A Case Study Using Modeling & Simulation To Predict Logistics Supply Chain Issues

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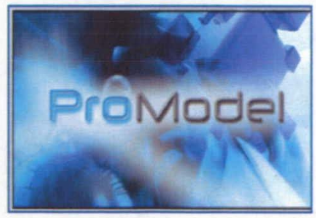
[Abstract] Optimization of critical supply chains to deliver thousands of parts, materials, sub-assemblies, and vehicle structures as needed is vital to the success of the Constellation Program. Thorough analysis needs to be performed on the integrated supply chain processes to plan, source, make, deliver, and return critical items efficiently. Process modeling provides simulation technology-based, predictive solutions for supply chain problems which enable decision makers to reduce costs, accelerate cycle time and improve business performance. For example, United Space Alliance, LLC utilized this approach in late 2006 to build simulation models that recreated shuttle orbiter thruster failures and predicted the potential impact of thruster removals on logistics spare assets. The main objective was the early identification of possible problems in providing thruster spares for the remainder of the Shuttle Flight Manifest. After extensive analysis the model results were used to quantify potential problems and led to improvement actions in the supply chain. Similarly the proper modeling and analysis of Constellation parts, materials, operations, and information flows will help ensure the efficiency of the critical logistics supply chains and the overall success of the program.

I. Introduction

PARAMOUNT to the success of the Constellation Program will be the optimization of significant supply chains to deliver thousands of parts, materials, sub-assemblies, and vehicle structures as needed. Proactive and real-time analysis needs to be performed on the integrated supply chain processes to deliver critical items efficiently. Process modeling provides predictive decision support solutions for supply chain problems which enable decision makers to reduce costs, accelerate cycle time and improve business performance. This methodology combines past process supply experiences with innovative technology to equip logistics and operations staff with a powerful "what-if" capability. This also provides a powerful, analytical framework which improves the speed, accuracy, and confidence with which they can make mission critical logistics decisions. Using "what-if" scenario analysis, options to various supply issues can be examined, compared, modified, and fully understood. Process simulation tools are capable of accurate predictive analysis and are invaluable for evaluating hotly debated operations and supply chain problems through precise analytics.

II. Simulation Model

United Space Alliance (USA), LLC utilized this approach in 2006 to build simulation models that recreate shuttle orbiter thruster failures and predict the potential impact of thruster removals on logistics spare assets. USA has extensive capabilities to develop simulation models that effectively represent manufacturing, refurbishment, repair, and integration processing as well as the associated logistics materials and supply chain issues. Valid simulated representations of important processes are built, modified, and analyzed for optimum performance and to reduce risk. These animated models are built using the discrete event simulation application ProModel.



The main concern in this modeling project was the early identification of possible problems in providing thruster spares for future shuttle missions. In the past, thruster failures have sometimes strained the limited supply of replacement assets; therefore, initial concerns about future supply issues seemed legitimate. If replacement thrusters

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are not available when needed then the Shuttle Program could incur processing delays and/or asset reallocation. Therefore, thruster part shortages could be serious enough to lead to Shuttle Flight Manifest changes.

A small team made up of logistics experts and a simulationist was assembled to address the thruster supply issues and management concerns. Some key questions raised at the start of the project were:

- What will be the demand on thruster spares for remaining shuttle flights?
- Will supply be able to meet that demand?
- What effect does repair turnaround time have on spares supply?
- Will spares shortages occur? If so, how frequent?
- Which shuttle missions will be impacted?
- Will cannibalizations (CANNs) from other vehicles be required to meet orbiter processing need dates?
- What actions can we take to mitigate the risks of the future?

Using ProModel the team created a series of thruster simulation models that utilize past process data from previous shuttle flights to help predict potential events in the future. The data included:

- Thruster failure rates for each unique part number
- Thruster repair rates in several categories by type
- Repair turnaround times
- Kennedy Space Center (KSC) orbiter processing times
- Launch delays

In addition, the shuttle flight manifest launch dates were also added to the model in order to simulate all remaining flights through 2010. The timeline below illustrates the manifest as of late 2006 (Fig. 1).

Figure 1. Shuttle Manifest (as of October 2006)

Some of the thruster model assumptions included:

- Future thruster failures, repairs, removals, and processing times / rates will be like the past.
- White Sands Test Facility (WSTF) will complete and ship their current repair inventory on the expected delivery dates to KSC. These dates can be adjusted as needed in the model.
- Atlantis will retire in September 2008; all of its thrusters will be removed, flushed, and placed in KSC Stores.
- There are no additional spares; the thruster inventory consists of those onboard the three orbiters as well as those out for repair and at KSC Stores.

One-way ANOVA: Failure Rate of Model Versus Historical

Source	DF	SS	MS	F	P
Model Vs Historical	1	0.00017	0.00017	0.06	0.806
Error	40	0.11220	0.00281		
Total	41	0.11238			

Figure 2. ANOVA Results During Verification

As the model runs, it utilizes the past historical data as input to generate random failure events after each simulated flight. A series of validation tests (example in Fig. 2) confirmed that the model produced output data that was similar to the actual historical data used as input. The high p-value in the one way ANOVA test led us to fail to reject the null hypothesis that the failure rates of the model versus historical data were statistically the same. Several scenarios were constructed to determine the baseline and make comparisons to potential process improvements like reducing repair time. The model was run 100 times through all 18 missions on the manifest for each of the scenarios which created data from 1,800 simulated missions. During the model runs, over 600 variables recorded data in the background for all the thruster failure, removal, and repair activities. For each of the 100 replications, the data were captured in output statistics and Excel spreadsheets then analyzed.

Figure 3 is a screen shot of the animated thruster model. When a run begins, all three orbiters show green, good thrusters, which was the actual condition prior to STS-115. After each mission, if failures occur then those thrusters turn red, are removed, and sent out to WSTF for repair. Thrusters co-located on manifolds with a failed thruster then turn yellow, are also removed and sent to WSTF for flushing. After all thruster removals, the model looks in the thruster inventory at KSC Logistics Stores - and if the right part numbers are available then they are sent to the Hypergol Maintenance Facility (HMF) for processing prior to installation on an orbiter. Ongoing repairs at WSTF happen independently from the rest of the model; flushed and repaired thrusters are eventually sent back to KSC Logistics Stores as spares for reinstallation.

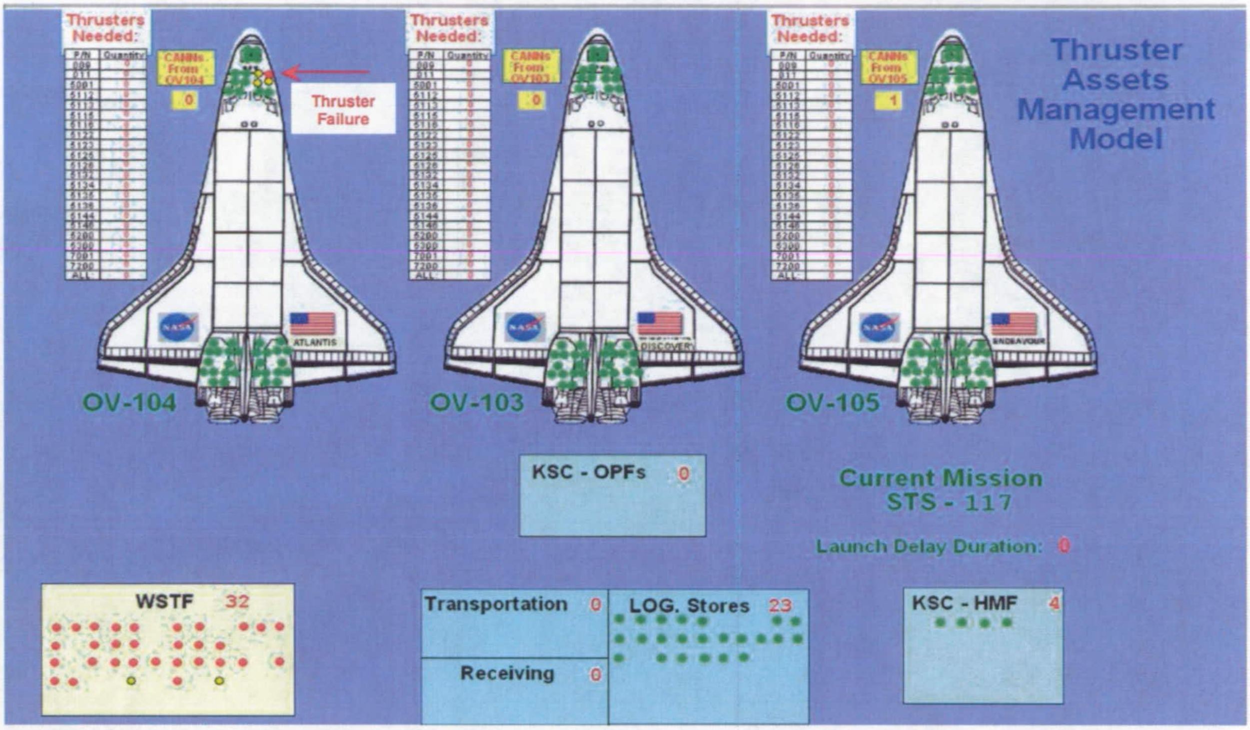

Figure 3. Screen Shot of Thruster Model

III. Scenarios & Results

Several model scenarios were developed for experimentation and data generation. The first scenario was a baseline "as is" model that predicted what would happen if no changes are made to the current state. Subsequent scenarios sought to explore potential impacts of reducing the repair times, reducing the failure rates, or providing additional resources for processing. Experimentation of the model produced results used to quantify potential supply chain problems in providing thruster spares for the remainder of the Shuttle Flight Manifest.

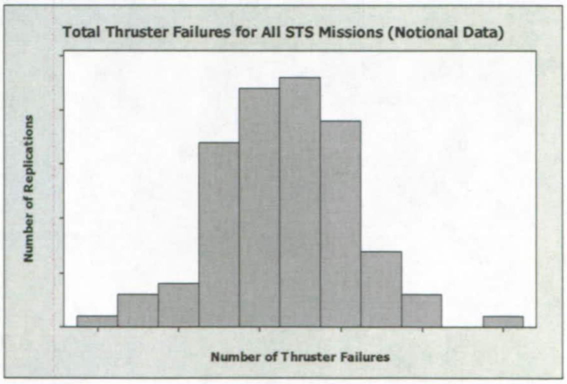

Figure 4. Total Projected Thruster Failures

The model data predictions included:

- Number of thruster failures (Fig. 4) and other thruster removals
- Manifolds with highest failures
- Part numbers (PN) most likely to have a shortage
- Number of orbiter cannibalizations (CANNs) from other vehicles that may be required to meet the PN shortages
- Missions with greatest probability of having a shortage (Fig. 5)
- Overall effects of CANNs and other removals on the Shuttle Flight Manifest

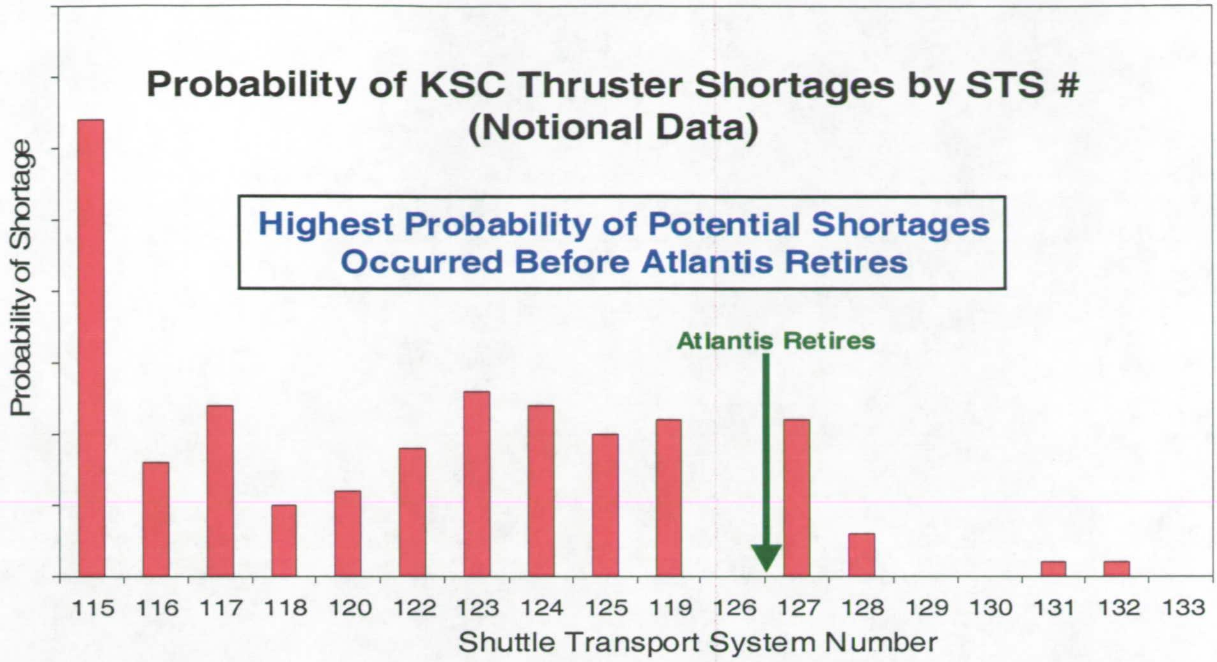

Figure 5. Probabilities of Thruster Shortages

Specific data and conclusions from the model were presented to NASA and USA Senior Management. The evaluation was accepted and a number of actions were initiated to mitigate the risk of thruster spares shortages in the supply chain (Fig, 6). Manifest changes were not considered a viable option; therefore, the focus was on finding ways to decrease demand rate through engineering design changes as well as a review of failure criteria and increasing spares availability by adding resources and reducing repair cycle times. To date, the actions implemented have reduced the risk of thruster spare shortages to the Shuttle Program.

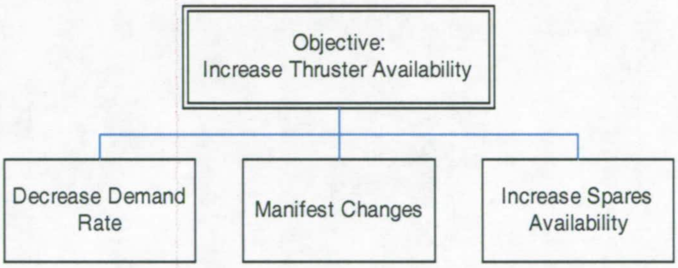

Figure 6. Solution Tree

The entire modeling and analysis effort for this simulation project was accomplished in about six weeks. Since completion last Fall, a number of new scenarios have been developed, the Shuttle Flight Manifest has been updated by NASA, and thruster failure rates have been revised. Future plans are to continue maintaining, updating, and re-running the thruster models as more data are collected from subsequent flights.

IV. Conclusion

In summary, simulation modeling capabilities strongly support analysis of integrated logistics supply chain processes and operations including program-level issues like critical spares. These tools allow analysts to model the characteristics of a real system for a specific purpose, allowing "why", and "what if" scenarios. The proper modeling and analysis of parts, materials, operations, and even information flows will help ensure the continued efficiency of the significant logistics supply chains for the remaining shuttle flights as well as other U.S. led space efforts. In a July 3, 2007 open letter titled ***Leading Your Leaders*** from Wayne Hale, NASA Shuttle Program Manager, he encourages the NASA community to use analysis to help understand the possible outcomes of what can happen in real life situations. Hale states, "A well characterized analytical tool, verified against real world performance, including all of the variables, peer reviewed, and operated within the limits that it was intended is a powerful way to understand what could happen." Modeling & Simulation is that tool; we would be wise to promote and expand its continued use throughout the emerging Constellation Program.

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