MEADEP Application Note:

Modeling Operational Availability using MEADEP

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DRAFT

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Introduction

This Application note describes the use of MEADEP to model Operational Availability. Operational Availability is the actual availability of a system under logistics constraints including technician (or other repair personnel) travel time, sparing level (i.e., the probability that a spare is present), and restocking time (i.e., the time needed to deliver a spare part if a part is not present). It is often the most important measure of availability for users who utilize the system in an environment of constrained resources and geographically dispersed maintenance and support personnel.

Model Description

Figure 1 shows a block diagram for an example system that consists of two subsystems, designated as Subsystem1 and Subsystem2. For the purposes of this example, we assume the following[1]:

1. Both subsystems are necessary for the entire system to be operational.
2. Both subsystems are are repairable,
3. Both subsystems are subject to different sparing levels and technician travel times.

Figure 1 shows the top level diagram for the two subsystems which are placed in series (from assumption 1).

Figure 1. Example Subsystem Top Level Diagram

Figure 2 shows the detailed model for Subsystem1. It is a Markov model with 3 states. The first state, Subsys1_up, is the system performing its function. The second state, Under_repair, is when the system has failed and is being repaired. The third state, Awaiting_Spare is the state that the system has failed and that a spare must be ordered from a central site. The numbers below each of the state names represent the *reward*, i.e., the value of the system in each of the states (see the MEADEP user guide for more information). The rewards for the Under_repair and Awaiting_spares states are set to 0.

[1] Models of any complexity can be built in MEADEP to incorporate logistics and sparing considerations. We have used these simplifying assumptions for the purposes of clarity.

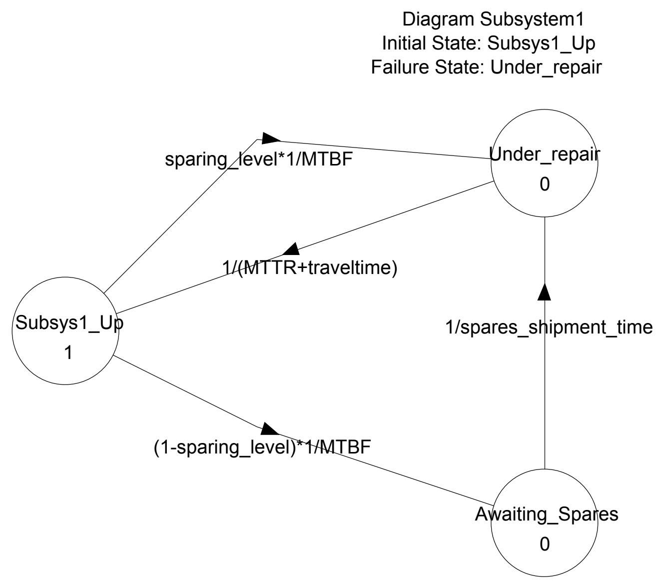

Figure 2 . Lower Level Markov Model for Subsystem 1

The key to modeling the impact of sparing level and travel time on availability is in the transitions. Consider the transition from Subsys1_up to Under_repair. If there were 100% sparing, the transition from the Up state to a failure state state would simply be the failure rate, or the reciprocal of the Mean Time Between Failures (MTBF) for Subsystem 1. In addition, all failures would transition from Subsys1_Up to Under_repair – i.e., immediately start undergoing repair.

However, if the sparing level is less than 100%, then only a fraction of the failures could be immediately repaired; the other remainder would have to wait until the spares were obtained from the central depot, storage facility or from the supplier. Thus, the model splits the failure transition into two separate paths. The first path -- when the spare is on hand-- results in a direct transition to the Under_repair state. The second path – when the spare is not on hand --goes through the Awaiting_Spares state. The system moves out of the awaiting spares state at a rate proportion to the inverse of the average spares shipping time.

Another logistics constraint is the time needed for a qualified technician to arrive at the system to perform the repair. This time is represented by the travel time. The travel time is simply added to the system average repair time, or MTTR. The rate at which the system leaves the under_repair state and return to the However, in order to perform parametric analyses on the impact of travel time on availability, the parameter is identified separately.

Table 1. Parameters for Subsystem 1 Model

Parameter	Initial Value in Model	Remarks
spares_shipment_time	24 hours	Next day delivery for spares
MTBF	1000 hours	Reliability of Subsystem 1
traveltime	4 hours	Technician travel time for Subsystem 1
MTTR	1 hour	Average repair time for subsystem 1
sparing_level	0.95	95% sparing level

An equivalent model was created for subsystem 2 as shown in Figure 3. However, different parameters were used for reliability, repair time and travel time, reflecting the different characteristics of this subsystem (a subsystem with greater reliability but increased complexity of repair).

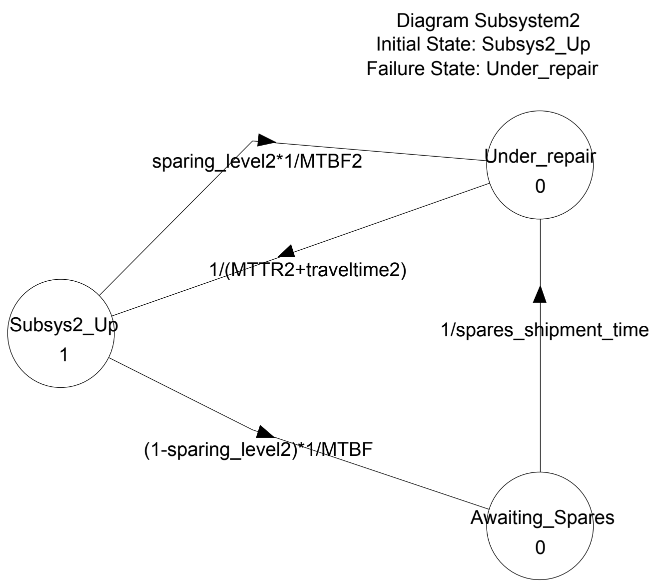

Figure 3. Lower Level Markov Model for Subsystem 2

The model was actually built by using Table 2 shows the initial values in the model for Subsystem 2.

Table 2. Parameters for Subsystem 2 model

Parameter	Initial Value in Model	Remarks
spares_shipment_time	24 hours	Next day delivery for spares (same as subsystem 1)
MTBF2	2000 hours	Reliability of Subsystem 2 is assumed to be twice that of Subsystem 1
traveltime2	8 hours	Technician travel time of Subsystem 2 is assumed to be twice that of Subsystem 1
MTTR2	2 hours	Average repair time of Subsystem 2 is assumed to be twice that of Subsystem 1
sparing_level	0.95	95% sparing level (same as Subsystem 1)

It should be noted that in this particular example, although the parameters were different, the logistics delay model was created as a MEADEP model (.mdl) so that a single model could be used for both subsystems. However, it is not necessary to use the same logistics model across the entire subsystem. For example, in some cases, there is no travel time, but the number of technicians might be constrained. A failure might occur when all qualified technicians were busy performing other repairs. In that case, a queuing model using the MEADEP queuing function can be used to represent the system. Also, there might be some repairs that are routine whereas others require additional support from a second level technician resource. Such cases can also be modeled by the inclusion of additional states.

Results

Table 3, shows the reliability and availability results for the initial values for the overall system and each of the subsystem.

Table 3. Results for Initial Values (shown in Tables 1 and 2)

Model-Name	Failure-Rate (per hour)	Recovery-Rate (per hour)	Availability (per hour)	Unavailability (per hour)
Main	0.00232913807	0.1364705882	0.9832194333	0.01678056674
Subsystem1	0.00124	0.2	0.9938382031	0.006161796859
Subsystem2	0.00108	0.1	0.9893153937	0.01068460625

Tables 4 and 5 shows the state residence probability, i.e., the probability of being any of the 3 states in the model. It should be noted that because of the reward specification (i.e., 1 for the up state and 0 for states 2 and 3), the availability is equivalent to the residence probability of state 0, and the unavailability is the sum of the residence probabilities in states 1 and 2.

Table 4. Results for Subsystem 1

State Number Designation	StateName	Probability
0	Subsys1_Up	0.9938382031
1	Awaiting_Spares	0.001192605844
2	Under_repair	0.004969191016

Table 5. Results for Subsystem 2

State Number Designation	StateName	Probability
0	Subsys2_Up	0.9893153937
1	Awaiting_Spares	0.00474871389
2	Under_repair	0.005935892362

A comparison between Tables 4 and 5 shows that the Awaiting_Spares and Under_repair states are higher in Subsystem2 than in Subsystem1. This reflects the doubled spares shipment and repair times for Subsystem2, and is reflected in the lowered availability of that subsystem relative to Subsystem1.

Parametric Studies

While the initial value results from the model are certainly of interest, the real power of MEADEP becomes apparent when system tradeoffs and parametric modeling become important issues. This section discusses the results of parametric studies of the logistics parameters defined for this model: spares shipment time, , MEADEP allows the results to be expressed in terms of operational availability, yearly downtime, unavailability. and MTBF. Figure 4 demonstrates the impact of spares shipping time on operational availability. As the shipping time increases from 8 hours to 1 week, the operational availability decreases from 0.9945 to less than 0.987.

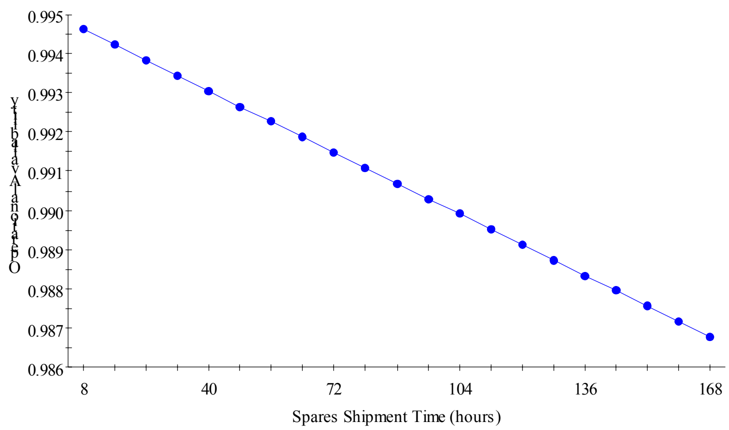

Figure 4 . Impact of Spares Shipment Time on Operational Availability

Figure 5 shows the impact on yearly downtime when the shipping time is changed over the range of 8 hours to 168 hours (1 week) on Subsytem 1. The annual downtime change is more than 80 hours.

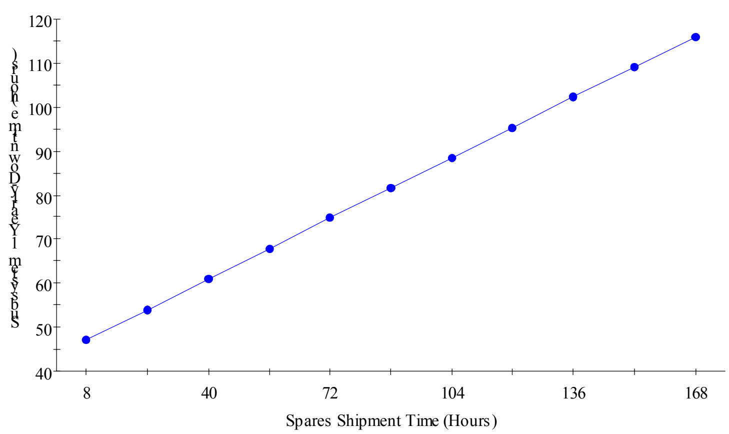

Figure 5. Impact of Shipment time on Annual Downtime of Subsystem 1

Table 6 lists the impact of the other logistics parameters, sparing level and travel time, on system operational availability and related parameters, and Table 7 lists the results of these parametric studies on the system as opposed to the subsystem level.

Table 6 . Results of Other Logistics Parameters on Subsystem 1 Operational Availability

Sparing Level	Parameter Value	Yearly-Downtime (hrs)	Unavailability	Availability	MTBF (hrs)
	50%	146.4307	0.016716	0.983284	299.1176
	55%	136.2552	0.015554	0.984446	321.4557
	60%	126.0556	0.01439	0.98561	347.4658
	65%	115.8319	0.013223	0.986777	378.1343
	70%	105.5839	0.012053	0.987947	414.8361
	75%	95.31157	0.01088	0.98912	459.5455
	80%	85.01485	0.009705	0.990295	515.2041
	85%	74.69363	0.008527	0.991473	586.3953
	90%	64.34783	0.007346	0.992654	680.6757
	95%	53.97734	0.006162	0.993838	811.4516
	100%	43.58209	0.004975	0.995025	1005
Travel Time	**Parameter Value**	**Yearly-Downtime (hrs)**	**Unavailability**	**Availability**	**MTBF (hrs)**
	1	27.94258	0.00319	0.99681	627
	2	36.63812	0.004182	0.995818	717.2857
	3	45.31635	0.005173	0.994827	773.2308
	4	53.97734	0.006162	0.993838	811.4516
	5	62.62113	0.007149	0.992851	839.3333
	6	71.24777	0.008133	0.991867	860.6585
	7	79.85731	0.009116	0.990884	877.5652
	8	88.44981	0.010097	0.989903	891.3529
	9	97.02532	0.011076	0.988924	902.8571
	10	105.5839	0.012053	0.987947	912.6393

The sensitivity to parameter changes in Table 7 are similar to those of table 6 with one significant exception: the spares shipping time. For this parameter, it was assumed that the same shipping time would apply to both subsystems 1 and 2 (under the assumption that both subsystems are collocated and the spares for both subsystems are stored in the same warehouse). Thus, an increase in shipping time would cause the operational availabilities of both subsystems to simultaneously decrease, and the impact on the system level would be the product of these negative impacts. The sensitivity of the overall system availability is therefore higher than for the individual subsystems.

Table 7. Results of Other Logistics Parameters Overall System Operational Availability

Spares Shipping Time	Parameter Value (hrs)	Yearly-Downtime (hrs)	Unavailability	Availability	MTBF (hrs)
	8	112.7689	0.987127	0.012873	548.8332
	24	146.9978	0.983219	0.016781	436.671
	40	180.9997	0.979338	0.020662	362.9839
	56	214.777	0.975482	0.024518	310.8726
	72	248.3317	0.971652	0.028348	272.0709
	88	281.6659	0.967846	0.032154	242.0572
	104	314.7817	0.964066	0.035934	218.1496
	120	347.6811	0.96031	0.03969	198.6568
	136	380.3663	0.956579	0.043421	182.4594
	152	412.8392	0.952872	0.047128	168.7868
	168	445.1018	0.949189	0.050811	157.0914
Sparing Level	**Parameter Value**	**Yearly-Downtime (hrs)**	**Unavailability**	**Availability**	**MTBF (hrs)**
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Travel Time	**Parameter Value**	**Yearly-Downtime (hrs)**	**Unavailability**	**Availability**	**MTBF (hrs)**
	1	27.94258	0.00319	0.99681	627
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Conclusions

Operational availability and reliability are the primary analytical figures of merit chosen by many users, and through the use of Markov models, MEADEP allows a variety of logistics constraints to be modeled. Examples of how three common parameters (sparing level, travel time, and spares replacement time) are modeled were shown in this example. Other parameters that can be modeled include:

- Extent of second level support required
- Qualification and Training
- Single vs. multiple technicians
- Successful vs. unsuccessful repairs
- Different failure modes with different repair times, travel times, and spares replacement times.

A MEADEP text modeling file (.mdt) for this entire example is shown on the following page. The library file (.mdl) for subsystem 1 and subsystem 2 logistics models are included in the MEADEP 1.9 and later release and can be downloaded from the SoHaR web site.

MEADEP Text Modeling File

```
bind
spares_shipment_time   24
MTBF  1000
traveltime2       8
MTTR2             2
MTBF22000
sparing_level2  0.8
traveltime        4
MTTR  1
sparing_level    0.95
end

evaluate
R$Subsystem2  markovR(Subsystem2)
A$Subsystem2  markovA(Subsystem2)
µ$Subsystem2  markovMu(Subsystem2)
λ$Subsystem2  µ$Subsystem2*(1-A$Subsystem2)/A$Subsystem2
R$Subsystem1  markovR(Subsystem1)
A$Subsystem1  markovA(Subsystem1)
µ$Subsystem1  markovMu(Subsystem1)
λ$Subsystem1  µ$Subsystem1*(1-A$Subsystem1)/A$Subsystem1
R$Main          R$Subsystem1*R$Subsystem2
A$Main          A$Subsystem1*A$Subsystem2
µ$Main
        (λ$Subsystem1+λ$Subsystem2)/(ë$Subsystem1/µ$Subsystem1+λ$Subsystem2/µ$Subsy
stem2)
λ$Main µ$Main*(1-A$Main)/A$Main
end

markov
Subsystem2  3  4
0  2  sparing_level2*1/MTBF2
2  0  1/(MTTR2+traveltime2)
0  1  (1-sparing_level2)*1/MTBF
1  2  1/spares_shipment_time
reward
0  Subsys2_Up 1
1  Awaiting_Spares 0
2  Under_repair 0
end

markov
Subsystem1  3  4
0  2  sparing_level*1/MTBF
2  0  1/(MTTR+traveltime)
0  1  (1-sparing_level)*1/MTBF
1  2  1/spares_shipment_time
```

```
reward
0  Subsys1_Up 1
1  Awaiting_Spares 0
2  Under_repair 0
end


output
Main
Subsystem1
Subsystem2
end
```