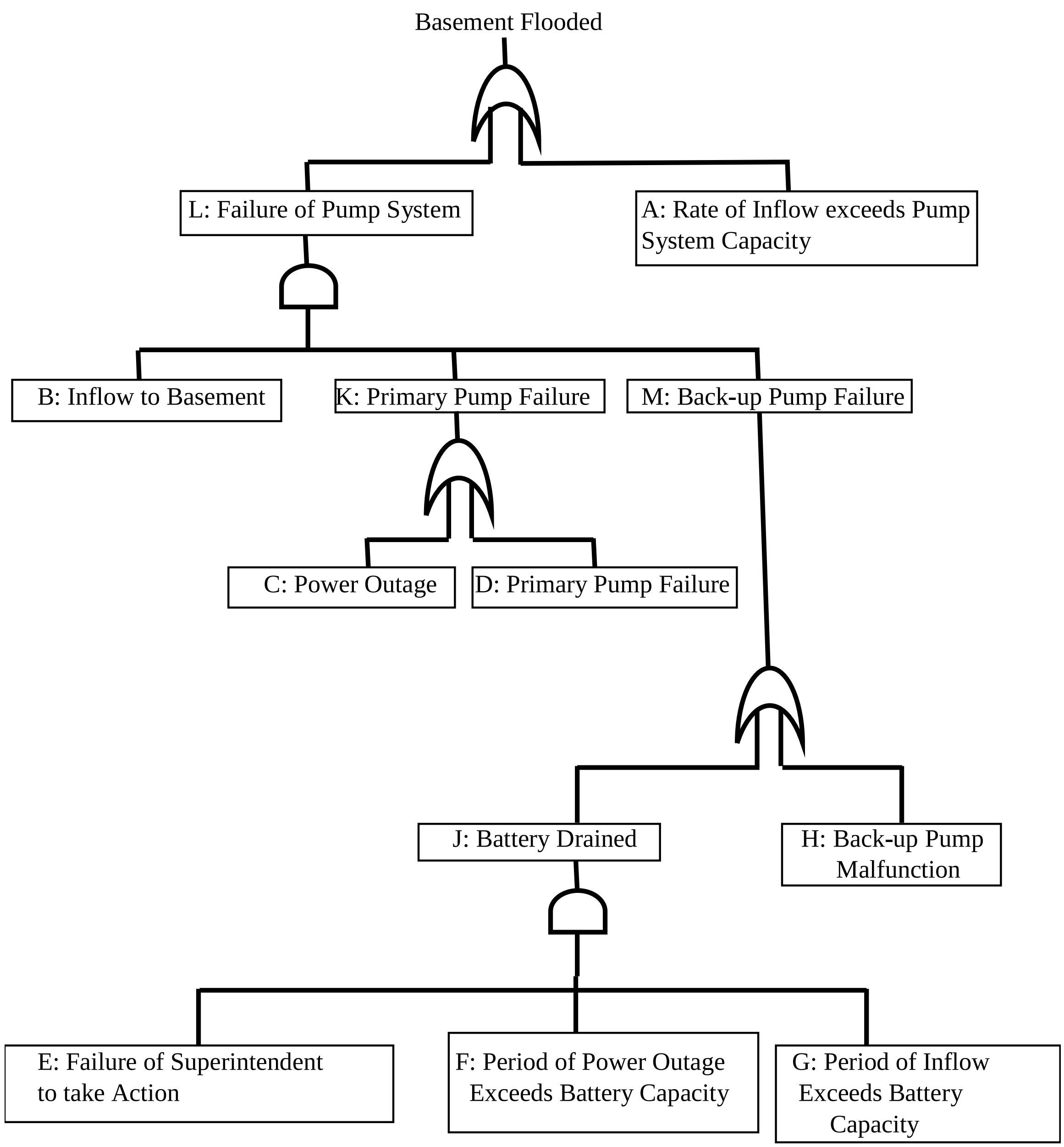
9. The modern scraper winch is of a very robust design in order to survive underground transport and operations.

Item	Function	Failure	Effects	Severity of the Effect	Cause	Probability of Occurrence	Control Action
Motor	Power source	Insulation breakdown	Motor failure	5	Motor cannot stand load variation	3	Design motor to operate at large slip values
Motor	Power source	Water ingress	Motor failure	5	Phase to phase or phase to earth	3	Improved sealing
Motor Shaft	Torque transmission	Shaft failure	Winch will not operate	5	Design torque exceeded	1	Redesign for adequate strength
Motor Pinion	Torque transmission	Pinion comes loose on shaft	Damage to gears and shaft	5	Incorrect fit on shaft	1	Redesign with tapered shaft, double keyway, locknut and lockwasher
Motor Pinion	Torque transmission	Tooth damage	Degradation failure	5	Lack of lubrication	1	Change to sealed for life gearbox with synthetic oil
Motor Pinion	Torque transmission	Tooth damage	Degradation failure	5	Lubrication contamination	1	Change to sealed for life gearbox with synthetic oil

Table 2.1 Sample of the first page of an FMECA

Fault Tree Assignment

The required fault tree is given below:



The Probabilities

The probabilities of the various events are given in the table below, as repeated from the book:

Event	Description	Probability
A	Water inflow exceeds the pump system's capacity	0.05
B	Water inflow occurs within the system's capacity	0.95
C	Power outage occurs	0.1
D	Primary pump failure	0.1
E	Superintendent fails to take remedial action	0.2
F	Length of power outage exceeds battery capacity	0.05
G	Period of inflow exceeds battery capacity	0.50
H	Back-up pump failure	0.05

P(J) = Probability of Battery Drainage = P(E) x P(F) x P(G)
= 0.2 x 0.05 x 0.5
= 0.005

P(M) = Probability of Back-up Pump Failure = P(J) + P(H) – P(J) x P(H)
= 0.005 + 0.05 – 0.005 x 0.05
~ 0.055

P(K) = Probability of Primary Pump Failure = P(C) + P(D) – P(C) x P(D)
= 0.1 + 0.1 – 0.1 x 0.1
= 0.19

P(L) = Probability of Failure of the Entire Pump System = P(B) x P(K) x P(M)
= 0.95 x 0.19 x 0.055
= 0.0099

Therefore the probability of the basement flooding is:
P(A) + P(L) – P(A) x P(L)
= 0.05 + 0.0099 – 0.05 x 0.0099
= 0.0599 – 0.00049
= 0.059 ie ~ 0.06

This is a yearly probability. In other words, the basement is predicted to flood about 6 times in a hundred years. But because all the mathematics is based on random failure, such a flood could occur at any time – even next year. But on average, floods should occur every 17 years.

Notice also that the inflow into the sump (Probability B) must occur in the diagram. If the pump system fails but there is no inflow, there is no flood. Hence P(B) and its complement, P(A) must occur in the fault tree.

With regard to improving the system we see that, looking from the top of the tree down, the main pump is only half as reliable as the backup pump. This is odd – the pumps are in the same service. Perhaps the backup is more reliable because it is not used as often. Remember, these pumps might be used quite a lot, usually able to prevent flooding. Perhaps the main pump is aged and some reliability has been lost. If we double the reliability of the main pump the probability of that system failing is 0.145. Then failure of the entire pump system is 0.95x0.145x0.055 = 0.0075 – an improvement of 24%. This changes the probability of flooding to 0.05 + 0.0075 – (0.05x0.0075) = 0.0571, leading to floods every 17.5 years.
So this does not offer much improvement but it may be the only option that is Th to replace the main pump with one like the backup. One is mains driven, the other battery driven, we know, but perhaps the pump part is the same.

Moving down into the fault tree we see that the most seriously high probability is G, “period of inflow exceeds the battery capacity”, at 0.5. Say we could halve this with a bigger battery.
Then the probability of battery drainage is 0.2 x 0.05x 0.25 = 0.0025. Then the probability of the backup system failing is 0.0025 + 0.05 – (0.0025 x 0.050) = 0.0525. This leads in turn to a total pump system failure of 0.95 x 0.19 x 0.0525 = 0.0095. Probability of basement flooding is then 0.05 + 0.0095 – (0.05x0.0095) = 0.0547, indicating a flood every 18 years. This seems a better option – increasing battery capacity should be no problem.

ASSIGNMENT 2.1
The V1

A suggested model for the V1 is as follows:

Level 1:

V1 WEAPON SYSTEM:
Reliability = 0.99

Level 2: The four main systems above must all have a reliability of just under 0.988 for the overall reliability to be 0.99

Level 3: The following subsystems have to attain the stated reliability for the main system reliability to equal 0.998

Propulsion System	**Guidance System**	**Airframe**	**Munition System**
Propulsion unit	Windmill	Fin	Impact switch
Flap valves	Magnetic compass	Lifting Lug	Warhead
Sparking plug	Dry battery	Elevators	Fuse pockets
Fuel jets	Secondary gyro's	Rudder	Main fuse pocket
Fuel control mechanism	Pneumatic servomotor – rudder	Wing Spar (passing through fuel tank)	Belly landing fuse switch
Fuel Filter	Altitude control	Balloon cutters	
Starting connection	Master gyro	Launching rail	
Mixing chamber venturis	Compressed air bottles	Spoilers	
Fuel tank filter	Veeder counter	Tailplane	
Fuel tank	Veeder counter		
Tank filler	Pneumatic servomotor – elevator		
No of subsystems:11	No of subsystems:10	No of subsystems:9	No of subsystems:5
Reliability for each subsystem: 0.9999	**Reliability for each subsystem: 0.9998**	**Reliability for each subsystem: 0.9998**	**Reliability for each subsystem: 0.9996**

This example clearly shows that as we go to lower and lower indenture levels, the reliability has to rise accordingly, often to very high levels. This was Robert Lusser's original contribution.

ASSIGNMENT 2.2
The Parallel System of Conveyors

The best place to put the interconnection is in the middle. Some see this intuitively, others do not. It has got to do with multiplying a series of numbers together, all of which are less than unity. The shorter the chain, the higher the resulting product. The interconnection gives the shortest chains.

ASSIGNMENT 2.3
Availability Upgrade

Since availability is the result of the system's reliability and maintainability, it is useful make two lists, one for items that will increase the system's reliability and one for items that will increase the system's maintainability, as shown below. Some initiatives will assist both reliability and maintainability and are hence shown on both lists. One such is redundancy – if some item fails, the redundant partner can be brought on line. And from a maintainability viewpoint, one item may be maintained while the redundant partner is on line. The end of this argument is to have three of everything – one working, one on standby and one being worked on. The author once worked in such a plant (it was a uranium reduction facility). Such extravagance is only justified when capital is cheap and lost production very expensive.

Reliability Improvements	Maintainability Improvements
Use more reliable parts	Use more maintainable parts
Add redundancy	Add redundancy
Reduce duty (load or cycle)	Improve accessibility
Increase operator skill levels - training	Optimise maintenance using RCM or similar
Supplier-operator contracts	Employ condition monitoring
Buy in the service eg oxygen across the fence, air across the fence	Increase spares levels
Retrofit – eliminating troublesome components or systems	Increase the number of maintenance personnel
Increase operator motivation	Add storage of product
Establish a reliability department	Supplier-maintainer contracts
Formalise a root cause analysis system	Increase artisan skill levels
Improve the operator environment	Increase artisan motivation
Get upper management's support	Improve the artisans' environment

ASSIGNMENT 2.4

Laplace Calculation

Considering the following times to failure of a maintained system:

100, 250, 3000, 450, 900, 1030, 1000, 2500

The Laplace Equation yields the following result, as shown on an Excel worksheet

TTF	Cum TTF	Σ D4:D10	Σ/(n-1)	Tm/2	√(1/12(8-1)		G10-H10	Tm*√(1/84)	U

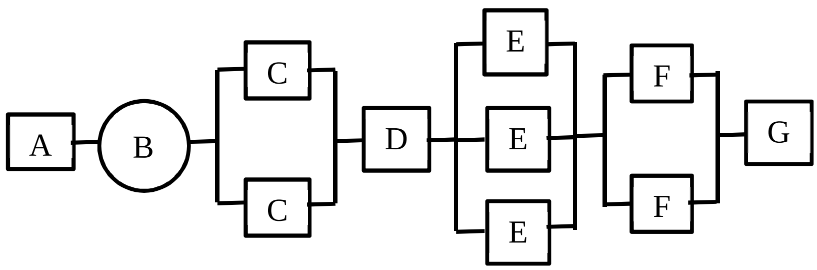
100	100								
250	350								
3000	3350								
450	3800								
900	4700								
1030	5730								
1000	6730	24760	3537	4615	0,109		-1078	1007	**-1,07**
2500	9230	**Tm**							

The U value of -1.07 is not sufficient to claim that the system is improving. The problem is the value of 3000 occuring early on in the train of TTF's. If that figure was 300 then the U value would be -2.32, as shown below, indicating that there is definite improvement.

TTF	**Cum TTF**	**Σ D4:D10**	**Σ/(n-1)**	**Tm/2**	**√(1/12(8-1)**		**G10-H10**	**Tm*√(1/84)**	**U**
100	100								
250	350								
300	650								
450	1100								
900	2000								
1030	3030								
1000	4030	11260	1609	3265	0,109		-1656	712	**-2,32**
2500	6530	**Tm**							

ASSIGNMENT 2.5
System Availability Prediction

The ABD is given below



The table can now be filled in:

Component A (in conjunction with component B)

For component A, 10% have failed by 2000 hours, that is, the reliability at 2000 hours is 90%. And we are given that the Beta value is 1.5. Proceeding now to the Weibull DR 21 program: From the opening page choose Test Design > then enter these values in the top row of four boxes:

- Target lifetime hours, cycles etc: 2000
- Required % reliability at target lifetime: 90%
- Weibull shape factor, Beta: 1.5
- Units being measured: hours

If we then press "Fill in first row – click here to fully define the distribution being tested" we will see in the second row of boxes the value for MTTF as 8093. This close enough for the MTBF or Θ for our purposes. We now have to modify this because of the storage capacity of Item B, according to the formula $\Theta'_a = \Theta_a * \exp(ST/\Phi_a)$

$$= 8093*\exp(750/750)$$
$$= 8093*2.72$$
$$= 22012 \text{ hours}$$

We can now work out the effective availability of component A as MTBF/(MTBF+MTTR)

$$A_A = 22012/(22012+750)$$
$$= 22012/\ 22762$$
$$= 0.967 \text{ or } 96.7\%$$

Components C

$$A_{cc} = 1- F_c^2$$
$$= 1 – 0.1^2$$
$$= 1 – 0.01$$
$$= 0.99$$

Component D

$$MDT = FFT+LT+MTTR$$
$$= 12+10+88$$
$$= 110$$

So A_D = MTBF/(MTBF+MDT)
= 5000/(5000+110)
= 5000/5110
= 0.9784

Components E

A_E = 10 000/(10 000 + 1000)
= 10 000/11 000
= 0.909

By Pascal's Triangle:

			1			
		1		1		
	1		2		1	
1		3		3		1

$A_{EEE} = A_E^3 + 3A_E^2U$
$= 0.909^3 + 3(0.909)^2(0.091)$
= 0.751 + 3*0.826*0.091
= 0.751 + 0.225
= 0.976

Components F

Truth Table:

Component 1	Component 2	Capacity Loss
up	up	0
up	down	0.5
down	up	0.5
down	down	1.0

$U_{FF} = 0.5U_1A_2 + 0.5U_2A_1 + 1.0U_1U_2$
= 0.5*0.1*0.9 + 0.5*0.1*0.9 + 0.1* 0.1
= 0.045 + 0.045 + 0.01
= 0.1

Therefore A_{FF} = 0.9

Component G

From the Weibull DR 21 program MTTF = 1737 = MTBF near enough

Therefore A_G = MTBF/(MTBF+MTTR)

$= 1737/(1737+48)$
$= 1737/1785$
$= 0.973$

System Availability

The System Availability may now be calculated as follows:

$$A_S = A_A*A_C*A_D*A_E*A_F*A_G$$
$$= 0.976*0.99*0.9784*0.976*0.9*0.973$$
$$= 0.805 \text{ or } 80.5\%$$