04.4 RAM

A **design** function to model and predict reliability, availability, maintainability, operational costs, etc. of complex systems

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RAM analysis can predict performance of alternative system designs in terms of:

1. Mean Time Between Failure (MTBF);
2. Expected down time (Availability);
3. Expected repair and maintenance costs;
4. Expected spares usage;
5. ....

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RAM analysis uses Monte Carlo Simulation (MCS)

MCS is “working backwards” Start with F(t) and find t.

–Assume a component’s failure and repair distributions respectively are:

Failure age distribution: $F(t)$=1-$e^{-\left(\frac{t}{1600}\right)^{3.2}}$

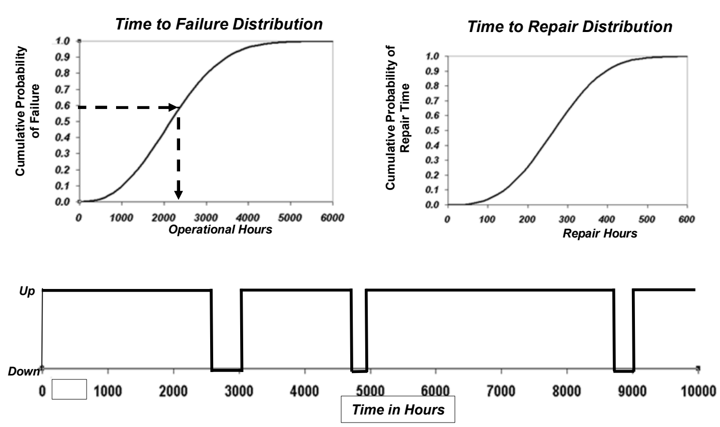
Repair time distribution: $F(t)$=Lognormal$\{\mu = ln(6.2),\ \sigma = ln(1.6)\}$

For both distributions:

1. Let F(t) be a random number (from 0 to 1)
2. Solve for t.

3

Simulation of a single mission of 10000 hours



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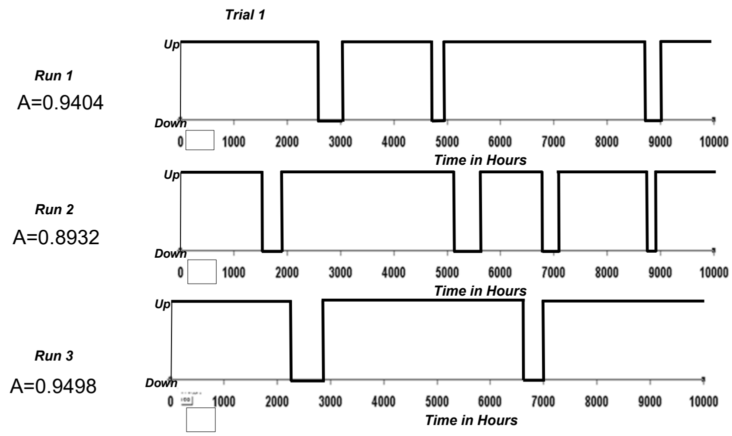
Multiples Simulation (e.g. 1000) results are averaged.



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Complex example 3 – a complex system

Problem statement

1. Five cooling water pumps.
2. Required: four pumps to be running.
3. Net revenue from product sales: $250,000/day
4. Repair times for all pumps: lognormal{μ=600, σ=25}
5. Average hourly repair cost for all pumps: $150/hr
6. Failure times for four pumps: Weibull{β=0.8, η=24350hours}
7. Failure time for fifth (older) pump: Unknown, but failures occurred on 11/13/91, 4/2/94, 8/19/95, 10/20/97, and 1/3/99
8. Cost of a sixth pump: $500,000 less 20% since existing auxiliaries can be used.
9. Projected usage: 20 years (20x365x24=175200 hours)

Is an upgrade justified? Compare the options: Status quo, replace older pump, add a sixth pump.

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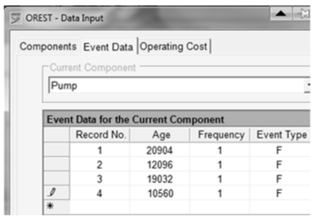
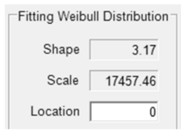
Failure times of the fifth pump

	Days	Hours
13-Nov-91		
2-Apr-94	871	20904
19-Aug-95	504	12096
20-Oct-97	793	19032
3-Jan-99	440	10560

Fit failure times to a Weibull model





$$F(t)=1-e^{-\left(\frac{t}{17457.46}\right)^{3.17}}$$

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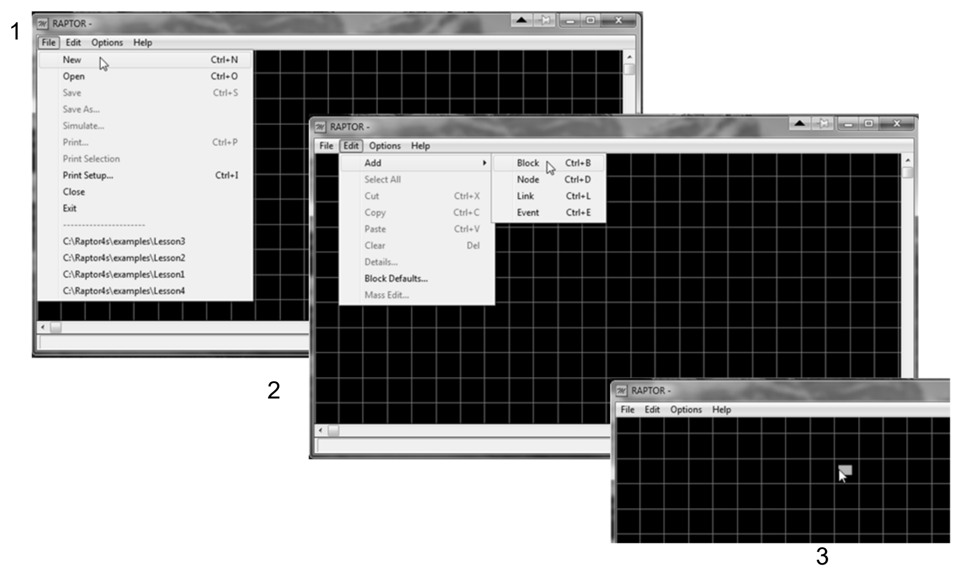
Set up the blocks and nodes for the status quo



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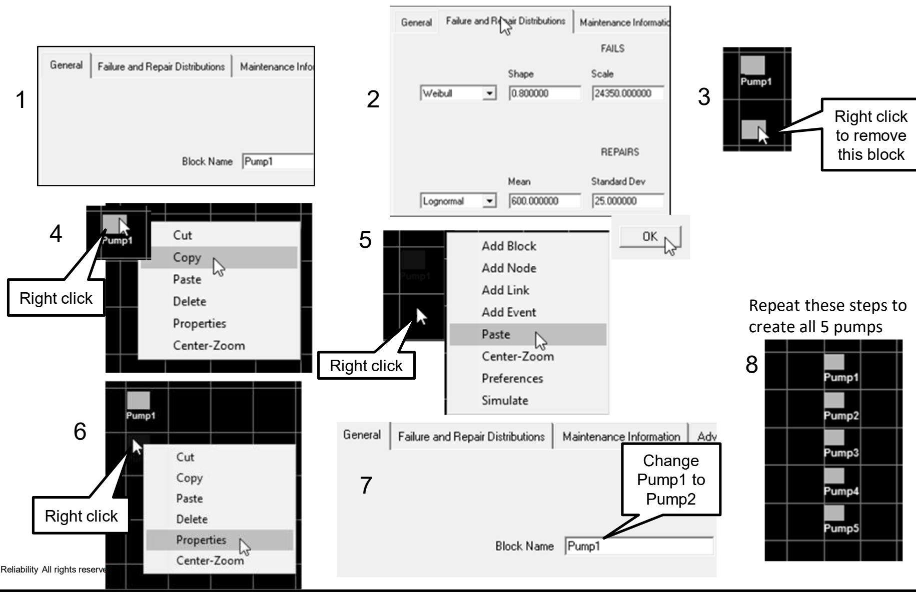
Set up the blocks for the 5 pumps



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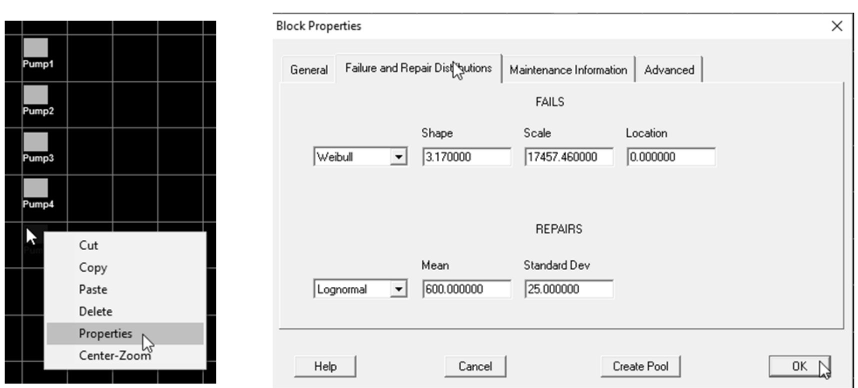
Change the properties of Pump5



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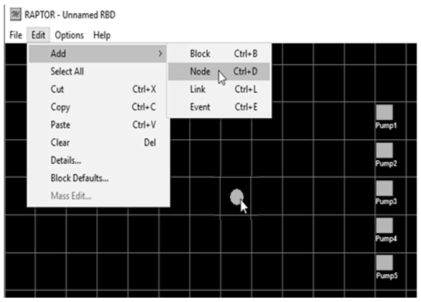
Create a Start Node

1



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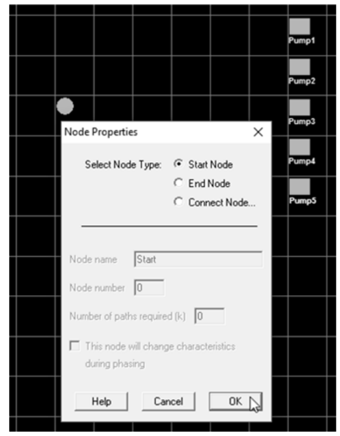

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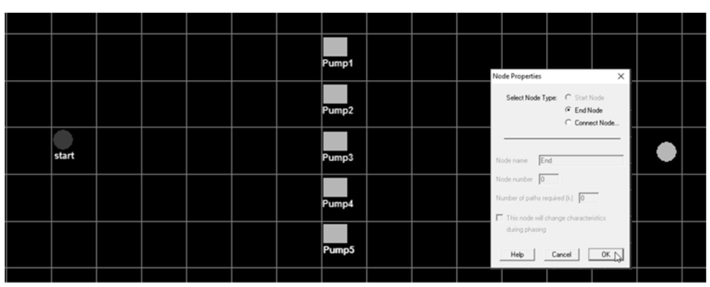
Create an End Node



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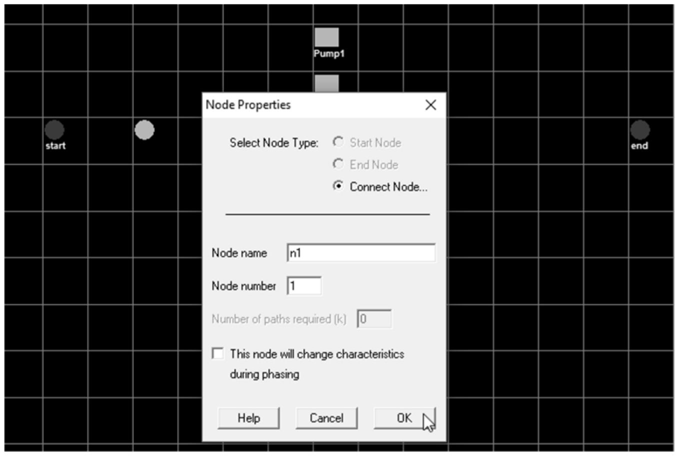
Create first Connect Node n1



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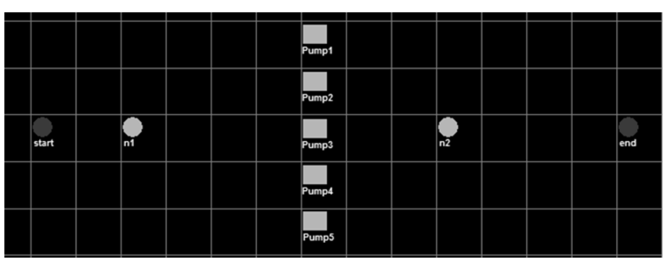
Create second Connect Node n2



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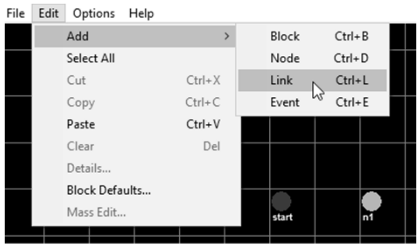
Add links from n1 to all 5 pumps

1



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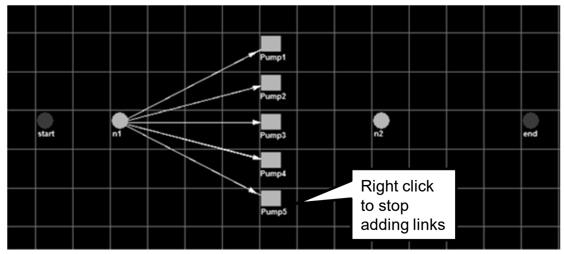

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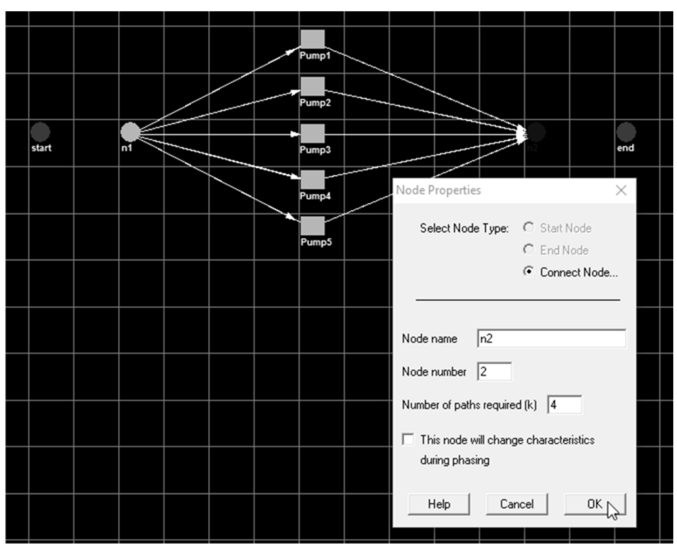
Add links to n2 and set Number of paths required to 4



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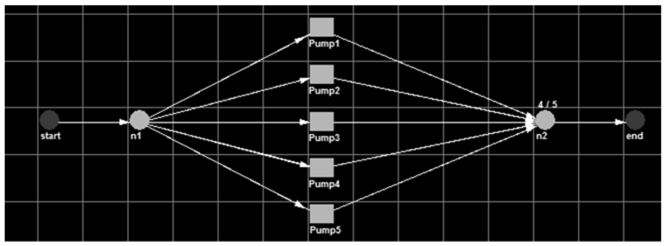
Add Start and End links



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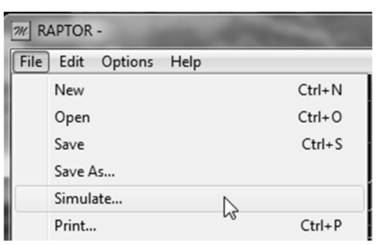
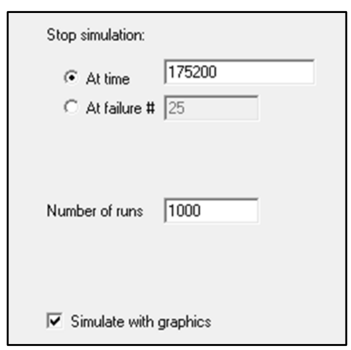
Simulate the status quo scenario



Set up stop time and number
mission time and number of runs



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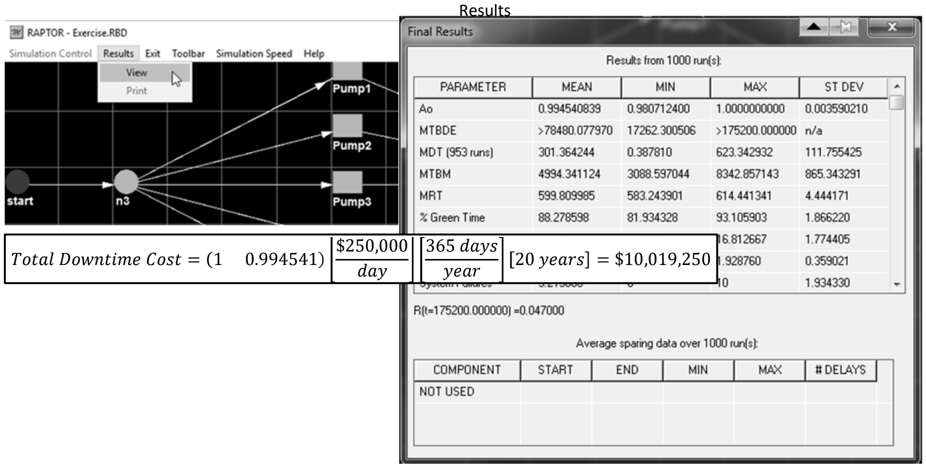
View results

Results



PARAMETER	MEAN	MIN	MAX	ST DEV
Ao	0.994540839	0.980712400	1.0000000000	0.003590210
MTBDE	>78480.077970	17262.300506	>175200.000000	n/a
MDT (953 runs)	301.364244	0.387810	623.342932	111.755425
MTBM	4994.341124	3088.597044	8342.857143	865.343291
MRT	599.809985	583.243901	614.441341	4.444171
% Green Time	88.278598	81.934328	93.105903	1.866220
			6.812667	1.774405
			1.928760	0.359021
			10	1.934330

COMPONENT	START	END	MIN	MAX	# DELAYS
NOT USED					

$$Total\ Downtime\ Cost = (1 \quad 0.994541)\left[\frac{\$250{,}000}{day}\right]\left[\frac{365\ days}{year}\right][20\ years] = \$10{,}019{,}250$$

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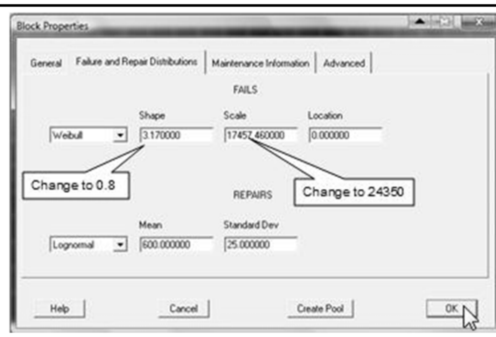
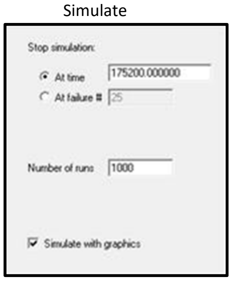
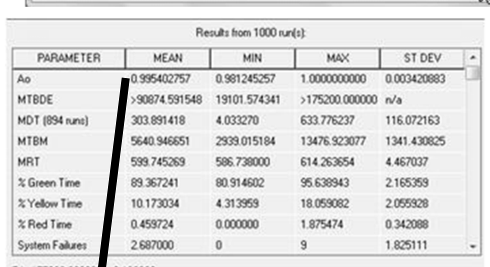
Simulate second scenario “replacing Pump 5”



Change Pump5 block properties

Simulate





PARAMETER	MEAN	MIN	MAX	ST DEV
Ao	0.995402757	0.981245257	1.0000000000	0.003420883
MTBDE	>90874.591548	19101.574341	>175200.000000	n/a
MDT (894 runs)	303.891418	4.033270	633.776237	116.072163
MTBM	5640.946651	2939.015184	13476.923077	1341.430825
MRT	599.745269	586.738000	614.263654	4.467037
% Green Time	89.367241	80.914602	95.638943	2.165359
% Yellow Time	10.173034	4.313959	18.059082	2.055928
% Red Time	0.459724	0.000000	1.875474	0.342088
System Failures	2.687000	0	9	1.825111

$$Total\ Downtime\ Cost = (1 \quad 0.99541)\left[\frac{\$250{,}000}{day}\right]\left[\frac{365\ days}{year}\right][20\ years] = \$8{,}395{,}000$$

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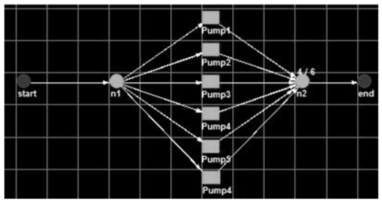
Simulate simulate 3rd scenario “adding a sixth pump”

RBD



Results from 1000 run(s):

PARAMETER	MEAN	MIN	MAX	ST DEV
Ao	0.9997754621	0.992815904	1.0000000000	0.000668225
MTBDE	>172885.325687	57980.448813	>175200.000000	n/a
MDT (189 runs)	196.160385	0.924733	551.833898	126.593892
MTBM	4238.826826	2576.470588	7963.636364	712.093652
MRT	599.954443	588.719779	612.040039	3.954049
% Green Time	86.334457	78.422430	92.605209	2.083991
% Yellow Time	13.641005	7.394791	21.577570	2.078994
% Red Time	0.024538	0.000000	0.718410	0.066823
System Failures	0.217000	0	3	0.481571

R(t=175200.000000) =0.811000

$$Total\ Downtime\ Cost = (1 \quad 0.999745) \left[\frac{\$250{,}000}{day}\right] \left[\frac{365\ days}{year}\right] [20\ years] = \$447{,}125$$

Conclusions

	A	B	C	D	E
5	Alternatives	20 yr. Avail.	Total Downtime Cost ($M)	Initial Cost ($M)	Total Cost ($M)
6	Existing System	0.99451	10.019	0	10.019
7	Replace older pump	0.9954	8.395	0.25	8.645
8	Add new pump to existing	0.999775	0.447	0.4	0.847

1. Best alternative: Add sixth pump.
2. This example shows how much impact even small improvements in system reliability can have.
3. Although the original availability, 0.99451 appears excellent, the example proves that it must be compared within an economic context to other alternatives.

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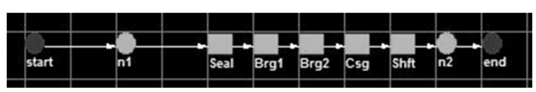
Complex example 2

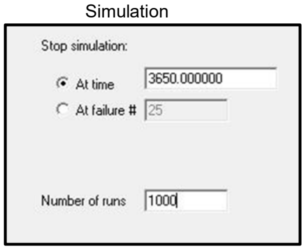
Problem statement:
A centrifugal condensate pump has components with the following Weibull failure distributions:

1. Mechanical seal (β = 0.75, η = 967 days)
2. Two bearings (β = 0.52, η = 2701 days)
3. Casing (β = 0.6, η = 6095 days)
4. Shaft (β; = 0.43, η = 7280 days)



All repairs are lognormal (μ = .5 days, σ = 0.2 days). What is the expected availability of the pump over a 10 year period?

Simulation



Results

Results from 1000 run(s):

PARAMETER	MEAN	MIN	MAX	ST DEV
Ao	0.998878691	0.996764151	1.0000000000	0.000503693
MTBDE	>569.441640	158.182137	>3650.000000	n/a
MDT (997 runs)	0.493422	0.273079	1.003953	0.077120
MTBM	>569.441640	158.182137	>3650.000000	n/a
MRT (997 runs)	0.493373	0.273079	1.003953	0.077169
% Green Time	99.887869	99.676415	100.000000	0.050369
% Yellow Time	0.000000	0.000000	0.000000	0.000000
% Red Time	0.112131	0.000000	0.323585	0.050369
System Failures	8.304000	0	23	3.552687

R(t=3650.000000) =0.003000

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4.4.1 Quiz 1 RAM Analysis

https://forms.gle/WsTCBdyhroEbVQEm8

1. Which of the following statements are true about RAM? * 1 point

- From an RCM perspective, RAM is not a form of maintenance, but rather of redesign
- RAM takes place in the conceptual design phase of a project to assist the owner with trade-offs between cost and capability..
- Maintenance engineers who do not perform RAM can still provide designers with useful data provided they have captured work order history consistently and accurately.
- RAM exposes the performance of various scenarios of interest.
- RAM uses the reliability and repair probability distributions taken from handbooks and from experience.
- All of the above.
- None of the above.

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