Applying Discrete Event Modeling in the Real World

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Key Words: Modeling, Discrete Event Modeling, MTBF Mean Time Between Failures, MTTR Mean Time To Repair

SUMMARY & CONCLUSIONS

There are many facets and features to applying the processes of reliability, availability, and maintainability (RAM) engineering during the lifecycle of a system. None are more important than the methodical, intentional application of modeling and simulation upfront in the design of a system to ensure that requirements are met. This paper presents and discusses solutions that demonstrate the practical application of complex modeling and how this process applies practically using real-world examples such as chemical manufacturing plants and space-borne systems. Many large manufacturing or development organizations are driven by costs of development and real-time maintenance and not seeking long term value by planning a system to be more reliable, and thus creating value by reducing cost of operation and ownership. RAM Simulation and Modeling is a process employed by RAM engineers for predicting performance of a system in order to drive value through reliability gap analysis, and project development as examples. The authors will demonstrate, through practical examples, how application of the RAM modeling has been applied to create maximum value to both Government entities and commercial companies alike. Modeling and simulation have been employed throughout all phases of the lifecycle of new system development (new plant designs, existing facilities improvements, integrated site design, spacecraft development, and maintenance task analysis) and have delivered value in the form of lower cost of operation, improved availability of the system, and value to corporate bottom lines. The authors will also demonstrate how reliability engineers have successfully provided value to design teams by helping them identify failure modes and mitigate them, thus improving the systems that they support.

1. INTRODUCTION – VALUE ADDITION

Any reliability engineer just starting out in his or her career will most likely hear the words – “why are you here…?” Reliability engineering has always been the pariah of the system engineering process, due in large part to the lack of understanding of what drives value on a project or program, both on the part of project management, and the reliability engineering team. To be cost effective, reliability must be designed-in, and a reliability engineer must know how to ensure that reliability requirements are met up-front via consistent and focused design activity, supported by analysis, verification, and a healthy dose of failure mode identification and mitigation. After all, a reliability engineer’s sole reason for existing is to identify failure modes and ensure that those modes have been mitigated. One of the most effective ways to ensure reliability is designed in is to employ a detailed discrete event model at the front of the system engineering life cycle on a project and to use that model as the primary means for showing the value of design trades and decisions on mitigation of failure modes. Effective implementation requires people skills, excellent system knowledge, and clever manipulation of all means available to improve system performance including design changes, operational workarounds, and optimization of maintenance practices.

2. MODELING – A “12 STEP” PROCESS

Just like anything else in life, deciding to ensure that reliability, availability, and maintainability are designed into a system is a 12 step process. The first step is admitting that you have a problem. The following eleven steps are focused on eliminating the first step, and are listed below, along with the first step (these steps assume that when implementing, that system is a 12 step process. The first step is admitting that you have a problem. The following eleven steps are focused on eliminating the first step, and are listed below, along with the first step (these steps assume that when implementing, that project champion exists and that the project team has been properly educated):

1. Define/understand RAM requirements
2. Allocate RAM requirements using a preliminary model
3. Develop detailed modeling plan and educate project team
4. Collect data and develop data sources for the model
5. Implement discrete event model by developing model architecture and entering data
6. Manipulate initial model, debug, and assess initial outputs
7. Work with project/system engineers to review model outputs and generate model baseline
8. Identify top areas for improvement and work with experts to generate improvement scenarios (gap analysis)
9. Run improvement scenarios and identify most effective combination of design improvements
10. Once all improvement scenarios have been identified, then run arbitrary failure rate and maintenance enhancement scenarios
12. Verify and ensure that design will meet requirements
13. Develop lessons learned, provide feedback to future engineering teams
The extra step is for good measure, but is also critical, collecting all value-added activities identified using the discrete event modeling technique and documenting for use on future projects.

3. DISCRETE EVENT MODELING

Discrete event modeling (DEM) is the simulation of the operation of a system that is represented as a chronological sequence of events. Changes in state are modeled sequentially as well, and each event is non-dependent on the others. Typically, simulators used will be based on the Monte Carlo Method, which depends on random number generation and detailed math to seed “failures” or faults in the model. The DEM Process is best laid out as defined in the twelve steps above. Figure 1 shows a typical model using a screen shot from the RAPTOR modeling tool.

Figure 1. Screenshot from RAPTOR Software tool, depicting a typical, high-level discrete event model.

The first step is to effectively identify and understand the reliability, availability, and maintainability requirements for the applicable system and associated project or program. This detailed assessment employs a methodical approach that is founded on developing a clear understanding of the reliability of the proposed design. Once requirements have been agreed to, or baselined, and also allocated to the lowest possible level of the design, a baseline model is developed and analyzed using as much information about the preliminary design as available. These models are intended to be used early and often in the design process, and are very useful in late stages of the life cycle.

3.1 Baseline Model.

In order to create a baseline model, we build a simulation based on the reliability logic of the system, also known as reliability block diagrams (RBD). Using input data identified in the Figure 2, we develop the RBD architecture for the system being modeled. This model features at the top level a function-based RBD (FBRBD). Each top-level “block” represents one of the main subsystem functions of the system. These FBRBDS are arranged sequentially to show that ALL are required in order to claim successful operation. Within each FBRBD, at a nested (lower) level, an RBD is drawn that depicts all possible success paths through the system to accomplish a particular system function, together with a listing of whatever parts are required to enable each path. Also, as part of the lower level “nests,” operational rules, operational workarounds, and contingency scenarios can be modeled to most accurately depict how the system will operate under real-time conditions. Once the architecture (reliability logic) is built, we populate the parts data library, where the operating and non-operating failure rates, duty cycles, stress derating, and other parts-specific data are captured. We also identify spares data, logistics data, and maintenance data to depict if the component or subsystem fails, the length of time required for it to return to operating state, which is a major driver in system availability. The simulation can be “run” to generate initial availability predictions as well as a Pareto chart (cut-set) identifying the most likely failure scenarios. From those we identify erroneous scenarios and pinpoint any inaccuracies in the model. We have the corrected model and data validated by subsystem experts from the program/project as well as by members of the engineering community. Once validated, we have a baseline model from which we can answer the question regarding “acceptability of the proposed design.” If the proposed design does not meet the reliability requirements set
forth in the design specification documents, we initiate the next stage and identify areas for improvement to narrow the gap between the existing reliability of the subsystem and the requirement. If there is a gap between the results of the baseline model and the reliability requirements, we perform sensitivity analyses and implement proposed design optimizations as part of the simulation, which closes the gap. As part of our design optimization recommendations, we assist by partnering with critical suppliers to improve the reliability of their supplied components. Once the gap is closed and we have verified that the new supplier data does, in fact, enable the improvement model to meet the requirement, we update the simulation and continue the process.

3.2 Sensitivity Analyses and Design Optimization.

Typically, an initial design will not meet RAM requirements, and we initiate development of design optimization scenarios. Our team uses model outputs in the form of Pareto charts and sensitivity analyses to determine what parts or “strings” are driving the unreliability. We then initiate tradeoff analyses of modifications to the baseline model that improve subsystem reliability by addressing specific failure scenarios. Some of the methods used to address these issues include using the reliability simulation tool to address:

3.3 Selective additional redundancy

Selective additional redundancy is used where one area or component of the design is depended upon by multiple functions and where design upgrades have already been exhausted.

3.4 Operational work-arounds

These are used to identify a number of scenarios that could be employed in response to a downing event or to spotlight an area where one is needed in order to bolster system reliability. These types of solutions are outside the bounds of design modifications.

3.5 Sparing and logistics optimization

These are used as a cost effective method for improving availability, where feasible. Equipment design upgrades are used when all other ideas for improvement have been exhausted as this is the most expensive get-well plan. We perform a global sensitivity analysis to identify candidate parts in the model that would, if individually improved at the component level, yield the greatest improvement in overall subsystem reliability. This list of candidates is included in our design optimization recommendations for the system that will assist in optimization of system availability.

We incorporate these availability optimization scenarios into the baseline model to identify the optimal enhancements. The optimization scenarios spotlight all candidate equipment items for reliability improvement based on the sensitivity of the overall system to changes in item reliability. Often, we will offer our support in partnering with suppliers to implement necessary corrective actions. Once the suppliers have made equipment upgrades, we replace earlier estimates with the new availability data and verify that the modifications achieve reliability requirements.

3.6 Tools

We use the following enhanced tools to perform our RAM Simulations: TITAN, RBDA, WinSIMITHTM, Weibull, PRISM, RELEX, RCM++, and SAPHIRE and RENO as necessary.

4. SPECIFIC EXAMPLES OF VALUE

The process above is not complete without demonstrating how, when implemented properly, it can deliver excellent value to a development project or program. Two specific examples are cited in this paper below, one from the petrochemical industry and one from the aerospace industry. This process can be applied to any project, large or small within any industry or application. It is merely focused on identification of failure modes and effective mitigation, as discussed.

5. SPARE EQUIPMENT PROBLEM

PETROCHEMICAL EXAMPLE.

The Dow Chemical Company has implemented a global strategy of utilizing discrete event modeling to drive value in new asset development and product improvement. Dow’s strategy includes the use of one simulation tool that can solve both complex and simple problems. This specific problem highlights the application of modeling applied to a practical problem that is often seen in existing chemical plants. However, as shown, what may seem simple can actually be complex and difficult. Within the six plants of one of Dow’s key businesses there are several very critical pumping installations that ensure optimal product manufacture. These pumps are spared using shared assets that are warehoused in central locations. This equipment is expensive and as such, Dow strives for the lowest stocking cost to support maximum production. The company applies a spares optimization process which is part of what is known as Most Effective Technology (MET). Dow believes that using the RAM simulation process provides optimization of cost versus risk. The author worked with the global reliability team for this specific business to develop a strategy to have minimum spare stocking level.

In this example, there are 6 plants each with one critical specific pump installed. If the pump fails, then production is lost. The plants have different production rates even though they produce the same product. The plants have yearly shutdown based on a catalyst replacement, but the business units want to optimize total production of all plants. Four of the plants are at the same location or site and the other two plants are located within a 12 hour distance. The cost of a new replacement pump is $65,000. The cost of a pump rebuild is $25,000. There is 80% probability that the pump can be rebuilt after a planned replacement or a catastrophic failure. The delivery time is also different for a rebuild versus a complete new pump, twenty eight weeks for a new order, and 14 weeks for a rebuild. This also had to be taken into account
within the model. The modeling tool has a separate input for replenishment time. This time is extremely important factor when calculating in-house stocking levels.

The pumps are replaced every 10 years during a plant turnaround and also have a catastrophic failure mode as depicted in Figure 3.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Failure Distribution</th>
<th>Parameter 1 (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pump-Failure</td>
<td>Exponential</td>
<td>292000</td>
</tr>
<tr>
<td>Pump-Overhaul</td>
<td>Constant</td>
<td>87600</td>
</tr>
</tbody>
</table>

Figure 3. Pump Failure Data

Figures 3 and 4 identify critical data for each pump and how the data was shaped for input into the model.

<table>
<thead>
<tr>
<th>Plant No.</th>
<th>Production Rate (Mlbs/hour)</th>
<th>Current Pump Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant A</td>
<td>22.2</td>
<td>0.5</td>
</tr>
<tr>
<td>Plant B</td>
<td>7.85</td>
<td>1</td>
</tr>
<tr>
<td>Plant C</td>
<td>4.77</td>
<td>12</td>
</tr>
<tr>
<td>Plant D</td>
<td>5.6</td>
<td>12</td>
</tr>
<tr>
<td>Plant E</td>
<td>5.06</td>
<td>10</td>
</tr>
<tr>
<td>Plant F</td>
<td>9.05</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 4. Pump Production Data and Age

The question and problem asked by this particular Dow business was: What is the best long term strategy for replacing the pumps and what should be the spare pump stocking strategy to support maximum production? It is obvious that some of the pumps existing ages already have exceeded the recommended age for replacement. The business recognizes this but they also understand the need to create a new strategy as these plants are required to produce maximum production. In this problem both modeling techniques are combined and a maintenance strategy is identified and defined.

In order to solve this problem a model was created that could calculate the production losses and also had the capability to introduce the process dependencies and spares strategy. The model was developed to have a close “distance to reality,” which is always critical to validate the model results to ensure credibility for the final customers of the analysis.

The model is comprised of three attributes.

- Flow structure
- RAM data
- Process dependencies (or logic)

Figure 5 shows a screen shot for the modeling tool used, TITAN, of the specific model described in this example. The flow structure indicates the production throughput from each plant. We total the production as we are trying to maximize production of all 6 plants.

There are six pumps each with two distributions. One distribution is for a random failure and the other distribution is constant to overhaul the pumps every 10 years.

A screen shot of the model logic or code, as shown in Figure 7 above, depicts the logic that is programmed into the tool using the Visual Basic (VBA). More detail is below:

A) Set the age of equipment to ensure that the overhauls do not happen at the same time. The logic above is an example only of how the code looks within the software. The model logic is constructed in VBA.

B) We also include the logic to tell the model that if a pump fails or is overhauled there is a probability than the pump can be rebuilt versus purchase a new pump.

6. RESULTS AND CONCLUSIONS

It was obvious during the data analysis that a work process was required to ensure overhauling the pumps one at a time. Dow leadership has now implemented an improvement to the maintenance operating procedures that includes only one pump overhaul at a time. The data also showed that three of the pumps have already exceeded their overhaul period. Based on this analysis, it was decided that the BU would immediately put in place an overhaul period to space these intervals. Long term, all the replacement times will occur separately. As a follow up on effort, another model was
developed to quantify our long term spare stocking strategy to support lowest long term cost of ownership.

**Figure 7. Pump Model logic, as written in Visual Basic**

<table>
<thead>
<tr>
<th>Stock Level, Dow Warehouse</th>
<th>Milb/year Lost Production using existing age</th>
<th>Milb/year Lost Production One Overhaul Strategy</th>
<th>Milb/year Lost Production Two Overhaul Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>27914</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>1</td>
<td>10238</td>
<td>2922</td>
<td>11322</td>
</tr>
<tr>
<td>2</td>
<td>5914</td>
<td>0</td>
<td>1711</td>
</tr>
<tr>
<td>3</td>
<td>998</td>
<td>0</td>
<td>189</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Figure 8. Results of Analysis**

The stocking levels risk calculations, as shown in Fig. 8, indicate that based on the current age that it would take a stock level of 4 to completely reduce the risk of lost production to zero. However, if the ages of the pumps are reset within the model as each pump is overhauled one a time, then 2 in stock would be completely risk free. For reference, the model output is in Milbs of product. The Dow BU has now implemented a work process that overhauls one pump at a time. A short term strategy has now been implemented to ensure that pumps greater than 10 years old are replaced. This will now allow for a long term strategy of one pump replacement. The analysis results have also driven the implementation of a 2 pump stock level. This somewhat simple example illustrates the use of Monte Carlo simulation to support practical everyday problems faced by reliability engineers within chemical plants to make data based decisions. Dow Chemical has a well established modeling process with full time expert modelers applying models to large new facilities and new grass roots site studies most of which are very complex and takes months of multi-functional team approaches. This example is just one of the many that do not require a high degree of modeling expertise, yet deliver value.

7. **LAUNCH AVAILABILITY ANALYSIS (AEROSPACE EXAMPLE)**

NASA has been building large, man-rated space-borne systems for decades, and they have been largely successful. With the latest NASA program, there are mission challenges that have never before been faced nor attempted, and the need for modeling up-front in the design process has been recognized. Discrete Event Modeling has been applied in several places on this particular program, but none more important that assisting in designing to the launch availability requirements that have been levied in program-level requirements document. The program management office for this particular program has a system engineering function and a safety and mission assurance function, and these two offices have partnered in developing a detailed model of the program’s systems and ground support elements to discern the major un-reliability and maintenance elements that will drive the un-availability of systems for on-time launch. Once the unreliability and unavailability items were identified, various improvement options were built into the model to trade the possible improvement in launch probability. This particular program has a very unique requirement to launch two vehicles within a specific timeframe, and thus design to a specific availability of systems requirement. The discrete event simulation was built using the TITAN tool marketed by The Fidelis Group, and the model included systems from both launch vehicles, ground support systems and various other factors such as sea states and weather delays.

7.1 **Analysis Detail.**

This analysis was completed to ensure that certain program requirements were adequate. The requirements being verified were launch availability per launch attempt and launch probability per launch attempt. The analysis was conducted using input data from several existing launch vehicle programs, and data from existing ground systems. Weather data, sea state data, and allocations for loss of mission estimates based on on-time launch given the two launch vehicles and on-orbit loiter limitations where also mined and used as part of the inputs. The simulation was initially run and baselined using inputs from experts on the program. The model focused on the overall time that starts when the vehicles were integrated in the vertical integration facility, rolled out to the pad, and the normal launch sequence executed. Rules and operational workarounds associated with system failures/faults at the pad were included in the model, given the capabilities of the TITAN tool.

7.2 **Results and Conclusion.**

The initial analysis showed areas of necessary
improvement, including the launch vehicle and ground systems. Several trades were run to generate improvement in expected performance based on the baseline model. The results of these trade studies were then used to optimize the program level availability requirements and to eliminate “to be determined” areas of flow-down requirements and specifications. This analysis basically provided an accurate means to identify and mitigate failure modes that drove the availability of systems for launch in the wrong direction. It also was used to baseline and finalize the requirements, showing the multi-faceted capability of these types of models. The NASA program is working to use Discrete Event Modeling in a wider fashion to ensure that reliability, availability, and maintainability are designed into systems that the Agency develops and operates.

8. CONCLUSION

Use of discrete event models is certainly not new, but application as a major analysis tool across the board on a system development project is not a widely known use of this tool. As depicted throughout this paper, use of modeling can help a project manager or engineer make more informed and verifiable design decisions that are focused on meeting requirements. Also, as demonstrated, this tool is very effective in identifying failure modes and optimizing mitigation of those modes, thus reducing technical risk in system operation. Program and project managers in all industries are becoming more and more aware of this powerful tool and the value it can provide. A program manager once exclaimed when discussing the results of this analysis – “Where have you been all of my life – this is wonderful, I will never do a project without this process again.” Hopefully, more programs and projects will have management that will become disciples of this common sense-based approach.

BIOGRAPHIES

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Jim Owens has worked at Dow Chemical for 33 years in various engineering and maintenance positions. Jim experience includes leading design and construction of large new facilities both domestic and international. The last ten years has been spent as reliability and maintenance professional engaging in Dow's efforts to develop a reliability simulation program. Jim is also the modeling leader within the maintenance function. Jim also is a certified black belt working within Dow's program of performance excellence. Jim is currently a reliability and simulation subject matter expert within Dow's Global Maintenance Technology Center.

Jim currently resides in London, Ontario, Canada with his wife Janet.

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Scott Miller is a 21 yr employee of The Dow Chemical Company, currently serving as the Reliability Simulation/Assessment Program Leader for a 20+ Billion US Dollar Joint Venture capital project being built in the mid-East region. Prior to this current assignment Scott spent 4 years in a Global Reliability Simulation Technical support role as a Senior Reliability Engineer, applying Reliability Engineering Principles and Tools across the globe on both new capital projects and existing assets. Scott has also served as the Project RE on several major 500 Million US Dollar capital projects, focusing on applying Design For Reliability Concepts into new capital designs. Other past assignments include 5 yrs as an in-Plant RE in Hydrocarbons and Power Plants, and 7 years in various Automated Process Control and Instrumentation technical and supervisory roles. Scott is an ASQ Certified Reliability Engineer and a certified Design For Six Sigma Black Belt. He and his family currently reside in southern Louisiana.

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