Simulation Modeling with Simio at Lockheed Martin Aeronautics

Applications and Challenges

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Lockheed Martin Overview

Lockheed Martin Aeronautics, based in Fort Worth, Texas is one of the world's leading defense contractors, producing iconic military aircraft over the years such as the U-2, SR-71 Blackbird, C-130 Hercules, and F-117 stealth fighter. Today, its largest contract is the F-35 Joint Strike Fighter, a 5th generation, multi-role stealth fighter with three versions: F-35A conventional take-off and landing (CTOL), F-35B short-take off vertical landing (STOVL), and the F-35C carrier variant (CV).

Problems/Challenges

The "design and build concurrent" nature of the F-35 contract resulted in initial low rate production of the aircraft beginning in 2008 followed by an increasing production rate that culminates in full-rate production by 2019. This increasing rate presents unique production challenges since each stage of production consist of changing factory configurations and flows. With the fluid nature of the production line, modeling each stage of production can be challenging since the production line never truly reaches steady-state before the next configuration is introduced. Further, as the production flow changes, the cadence, work schedules, and manpower requirements may change, each needing to be reflected for an analysis to be beneficial to decision-makers.

Another unique challenge that at times requires a model to address is the fact that all three versions of the aircraft flow through the same production line. With each version having unique work content (i.e., CV requires installation of a tailhook whereas CTOLs and STOVLs don't; or STOVL requires installation of a lift fan whereas CTOLs and CVs don't), depending upon the level of modeling detail, differences in work content may need to be considered.

Finally, since the F-35 production line never truly reaches steady state before another change to physical configuration, work schedules, and cadence is introduced, summary statistics that reflect the performance of the system over the entire simulation run do not fully capture the performance of the system over time. Instead, user-defined time-phased statistics summarizing the performance of the system at pre-defined periods of time allow us to assess the system as the configuration, work schedules, and cadence changes.

Simio is the preferred tool for discrete event simulation among Lockheed Martin Aeronautics' Industrial Engineering Systems group as it allows for quick creation of simple prototype/proof-of-concept models, its flexibility to model extremely complex processes, its easily traceable process logic, and its object-oriented features that allow for tracking of entities through the system during model run which reduce model verification time.

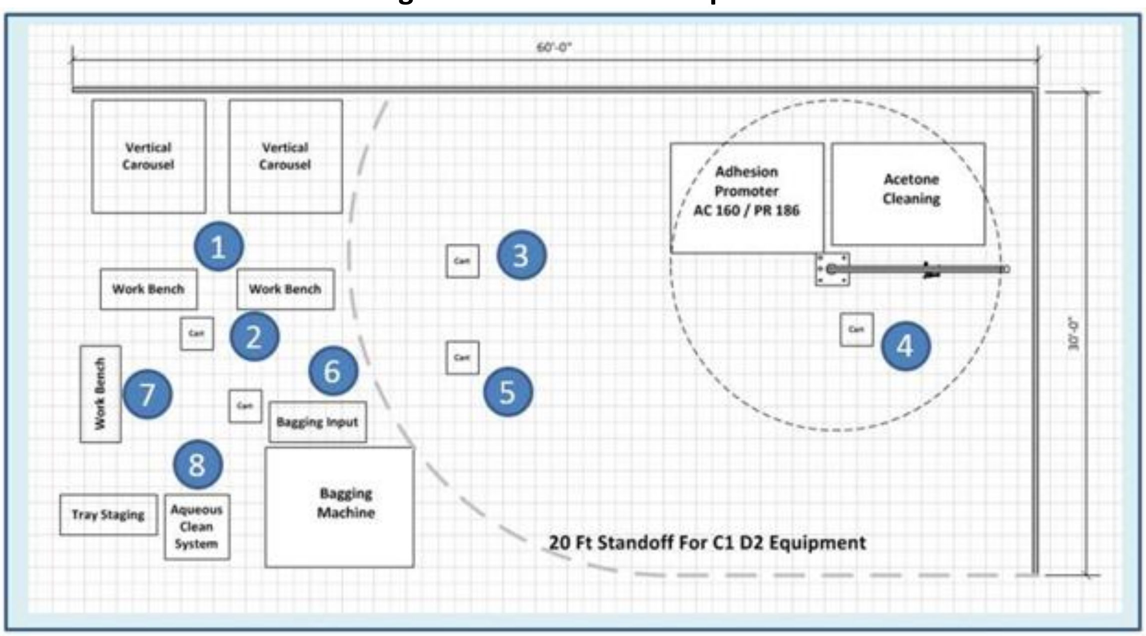
Recent Applications

Two recent applications of discrete event simulation and Simio were in two very different areas within F-35 production – F-35 Flight Line and the F-35 FastPAKS.

Fastener Prep and Kitting System (FastPAKS)

Currently, mechanics in F-35 Wing assembly manually prepare fasteners prior to Wing assembly. The preparation of fasteners by the mechanics is a time consuming process and takes away valuable assembly time. The F-35 Fastener Prep and Kitting System (FastPAKS) is a proposed semi-automated system that will allow for faster sorting of fasteners into manageable quantities, cleaning the fasteners with chemical solution, and kitting them into required quantities for delivery to the production line. Once fasteners are chemically treated they assume a shelf life – they must be bagged within 2 hours and installed on the aircraft within 5 days – therefore building an inventory of treated fasteners is not an option. The system will initially handle the fastener demand for the F-35 Wing, however, it may be expanded to handle demand for other F-35 components. The basic flow of the FastPAKS is illustrated in Figure 1:

Figure 1. FastPAKS Concept



1 Sorting Into Trays
2 Stacking Trays Into A Tower
3 Transport Tray Stack To Chemical Process
4 Chemical Processing
5 Transport Stack To Bagger Input
6 Input Fasteners Into Bagger
7 Organize Fasteners For Delivery To Line
8 Tray Cleaning Station

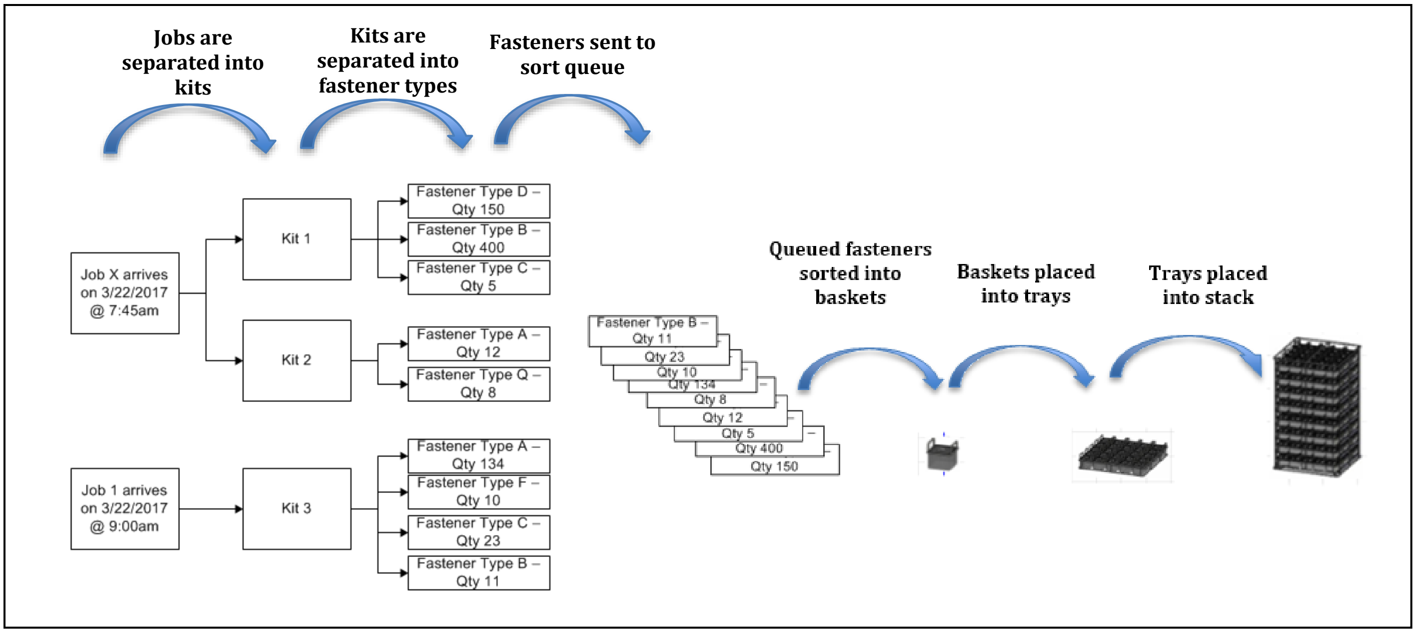
Approach

The approach used to model the FastPAKS was to develop a Simio model that tracks the flow of batched fasteners from the time the job arrives to be sorted until all fasteners for that job are kitted and sent to the production line. The duration of the simulation was from 2018 through 2022, or from the time the proposed system is to be operational through full-rate production.

The daily demand of fasteners arriving to the system is generated by reading in the scheduled Wing assembly "jobs", with each job requiring a different number of kits, and each kit consisting of different types and numbers of fasteners. Once the demand is broken down into individual fasteners (each with different physical dimensions), they are presented to the sorter via the vertical carousel where they enter the Facility view in Simio. As the sorter fulfills the job request, the automated vertical carousel presents the correct fastener type for picking and sorting into baskets, with each basket holding only one fastener type simultaneously. Once the sorter fills the baskets with fasteners, baskets are then placed in trays which are then placed in stacks.

The flow of daily jobs into individual fasteners and individual fasteners into baskets, trays, and stacks is shown in Figure 2.

Figure 2. Example of Grouping of Jobs to Fasteners to Trays to Stacks



The full stacks then flow to the acetone cleaners, adhesion promoters, and bagging stations (per Steps 3-5 in Figure 1). Once stacks reach the bagging station (Step 6), trays are removed from stacks, baskets are removed from trays, fasteners are emptied from baskets and bagged, and bags of fasteners are grouped into their respective kits and delivered to the production line for installation on the aircraft.

With the validated model, the following requirements were determined to ensure the system was sized appropriately with respect to the following:

- Number of vertical carousels required
- Number of acetone cleaning tanks required
- Number of adhesion promoter tanks required
- Number of bagging stations
- Number of sorters, chemical workers, and baggers (assumed to be 1 per station)
- Number of baskets, trays, and stacks required

Results/Solution

Enumerating the possible combinations of sort carousels (1-2), cleaning tanks (1-2), promoter tanks (1-2), bagging stations (1-2), number of baskets per tray (6 combinations), and number of trays per stacks (2-10) resulted in a total of 864 possible scenarios. However, by taking into account anticipated ergonomic restrictions of tray and stack weights as well as a simple balancing of the system, this was reduced to 48 scenarios.

Based on 10 replications, a single vertical carousel results in 90.7% of kits being completed on the same day that they are promoted, leaving 9.3% of kits at risk of expiration. Adding a second vertical carousel increases performance to 98.4% of kits being completed on the same day they are promoted, and only 1.6% of kits at risk of expiration. While not only improving performance, adding a second vertical carousel also has the additional benefit of providing a contingency plan in the event of failure of the first carousel. Adding a second acetone tank and promoter tank did not significantly improve performance.

Once the baseline sizing of the system was established – 1 vertical carousel, 1 promoter tank, 1 acetone tank, and 1 bagging station – Simio's OptQuest ad-in was utilized to conduct the following equally-weighted multi-objective optimization to determine ideal tray and stack sizes:

Maximize	% of kits that complete on same day they are promoted AND % of kits that complete on same day they are sorted
s.t.	Number of baskets per tray (equal to 25 or 30) Number of trays per stack (between 3 and 8) Weight of full tray must be less than OSHA manual lift requirements Number of vertical carousels (1 and 2)

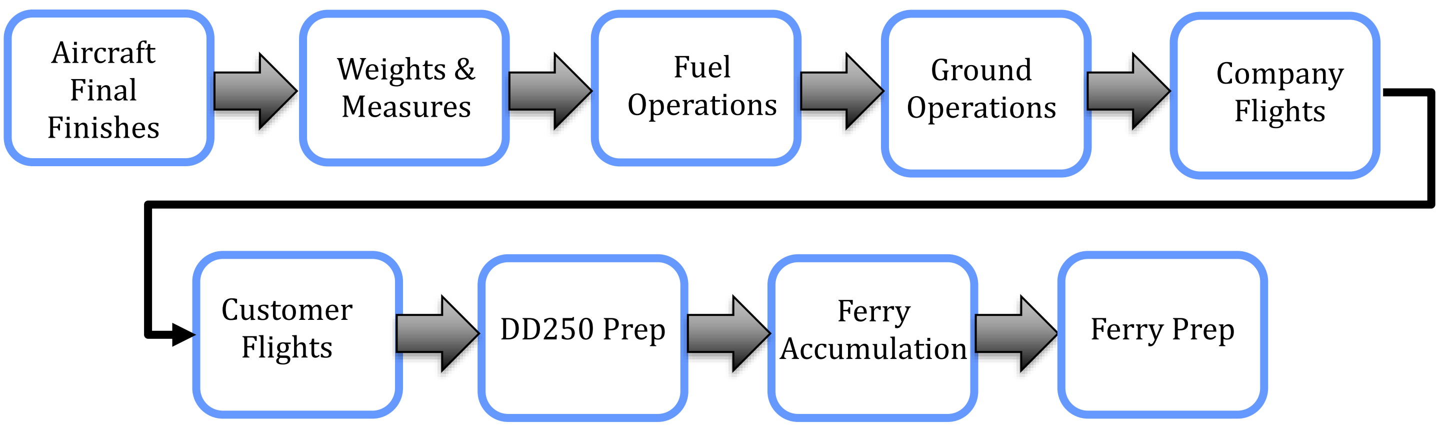
When optimizing the trays and stack sizes, 30 baskets per tray (5 X 6) and 4 trays per stack resulted in the optimal performance for a single vertical carousel system, expandable to 5 trays per stack for a two carousel system. Both of these systems resulted in 100% of kits being completed on the same day that they are promoted, minimizing the risk of re-work and waste.

F-35 Delivery Operations: An Evaluation of Flight Line Capacity, Span and Ferry Accumulation

Approach

A Simio simulation model of the F-35 Flight Line was initially created to help the program evaluate a series of different ferry plans and ultimately help forecast the ferry schedule and flight line capacity requirements gearing up for full rate production. When aircraft complete the build process and are ready for flight test, they proceed through a series of steps on the flight line as shown in Figure 3.

Figure 3. Flight Line Flow



Detailed capacity analysis had been done in the past based on stochastic values such as scheduled or average station spans, but the amount of variation which has been demonstrated within historical performance to station span, due to a variety of factors such as nonstandard work, weather delays, ground aborts and amount of unplanned flights, had not been directly incorporated into the capacity analysis.

The value of discrete event simulation is the ability to incorporate unique distributions on each station within the process, and better predict the resource requirements ahead of time.

Results/Solution

Initially, the goal was to show the impact of different ferry plans to help the F-35 program solidify a ferry plan. For example, is there a difference in number of jets held on the flight line if the jets are ferried two at a time verses four at a time depending on the country or ferry location. The value is the amount of information the model provided to help assess how many run stations are required for ferry accumulation (period of time between DD250 and ferry prep), and model how changing the ferry rules affect the requirements. The variation in the schedule that was incorporated into the model results in, for the first time, a model that accurately captures the required capacity or WIP on the flight line span distributions of each flight line task. Results are further broken down by the number of planes in each area within flight line or number of run stations required. With the validated model, the number of pilots and run stations was projected out to full rate production and statistics gathered on a yearly basis.   Changing the ferry rules greatly affect the requirements.

Within the simulation model, details were provided on the flight schedule on a daily, weekly and monthly basis. This included the number of ferry flights, the number of customer flights vs. government flights, the number of government pilots and company pilots required. Additional measures included a percent of unplanned flights due to weather, additional system checks and ground aborts.