

Utilizing Discrete Event Simulation for Schedule Analysis: Processes and Lessons Learned from NASA's GOPD Integrated Timeline Model

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ABSTRACT

In planning, simulation models create microcosms, small universes that operate based on assumed principles. While this can be powerful, the information it can provide is limited by the assumptions made and the designed operation of the model. When performing schedule planning and analysis, modelers are often provided with timelines representing project tasks, their relationships, and estimates related to durations, resource requirements, etc. These timelines can be created with programs such as Microsoft Excel or Microsoft Project. There are several important attributes these timelines have; they represent a nominal flow (meaning they do not represent stochastic processes), and they are not necessarily governed by dates or subjected to a calendar. Attributes such as these become important in project planning since timelines often serve as the basis for creating schedules. Simulation techniques such as discrete event simulation (DES) provide the opportunity to introduce variability into the timeline tasks, as well as subject the timeline to certain parameters in order to create a broader understanding of timeframes and schedule impacts. NASA utilizes DES to provide analysis for certain program requirements, budgeting activities, and schedule risk. A major tool for these analyses is the Ground Operations Processing Database (GOPD) Integrated Timeline Model. Updates to the GOPD occur on a semi regular basis allowing for a comparison of analyses providing an opportunity for improvements in modeling and rework of planned activities. It was during one of these comparisons that an issue was discovered as it related to the application of a factor to account for shift work assumptions. This paper presents the GOPD modeling process along with lessons learned and solutions to the shift work assumption problem.

CITATION: Conner, A. and Rabelo, L., "Utilizing Discrete Event Simulation for Schedule Analysis: Processes and Lessons Learned from NASA's GOPD Integrated Timeline Model," *SAE Int. J. Aerosp.* 8(1):2015, doi:10.4271/2015-01-2397.

INTRODUCTION

"Over 60 years of simulation presence in the areas of manufacturing and business, has led to a wide spectrum of successful applications in different areas such as design, planning and control, strategy making, resource allocation, training, etc." [1]. In planning, simulation models create microcosms, small universes that operate based on assumed principles. While this can be powerful, the information it can provide is limited by the assumptions made and the designed operation of the model. When performing schedule planning and analysis, modelers are often provided with timelines representing project tasks, their relationships, and estimates related to durations, resource requirements, etc. These timelines can be created with programs such as Microsoft Excel or Microsoft Project. There are several important attributes these timelines have; they represent a nominal flow (meaning they do not represent stochastic processes), and they are not necessarily governed by dates or subjected to a calendar. Attributes such as these become important in project planning since timelines often serve as the basis for creating schedules. Simulation techniques such as discrete event simulation (DES) provide the opportunity to introduce variability into the timeline tasks, as well as subject the timeline to certain parameters in order to create a broader understanding of timeframes and schedule impacts. "Discrete-event simulation (DES) has been the mainstay of Operational Research (OR) simulation community for over 40 years" [5].

DISCRETE EVENT SIMULATION

Discrete event simulation (DES) is a computer-based modeling technique used to analyze complex and dynamic systems.

"Discrete-event simulation concerns the modeling of a system as it evolves over time by a representation in which the state variables change instantaneously at separate points in time. (In more mathematical terms, we might say that the system can change at only a countable number of points in time.) These points in time are the ones at which an event occurs, where an event is defined as an instantaneous occurrence that may change the state of the system" [2].

The DES process involves building a model that represents a process or system to be studied, simulation experiments, and the collection of data from simulations which is utilized to make inferences about the process or system.

"DES is useful for problems that consist of queuing simulations or complex network of queues, in which the processes can be well defined and their emphasis is on representing uncertainty through stochastic distributions. Many of these applications occur in manufacturing and service industries as well as queuing situations" [5].

Such a technique is useful as it provides the opportunity to resolve uncertainty, gain valuable insight into a system's behavior, and the ability to compare alternative architectures.

DES MODEL DEVELOPMENT

In order to estimate the labor required to process a flight vehicle, validate programmatic requirements, and estimate the planned ground operations throughput and cycle time, Kennedy Space Center's (KSC) Ground Systems Development and Operations (GSDO) Program employs a DES Modeling and Analysis Center. This center has been tasked by the GSDO Program to develop a model representing Orion and SLS flight processing for Exploration Mission One (EM-1) and Exploration Mission Two (EM-2). Such an activity is directly associated with GSDO Goal 1 which is to

Provide sustainable, affordable, and safe ground operations and integration capabilities required to extend human presence across the solar system.

and

Drive operability into flight and ground systems

as well as Strategic Objective 1.3 which is to

Maximize efficiencies in flight and ground system operations

Members from GSDO Integrated Product Teams (IPT), Element Integration Teams (EIT), SLS, and Orion programs have come together to act as subject matter experts in order to develop operational concepts related to flight processing. This information is then input into a tool known as the Ground Operations Planning Database (GOPD). GOPD inputs include the tasks required for vehicle processing, their predecessor/successor relationships, duration estimates, resource requirements, facility, etc. Subject matter experts rely upon experience and historical data to inform their GOPD inputs. Most of the historical data utilized comes from Space Shuttle operations, but also includes information from various other expendable launch vehicle programs like Atlas, Delta, and Falcon where analogous information is available. Updates are then made to the GOPD through a semi-regular drop cycle as understanding of operations matures. After each cycle an integrated timeline is created which is in turn used by the DES Modeling and Analysis Center to develop its GOPD Integrated Timeline Model.

GOPD INTEGRATED TIMELINE MODEL PARAMETERS

Lognormal Distribution

Along with their various GOPD inputs, subject matter experts are asked to make 3 estimates related to task durations (the minimum, nominal, and 95th percentile). This is because intuitively, one can assume that a task to be performed in vehicle integration and launch will vary in duration from one instance to another. Or, for example, one

may say that if it is observed that 2 hours are required to tighten a set of bolts, it cannot be assumed that the next time those bolts must be tightened it will take exactly 2 hours. That is to say however, there are assumptions one can make about the duration of the task. Firstly, the task will take at least a certain amount of time (the minimum duration). Second, the task duration may take on a large value, albeit with low probability. Keeping this in mind, one must choose a particular statistical distribution that can adequately model the task's duration.

Commonly, either the normal or beta distribution is used to model process durations. However, it has been found that the lognormal distribution offers a better choice. Empirically, Premachandra and Gonzales (1996) give evidence for this statement by providing a histogram of 650 drilling times which is fit with a lognormal distribution (Figure 1). This distribution “easily passes a Chi-square goodness-of-fit test” [4].

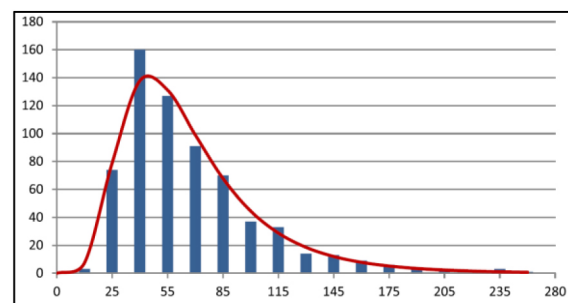


Figure 1. Drilling times in minutes [8]

Other reasons for utilizing the lognormal distribution are that it is strictly positive, it can approximate sums of positive random variables, it can represent the relationship between capacity and activity time, and it can represent the ratio between actual and estimated activity time [8]. For these reasons, the lognormal distribution is used in the GOPD integrated timeline model to give variability to the task durations.

Historical Delays

To further provide an understanding of the risk to the operations timeline presented in the GOPD, an analysis was conducted of historical delays. A survey was conducted of Critical Path Assessments produced for each mission during the Space Shuttle Program (pictured below). These assessments provide invaluable information related to delays to milestones such as Orbiter OPF Roll-In, Start SRB Stack, ET/SRB Mate, Orbiter/ET Mate, Payload to Pad, SSV to Pad, Launch, etc. incurred.

This information was then compared to the SLS/Orion processing flow in order to determine analogous operations. Once analogous operations were determined, future delays were projected and statistical distributions created for potential delay durations. These distributions were combined into submodels with probabilities of occurrence, and appropriately placed into the logic flow. For example, the Launch Countdown Delay risk model was placed in the GOPD Integrated Timeline model just prior to SLS First Motion.