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# Boeing Arena Simulation

## Safety Stock Analysis

An Overview affects of Second Issue Operations



University of Idaho



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## Executive Summery

At the beginning of the spring 2009 school semester our group from Scott Metlen's business simulations class was assigned a project with Boeing Skin and Spar in Frederickson, Washington. The nature of the project involved utilizing the simulations programming skills we would acquire throughout the semester on a real life, real time, and real money situation.

The group was comprised of five seniors from the University of Idaho Production/Operations Management program: Dustin Smith, Jeremy Wemple, John Noble, Nic Pentzer, and Shane Wemhoff. We traveled to Boeing at the beginning of the class at met with Boeing's Industrial Engineering group to discuss project scope and expectations. Our assigned group sponsors were Rick Jones and Don McCart.

We utilized Rockwell's Arena simulations software to complete the project modeling Boeing's skin and spar production facility in order to determine an appropriate level of finished goods inventory. Each student had access to personal laptops for use, while the main model was ran through a personal high capacity desktop computer owned by one of the students.

We reported our discoveries on May 1, 2009 to Boeing. This report is a follow up to the presentation and its purpose is to relay all the research and conclusions we came to as a team, as a deliverable document for Professor Metlen Ph.D and Boeing's Industrial Engineering group.

We have accumulated a lot of knowledge throughout the semester on process management and the value of simulation as a powerful tool to assess and improve any process in any organization. We would like to thank Boeing for the opportunity to work with them, especially Rick and Don. We are confident the following information will aid the process improvement situation at Boeing skin and spar.

## Goals

The purpose for modeling the production, kitting, and transportation system for the Frederickson plant is to determine adequate levels of safety stock either in raw material or finished goods inventory. The objective is to minimize factory disruption caused by independent demand defined here as additional demand occurring from customer requests or parts rejected by quality control procedures. The objective arises from five observations taken directly from the factory:

1. Direct module loading philosophy minimizes finished goods inventory. This observation occurs as part of a broader company initiative to implement lean manufacturing principles and subsequently eliminate most finished goods inventory. The production system is intended to produce parts with a mindset analogous to a just-in-time philosophy. In theory, when parts need to be transported they should be finishing the manufacturing process with the timing set to almost eliminate inventory. This process is effective at reducing inventory but it leaves the system highly vulnerable to disruptions caused by rejected parts or additional unforeseen demand.
2. Lack of floor space impacts the ability to store finished goods. After lean practices were implemented in the Frederickson factory, the additional floor space that was created from removing finished goods inventory was used to house additional production equipment. This creates a dynamic that limits the ability of the factory to utilize a blanket solution calling for the increase in the general finished goods inventory for all parts. This problem creates a need to generate optimal safety stock for a select number of parts that are most affected by second issue demand.
3. There is a lack of visibility for independent demand. The unpredictable nature of the additional demand creates added pressure on a highly nervous system. While average part scrap rates can be computed and integrated into the production schedule, outlier demand can still have a profound impact on the system. This observation further highlights the need for an optimization of finished goods safety stock.
4. The factory reacts to quality rejections rather than anticipating them. Currently, quality rejections have a material impact on the production system. Instead of building a buffer against average scrap rates in anticipation of rejected parts, a scrapped part will require priority rework causing disruption of other scheduled parts and decrease in normal flow resulting in large amounts of overtime.
5. The factory buffers safety stock items by purchasing additional raw material. The raw material kept on hand to satisfy second issue demand does not guard against disruption from parts that need to reenter the production process. To optimize the system, the model will explore efficient levels of safety stock of finished goods.

## Expected Output

1. Transport tool utilization
2. Cost comparison between the base model vs. experimental models.
3. Excess capacity created by eliminating scrap.
4. Throughput of parts, planes, kits and batches

The project will be organized into two reporting periods. All preliminary work will be completed after the assignment has been delivered by Boeing. The first reporting period was scheduled for mid-April during which all simulation work was critiqued by the project sponsors, Rick Jones and Don McCart. The final reporting period was scheduled for May 1 at Boeing's Skin and Spar Frederickson facility.

## Process Flow Modeling

We modeled the flow of spar and stringer parts through the entire production system from raw materials to finished goods. From there we modeled the shipping and unloading phase of the kitted parts in order to integrate the timing data back into the model. Greater detail will be placed on the finished goods required to reduce overtime and ensure on time shipment of full kits. We first modeled the existing production system which will be referred to as the base model. Afterwards we created a series of experimental models representing changes in safety stock, overtime usage, and theoretical changes to scrap rate. This two model approach allowed us to see the impact of potential changes

The model utilized a variety of inputs.

1. Raw Materials. The average stock on hand used to cover second issue demand.
2. Fabrication inputs.
  - a. Part numbers
  - b. Process times and rates
  - c. Resource utilization
  - d. Queue size
  - e. Failure rates
  - f. Available up and down times
  - g. Part arrival rates
3. Kitting inputs
  - a. Frequency statistics
  - b. Production rates
  - c. Resource utilization
4. Costs
  - a. Raw material costs
  - b. Raw material inventory costs
  - c. Finished goods inventory costs
  - d. Production costs of people
  - e. Scrap costs

Our model will begin with the raw material and milling step in the production system. Rather than simulating the entire production facility in order to provide part arrivals for the purpose of kitting, we will simulate the production system using a limited number of processes by using average flow times and scrap rates associated with each part number. In order to simulate the milling and fabrication times for “black-boxing,” we will use flow times for each part based on its duration time distribution. Individual raw material stock may be simulated if Boeing wants to include that analysis in the project scope for purposes of reducing or optimizing raw material safety stock.

Figure 1 represents a simplified map of the manufacturing process at the Frederickson plant. A variety of wing skins and spars move through the system based on higher level demand. For the purposes of this project we will focus on the final kitting process outlined in red. We will reduce the manufacturing process flow to a “black box” model that will provide an accurate output of parts without modeling the individual processes.

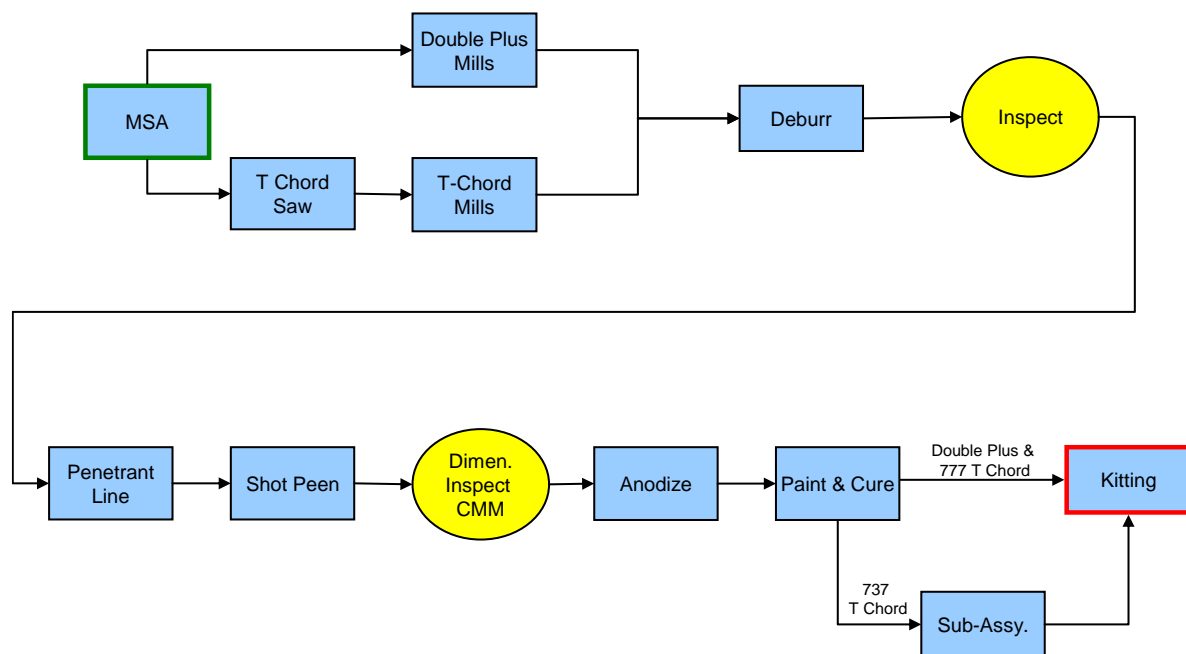


Figure 1 Frederickson Plant Manufacturing Process

The second phase of the current process consists of the transportation of the completed parts and kits to locations in Renton and Everett, WA. The availability transportation tools can affect the timing of delivery and will be included in the modeling process.

### *Part Numbers*

Part numbers will be inputted into the system from specific parts derived from the multiple parts lists furnished by Boeing. Demand for specific parts will be generated by historical demand for entire planes. For instances of second issue demand, or additional demand caused by scrapped parts, the part will be rereleased into the system and will take immediate precedence over existing production that covers scheduled demand.

### *Kitting*

After the individual parts are produced they are collected into various groups called kits. The kits are arranged in a way that allows them to be shipped to the final assembly locations at either Renton or Everett and be easily assembled by the on-site wing facilities. Based on the type of airplane more or less kits may be required to assemble a completed wing. Smaller parts are loaded into final storage racks by hand and larger parts are handled by a series of overhead cranes and hoists.

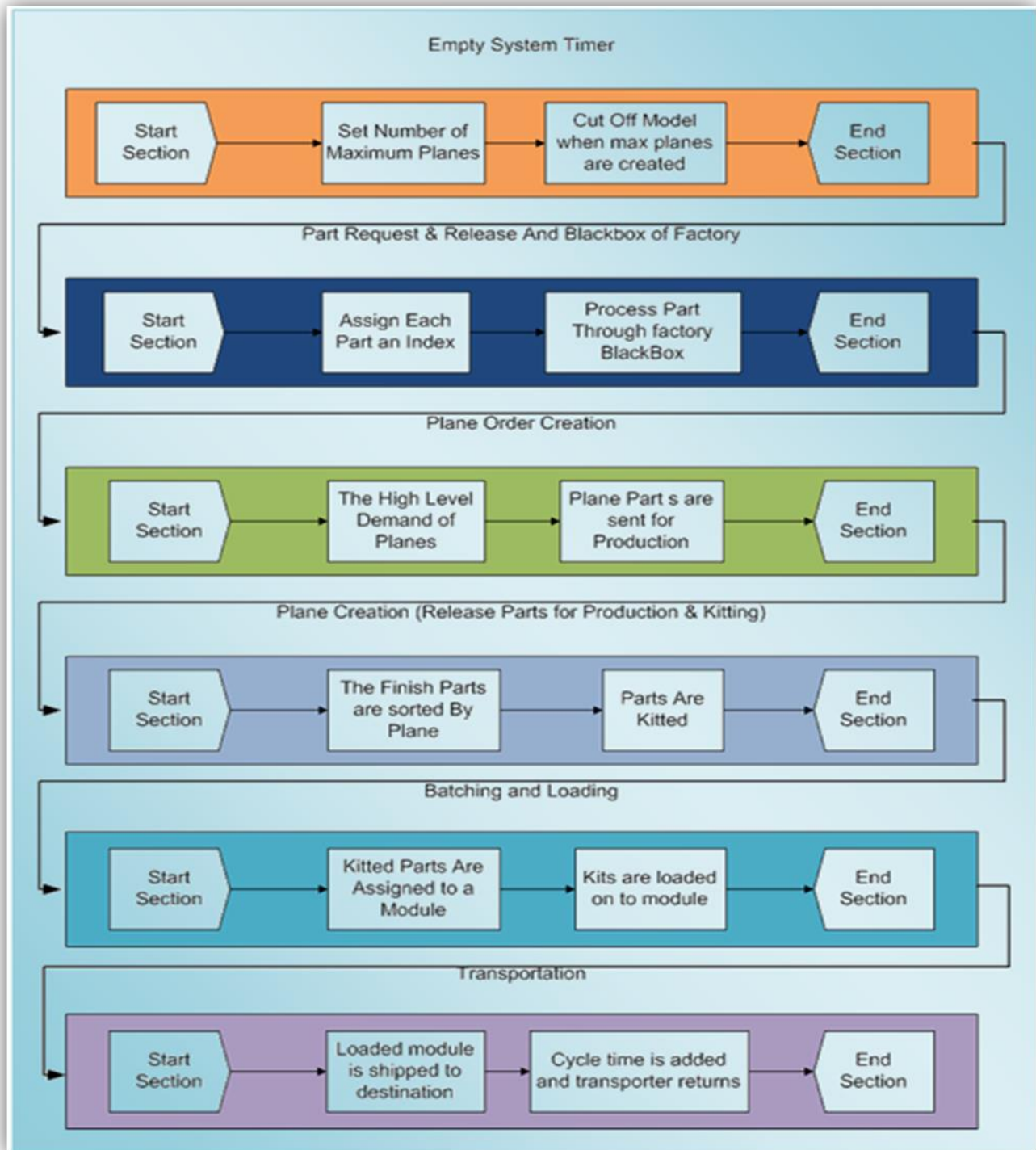
### *Animation*

We will use animation in the model in order to assist in increasing the ability to visualize the modeled processes. Our intention is to use a basic layout of the factory as a background for the model to show how the processes beginning with milling and continuing to kitting and transportation interact with the entire system. We believe the ability to picture the system as a whole will increase understanding and further aid in optimizing the level of safety stock required for efficient operation. Depending on time constraints additional animation may be added to further add to the understanding of parties that may not be fully versed in Arena's functionality. While animation is purely cosmetic and does not affect the inner workings of the model, the added benefit of ease of understanding it could create for third parties means that it may be a valuable addition to the final product.

### *Logical Diagram*

In this diagram the model is brought to its context level showing the purpose of each major section of the model and its key operations.





### ***Empty System Timer***

In all models there needs to be a cutoff point that the model runs too. We wanted to show the completed transportation modules, so the model runs until the transportation has completed for the high level demand.

### ***Part Request & Release and Blackbox of Factory***

In order for a part to obtain a part number, Arena assigns an Index that is correlated to the physical part number used to refer to the part. Once Arena assigns the part an Index that index is used to refer to the part in the remainder of the model using a data set. In order to evoke a process on a part it needs to be created in Arena, which is the job of the *Assign* function. To Process the Part in the factory a calculated delay of manufacturing time is applied to the parts duration in the “Blackbox” *Process*.

Plane Order Creation

To simulate the demand of a part included in a plane the model requires that “Plane Order” be addressed. To Simulate production of plane types the high level demand of the planes was determined by the historical averages of planes per model produced.

### ***Plane Creation (Release Parts for Production & Kitting)***

For a kit of parts to be created it needs a certain criteria or parts that make up the kit per plane per version. The process was devised to be made up of multiple modules that include all of the plane versions, because all the planes need different kits. One problem that this method addresses is the inherent modeling barrier of duplicate parts going to different kits.

### ***Batching and Loading***

In this segment of the model, the kits are held to get ready to go in to the transportation modules. Each batch of kits require a specific module to be loaded in. the loading of kits into modules occurs in this step through the Batching Process.

### ***Transportation Modules***

After the parts have been collected into kits they are loaded onto a transportation module which is attached to a semi-trailer for shipping. The demand for transportation modules is based on the demand schedule based on assembly of planes in Everett or Renton and their associated kits. In addition to the kit attached to the module, additional parts may be attached as necessary to cover second issue

demand. In a fully functioning system, transportation modules will be routed from their destinations and return to the factory in time to load another set of wing kits.

## Assumptions

One of the first things needed to create a working model is a time period for which the model will run. We chose to model an entire year's worth of plane demand and production for the Frederickson facility. Thus, we needed to determine the total amount of hours the Frederickson facility is running in a year. The data was given to us for normal non-overtime production days in a month and the hours for each day. Some overtime data was given to us, but after reviewing the total overtime costs in a year for Frederickson, we used some of the data given and the overtime costs to work backwards and establish the number of overtime hours used across the year. For model running purposes, it is a lot easier to take total productions hours in a year and divide that across 365 days equally, rather than setting up more complex schedules to control operating time. This was the main driver for our purpose of setting up the data this way. Data and numbers used for determining total operating hours in a year for the current/control model are listed below. Those for the variable models have overtime hours at 50%, 25%, and 0% of that of the current/control. As the overtime reduces, the total hours in a year reduce as well, so when divided by 365 the hours per day becomes less as well. The total hours in a year and the hours per day for the variable models are displayed in Exhibit 1 and Exhibit 2.

- 20.75 operating days per month
- 22 regular production hours for weekday shift
- 8 overtime production hours on Saturday and Sunday
- 249 weekdays in a year
- 52 Saturdays in a year
- 52 Sundays in a year
  - 6434.5 total hours per year in current production system
  - 17.63 operating hours per day

## Arrival Rates

For plane arrival and plane demand we used the plane demand schedule by month for the year of 2009. We summed up the total planes demanded across the entire year to get a total for each. Next we divided the total number of demanded planes for each version into the total number of current operating production hours per year. This gave us an arrival rate based on hours between each plane arrival based for each version. Arrival rates for all the models are listed in Exhibit 1, but the control (current) model arrival rates are listed below:

|     | Plane Version | Arrival Rate (hrs) |
|-----|---------------|--------------------|
| 737 | 700           | 140                |
| 737 | 800           | 22                 |
| 737 | 900ER         | 230                |
| 737 | P-8A          | 3217               |
| 747 | FRTR          | 429                |
| 767 | 300ER&FRTR    | 536                |
| 777 | B/200ER       | 1287               |
| 777 | 200LR         | 643                |
| 777 | 300ER         | 129                |
| 777 | FRTR          | 379                |

### *Number of Planes*

The number of planes used in the model is 10 different planes broken down to specific version. Where there are two different versions using all the same parts from Frederickson such as the 767 300ER and the 767 FRTR, we combined the demand for those planes into a single version or demand. Thus, the result is 10 different plane versions modeled.

### *Number of Parts*

From the data given, the total number of parts required or Frederickson produced was broken down from the transportation modules. We used only transportation modules that leave Frederickson and go to Renton or Everett because we wanted to model strictly Frederickson production and not model parts produced in Auburn or elsewhere and shipped to the Frederickson facility to be reloaded into a module. Using these specific modules, we worked backwards through the list of modules, to the kits, and to the parts to determine only the Frederickson parts.

The total list of different parts comes to 875. For modeling in Arena, any part within our list cannot be listed twice. Therefore anywhere a part was shared across different versions it had to be removed and listed only once, then noted that it goes into other versions or kits. As with all parts, the shared parts go

to their respective or multiple respective kits and planes. This is done through a large excel spreadsheet we call the “matrix” which will be discussed later in the report.

### *Number of Kits*

The number of kits used in the model was 73 total for all versions. Once we had the part list limited to Frederickson only parts we then pulled all the different kit numbers into a list. Like the parts, the kits cannot be repeated or listed more than once. This was an issue for the 777 200LR and the 777 300ER because they share almost all the same kits. So we listed all those shared kits twice but had to provide arbitrary kit names. This was done by adding W2LR or W3ER to the end of the kit number.

Plane versions of 747 and 767 do not have kits, but to continue with the logic of the model we had to create kits for these planes. We created arbitrary kit names for these planes by adding a K to the beginning of each 747 or 767 transportation module number.

### *Number of Modules*

The assumptions made when dealing with the transportation modules were; total number, number available, number issued to be scrapped, and number currently undergoing preventative maintenance. To model these modules we used cycle times and travel times that were given to us in the data. To model the possible factors that have an effect on the travel of each module we used data given to us on various delays which included weather, fueling, security, and waiting for kits. The available models give to us are shown below.

| Tool Number      | HAVE | NEED | PM | Scrap |
|------------------|------|------|----|-------|
| SME112A4001-7001 | 13   | 8    | 2  | 3     |
| SME112U4000-10   | 3    | 2    | 1  | 0     |
| 4SME112U3000     | 2    | 1    | 1  | 0     |
| SME112U4000      | 2    | 1    | 1  | 0     |
| 10SME112T3000    | 2    | 1    | 1  | 0     |
| 10SME112T4000    | 2    | 1    | 1  | 0     |
| SME112W3000      | 5    | 2    | 1  | 2     |
| SME112W4000      | 7    | 4    | 2  | 1     |
| 2SME112W3000     | 4    | 2    | 1  | 1     |
| 2SME112W4000     | 4    | 2    | 1  | 1     |

### *Matrix*

The matrix is a large variable array with parts 1 through 875 listed horizontally across the top, and kits 1 through 73 listed vertically along the left side of the spreadsheet. This creates a matrix spreadsheet of

65,625 cells. Arena uses this matrix array during a variable function where it matches which parts are needed for which kits. All 65,625 cells have either a 0 or 1 placed in them. A cell with the number 1 would mean that the part number listed at the top for that respective column goes into the kit number listed on the far left for that respective row. A cell with 0 would mean that the part number for that column is not needed for the kit of that row. Every time a plane demand arrives, the kits for that plane are demanded as well; Arena will then use those kit numbers to run horizontally across the matrix spreadsheet and will pick up all parts with a 1 in its cell for that respective row.

## *Second Issues*

We were given data on all second issue demands for the year of 2008. We scanned the list for individually for all parts 1-875 and totaled the number of second issues for each part number. The 2008 and 2009 demand of total planes for each plane version are really similar, so we used 2009 plane demand requirements which we already had calculated and the 2008 second issue numbers for calculating the second issue rate of each part. The second issue rates are a percentage probability that a part will be produced correctly and make it into an assembled and completed plane without having any second issue demand. For modeling, Arena uses a probability that it will make it, versus the probability of a failure or second issue arriving. Thus the second issue rate was calculated by adding the number of second issues a part had with the total times that part was required in a year (i.e. the total number of times the part was put into the system to be produced). The totaled number of second issue demand for a part was then divided into the total times it was put into the system giving us a probability of failure or second issue. Subtracting that probability from 1, gave us the probability that the part will make it through without any second issue. These probabilities ranged from 40% to 100%, and were put into the current/control model and all the deliverable variable models.

We also recognize that in reality there never is a 100% probability that a part will make it through. There is always a chance that a second issue demand can occur. Therefore, we did run the variable 50% overtime model a second time with all 100% second issue probabilities changed to 99.5% to factor in true reality of any production process.

The entire list of second issues and with percentage pass rates can be found in the “Second Issue Numbers and Rates” sheet of the attached “All Parts and Kits Master List” excel file.

## *Finished Goods Inventory*

For the variables models used at deliverables we used a finished goods inventory that was a combination of rules. It starts off as a finished goods inventory identical to the number of second issues for each part. For example, if a part had 5 second issue demands, then we determined to hold 5 of that part in finished goods inventory. Then we manipulated the inventory levels, by holding 0 finished goods inventory for all parts with a pass rate of 99%, similar to 100%. Next we manipulated that inventory

level with a skin rule by holding 1 of each skin for any plane with a demand of 2 or less planes per month. The result of this was a finished goods inventory level of 788 parts.

After presenting to Boeing, they sent us a suggestion for a new business rule regarding inventory holding. This established a hold of 2 finished goods inventory parts for any part that had 6 or more second issues, a hold of one finished goods inventory part for any part that had 5 or less second issues, a hold of 0 finished goods inventory parts for any part with 0 second issues, and then to hold 0 finished goods inventory for all 737 P-8A only parts and all 747-8/FRTR only parts. The total finished goods inventory held with this business rule is 344 parts. This rule was then implemented into the variable model of 50% overtime, and then ran with both second issue passing rates (normal calculated probabilities, and 99.5% in place of 100%).

The entire lists of finished goods inventory and with percentage pass rates can be found in the “Finished Goods Inv.” sheet of the attached “All Parts and Kits Master List” excel file.

### *Part Processing/Flow times*

For all parts we were given actual and planned days it takes for a part to be produced and processed by the system from start to finish. We used the actual days for determining the processing or flow time for each part. These days were multiplied by 22.5 hours to get the processing time in terms of hours. Since we used actual processing times, the 15% physical delay and fatigue factor is already factored into those times, so we did not have to consider that 15% anywhere in the model. The processing time for each part used to create a triangular distribution with fast, mode, and slow processing times. Fastest was created by multiplying the mode by 90% and the slowest was created by multiplying the mode by 120%. The distribution list of processing time for parts 1-875 was then entered into the model.

To reduce overtime and get the same amount of parts out of the system, the production rate must be increased thus reducing the processing time for each part to be completed in the system. Reducing overtime reduces the total number of production hours over the course of the year. Therefore, with the same part needs but fewer hours to produce them in, we calculated the parts produced per hour requirements for 50% overtime usage, 25% overtime usages, and 0% overtime usage. Listed below are the overall production rates for the current/control model and all overtime variable models, also including the production rate percentage increase needed to go from the current/control model to each variable model.

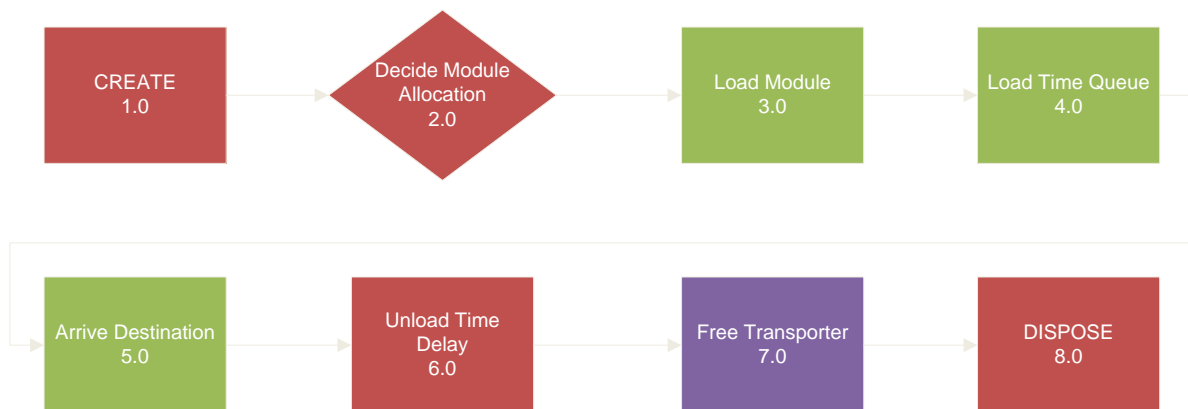
- Current/Control model
  - 7.06 parts/hr produced
- Variable 50% overtime usage model
  - 7.41 parts/hr produced
  - 5.02% production rate increase needed
- Variable 25% overtime usage model
  - 7.82 parts/hr produced

- 10.74% production rate increased needed
- Variable 0% overtime usage model
  - 8.11 parts/hr produced
  - 14.85% production rate increase needed

For all the variable models, the processing times of all parts used in Arena were reduced by the respective production percentage increase. For example, in the variable 50% overtime usage model, each part's processing time was reduced by 5.02% from the current/control model processing times.

Exhibit 2 also displays the productions rates, increases needed, and costs for the variables models. The entire list of parts with triangular distribution processing times for all models can be found in the "Parts List With Times" sheet of the attached "All Parts and Kits Master List" excel file.

### *Transportation Module Flow*



In modeling the flow of transport modules, unknown variables may cause the delay of transportation modules. This loss of transport time and subsequent effect on kit delivery must be modeled in order to increase the accuracy of the final model. The process flow for kit delivery will be as follows: If the required transport module is present and the matching kit is in inventory, a transportation routine will begin. After transport and unload time has elapsed, a return time will be assessed before beginning the routine again for additional kits. In order to accurately model the effect the transportation modules will have on the system we will determine a distribution of transport, load, unload and return times for the transport modules. After the distribution is created, we can incorporate the effects of these times into the main model.

Once the parts are collected the average time required to load the kits into transport modules is 45 minutes and 30 minutes to load the module onto a truck.



In this section of the model the loading of the transportation modules are processed with loading time delays that have been based on average historic times. After being loaded and processed on the truck the modules are shipped to their destination. The cycle time and utilization of all the modules are recorded and assessed to make sure that there is availability of the right module for use at both the starting and ending location of the module.

### *Distance Factors*

In modeling transportation in arena all the possible variables are needed to accurately portray the transport process. The key variable is the distance that each transporter travels as it is how we can control the routes, and direction that the modules need to go to reach the destination. As there are more than one possible route that a transporter can follow all possible outcomes must be modeled. For instance a single transporter may have up to four different or similar distance values.

| From               | To           |
|--------------------|--------------|
| <b>Fredrickson</b> | Renton       |
| <b>Fredrickson</b> | Everett      |
| <b>Renton</b>      | Frederickson |
| <b>Everett</b>     | Fredrickson  |

### *Speed Factors*

The velocity of the transporter can and must be entered initially to model the flow of the modules and latter to adjust for variation of travel delays as in weather conditions.

### *Loading/Unloading Delay Factors*

The delays that can be assigned to each transporter represent the time that it takes on average to unload and load the modules. The data that can be used to create variable outcomes to simulation business activities are; cycle time forecasted delays including weather and, fuel stops.

*From Fred / Auburn to Everett and Back (1-4) days*

*From Fred / Auburn to Renton and Back (1-6) days*

*From Auburn to Fred and Back (1-4) days*

*For Preventive Maintenance and Planned Minor Rework (1-7) days*

*For Unplanned Maintenance (0-1) days*

## **Costing**

### *Regular and Overtime Costs*

Hourly wages of \$35 for weekday regular time, \$52.50 for Saturday shifts, and \$70 for Sunday shifts were given to us. For weekday workers, we used 497 workers divided into 3 shifts, equaling about 166

workers per shift. 497 workers comes from taking 65% of the 850 total workers between Frederickson and Auburn, and then taking 10% on top of that for consideration of vacation and sick leave. We did recognize that the 3<sup>rd</sup> shift workers only work 6 hours but are paid for 8, thus 24 hours worth of labor wage was taken into consideration. Overtime workers for each Saturday and Sunday shift is 77 workers. This number was figured by working backwards from an estimate of about \$4,000,000 overtime at Frederickson each year, the hourly wage on Saturday and Sunday, and the total Saturday and Sunday hours worked. Total labor costs for the current/control model are listed below:

- \$36,339,030 total weekday cost for year
- \$3,923,920 total weekend (overtime) costs for year
  - \$40,262,950 total cost per year to run plant

Total cost and cost savings in labor for each overtime reduction variable model are listed in Exhibit 2.

### *Second Issue Costs*

The costs of second issue parts are not directly used in the models, but they were calculated outside the model using excel. Total processing time requirements for all parts, which include the regular scheduled parts and all the second issue produced parts, were summed together for each model. That sum was then divided into the total labor costs for that model, which gives a labor cost for each hour of required processing time. This rate was multiplied by the processing time of each second issue part, which gives a labor cost associated with a second issue part. Adding to this was the cost of raw material for that second issue part, which was taken from data given to us. The combination of both results in our calculation for the cost of each second issue part.

### *Finished Goods Costs*

For determining the cost of finished goods inventory we use the report created by Arena after running each model. The report lists the average number of parts held in finished goods inventory over the entire one year simulation run. Excel data give to us from Boeing has the raw material price for all parts. We filtered through that data and listed the raw material price for all parts 1-875. As requested, for determining the cost of the inventory we used a percentage cost of capital only. 15% cost of capital was chosen as it seems to be a common cost of capital used by many companies. The 15% is yearly cost of capital, so we broke that down into daily, then down into hourly cost of capital percentage. Because our models all have a different total hours used in a year, having the cost of capital percentage per hour allows us to apply it easily to all model results. The product of hourly cost of capital and the raw material price of each part gives us an hourly price that we can multiply by the average number of parts in the system and the total hours in a year. The costs of finished goods inventory for each variable model is displayed in the results section.

For all the models, the lists of finished goods hourly cost of capital for all parts is found in the “Finished Goods Cost” sheet of the attached “All Parts and Kits Master List” excel file.

### *Raw Material Safety Stock*

Due to the carrying of finished goods inventory as a safety stock buffer, the need for raw material safety stock becomes less. As a result of this we reduced raw material safety stock to keep only 40% of the original stock. A cost of capital at 15% was applied to total dollar worth of raw material stock aluminum. The savings in both raw material aluminum cost and the cost of capital are shown below:

|  |  |
|--|--|
| <b>Current Raw Material Safety Stock</b> |  |
| \$402,841                                | = total value of RM safety stock                           |
| 15%                                      | = cost of capital per year                                 |
| \$60,426                                 | = cost of on hand RM safety stock                          |
|  |  |
| \$161,136                                | = total value of RM safety stock if keeping only 40%       |
| 15%                                      | = cost of capital per year                                 |
| \$24,170                                 | = cost of on hand RM safety stock                          |
|  |  |
| \$241,705                                | = point cost savings from 100% down to 40% RM Safety Stock |
| \$36,256                                 | = cost of capital savings                                  |

### **Control Model**

The control model was developed using Rockwell Software’s Arena software. It simulates any sort of process as long as you have processes with measurable results. We broke the whole model down into different sections so that Arena could manipulate the entities as they flow through the plant. An entity is just a product which flows through processes, think of it as a Skin or Stringer. The four major sections were:

1. Plane Tracking

- a. Develop a way to consistently produce the same amount of plane parts as the current Fredrickson plant creates based on high level plane demand.
- 2. Part Production & Black box
  - a. Produce the parts needed based on Plane Tracking.
- 3. Kitting
  - a. Put the entities into a kit or grouping whether it be actual or hypothetical.
- 4. Loading & Shipping
  - a. Physically put the parts into a kit (module in most cases) then ship them.

Each of these sections carries statistics which would correlate with a part of the actual Fredrickson plant. The plane tracking section produces a high level demand of each model of aircraft similar to the demand figures which Boeing had for 2008. This allows us to accurately produce parts and kits based on a real schedule. The variability in our model comes from second issue parts as well as flow times through the factory.

Once a plane order comes in as paper work, we release the parts needed to make the plane into our system. Our group has modeled the entire Fredrickson plant in a single process (the Blackbox) which holds the part based on a triangular distribution which we produced from the data Rick gave us. This takes the mean and gives it a faster time of  $\text{Mean} \times 90\%$  and a slower time of  $\text{Mean} \times 120\%$ . Thus for each part we have a low, middle and high production time which we use to give the part a flow time through the entire production. Once the part is produced it is inspected and if it passes is sent to inventory to be kitted.

Kitting takes place on two levels, we have an Arena section where the program understands our grouping and another section which adds the actual time it took to put those parts into a module. Our kitting section essentially takes the parts for one kit and combines them. The kit first tries to assemble at the time where its longest duration part should be rolling off the assembly line. At this point in time, it checks to make sure all parts made it off the assembly line. If a part which it needs didn't, it waits before assembling the rest of the parts. This variability is what we are monitoring. Once the part it is waiting for is finished and is sitting in inventory the kit takes it and continues on through the process.

Once all of the parts are combined into a single kit, we send it to a process where all the parts are loaded into a module. This assigns a triangularly distributed loading time. The loading time and the shipping times are calculated and recorded.

## Control Model Verification

The base model or control model was used to validate the effectiveness of our model in representing Boeing's Fredrickson Skin and Spar plant. We verified our model using several different techniques. The different techniques could be lumped into three different categories.

1. Volume Verification

2. Time Verification
3. Batching Verification

The first verification method consisted of record modules counting the number of each entity out. We started with the top level demand which would monitor the number of planes out in general but also record exactly what type of plane it was (Ex. 737-800). This method was then used to verify the correct number of parts were produced and then used to determine if the correct number of kits resulted. Lastly, this method was used to determine if the correct amount of planes were shipped correctly. By monitoring each portion of the model, we can quickly identify problems with our data.

The second method used time to determine whether the data we provided to the program was correct. We used time measurements to determine whether or not parts were produced at a similar time to those at the actual Fredrickson plant. Furthermore, we could track the total time it took for a plane to enter the system and arrive at the assembly plant in either Renton or Everett. The total time could be broken down into 'M' date information for parts and kits. This 'M' date can determine whether or not the plant met the shipping date and jig dates.

The third method was used to verify the huge data sets entered into Arena were correct. This helped us determine whether the parts ended up in the correct kits. Records were used to track which parts came into a kit section. Only certain parts should have ended up in each kitting area.

Using these methods, we determined the Control model we first produced validated to the actual Fredrickson plant we were modeling.

### *System Inputs and Initial Results*

As discussed earlier, our data was manipulated from the raw form Rick handed to us to a form in which Arena could understand. The main inputs which were produced and entered in the system were as follows:

1. Processing Flow Time and Arrival Times
2. Second Issue Rates
3. Entity Relationships
  - a. Planes
  - b. Kits
  - c. Parts
  - d. Modules
4. Loading Times
5. Shipping Distances & Times

With these data points known we are able to produce standard normal distributions which Arena can run statistical analysis on. These variables combined represent the same variables present in the Fredrickson factory.

The first thing we verified was that the correct number of planes, parts and kits were being produced over a year. We simply used count variables to ensure our model was producing the correct number of entities. Once we verified the correct number of parts were created we verified they went to the correct kits.

|                | On Time | Not On Time | Mday+2 | Mday+3 | Mday+4 or Greater |
|----------------|---------|-------------|--------|--------|-------------------|
| Current System | 31%     | 69%         | 60%    | 21%    | 19%               |

This tells us we had parts for a kit only finish on time 31% of the time, the remainder of the time the parts were late causing the kit to become late. 60% of the time a kit finished and shipped on 'M' Day + 2 days for loading, 21% of the time the kits shipped one day late ('M' Day + 3) and 19% of the time it shipped on two days late or greater ('M' Day + 4).

## Variable Models

After we verified our control model, we used it to develop four other models initially. Each model was essentially the same physical model except for mathematical changes to the Flow Times, Second Issue rates and Finished Goods Safety Stock inventory.

The Variable Model was changed by adding an area for Arena to model finished goods safety stock. When a part failed inspection, instead of sending an order to the start of the system and expediting the order, the system will now just draw the part from finished goods inventory if it existed. If the part wasn't present in finished goods inventory the normal procedure of part expedition occurred.

## System Outputs

The system produced many different data points which we could measure. The key outputs we used to produce our deliverables were the 'M' date information, inventory levels and scrap rates. As we manipulated the model in different ways, we were able to view how the changes affected the 'M' date and the inventory levels. This allowed us to produce recommendations for Safety Stock.

## Data Results

Initially we ran five models of the skin and spar production process at the Frederickson, WA location. Our thinking process during this stage of the project was to attempt and show Boeing the production output results and finished goods inventory costs of their current system. From this point we wanted to see if we as a team could come up with a scheme to put in the model which would make improvements

upon the current process. Any positive or negative results would then be corresponded to Rick Jones and Don McCart, for their use. The subsequent models we ran included a finished goods inventory and started with a decreased overtime usage of 50%, 25%, and finally 0%. The idea here is that Boeing will be able to reduce their overtime hours with a finished goods inventory because second issue parts will be previously scheduled into production requiring no part expediting, which is a large portion of overtime. We also thought it would be relevant to run a model with no finished goods inventory and no overtime, the ideal production situation. After our presentation date at Boeing on May 1, 2009 we received feedback on our models and were assigned to run additional simulations from the inquiries of the Boeing team. We ran the model two more times with the Boeing pre-approved business rules. The first used a 50% overtime usage rate and second issued parts that were at 100% were set to 99.5%. The second used a 50% overtime usage rate and second issued parts were allowed to remain at 100% if they never failed.

The model results were given in a format aligned with M Day requirements at Boeing. Parts were first determined to be *on time* or *not on time*. Parts were then observed to be completed and shipped by M Day 2, M Day 3 (between 48-72 hours), and M Day 4 and after. Under current system 69% of parts were not on time and 31% were on time. 60% of parts were completed by M Day 2, 21% were completed by M Day 3, and 19% were not completed until M Day 4 or after the jig date. These are definitely not the type of results that Boeing wants to see. The goal is for all the parts to be completed and shipped before the M Day 4 or the jig date. The following table analyzes the results of the six run simulations compared to the current system.

### *Parts Completion Percentage*

|                                 | On time | Not on time | Mday2 | Mday3 | Mday4 |
|---------------------------------|---------|-------------|-------|-------|-------|
| Current System                  | 31%     | 69%         | 60%   | 21%   | 19%   |
| 50% OT Usage/FGI                | 84%     | 16%         | 94%   | 5%    | 1%    |
| 25% OT Usage/FGI                | 100%    | 0%          | 100%  | 0%    | 0%    |
| No OT / FGI                     | 100%    | 0%          | 100%  | 0%    | 0%    |
| No 2 <sup>nd</sup> issue/No FGI | 100%    | 0%          | 100%  | 0%    | 0%    |
| Boeing 1st Request              | 80%     | 20%         | 91%   | 6%    | 3%    |
| Boeing 2nd Request              | 81%     | 19%         | 92%   | 5%    | 3%    |

It is apparent that if Boeing implements a finished goods inventory it will only help their part completion percentage. The question then becomes what would a finished goods inventory cost and is it worth it in terms of cost? The following table is a view of finished goods inventory cost from every simulation that was ran. The cost analysis takes into account the average number of parts waiting in inventory and the holding cost.

### *Finished Goods Inventory Costs*

|                                |    |            |
|--------------------------------|----|------------|
| Current System                 |    | 0          |
| 50% OT Usage/FGI               | \$ | 397,420.20 |
| 25% OT Usage/FGI               | \$ | 383,513.46 |
| No OT/FGI                      | \$ | 369,566.55 |
| No 2 <sup>nd</sup> issue/NoFGI |    | 0          |
| Boeing 1st Request             | \$ | 124,013.28 |
| Boeing 2 <sup>nd</sup> Request | \$ | 123,991.65 |

## Conclusions

We recognize that overtime is a major cost to Boeing Skin and Spar annually, around \$4 million. A large portion of this overtime is spent expediting second issue parts through the production system because the lean manufacturing emphasis has eliminated all finished goods inventory from Boeing's Skin and Spar plant. Production delays not only cost money but harm customer relationships by forcing late deliveries to Everett and Renton. This puts a bind on Everett and Renton's processes. We feel that a finished goods inventory stock would help to reduce the heavy overtime costs and allow Boeing to better meet jig dates for delivery and shipment of products.

The cost of a finished goods inventory system is significantly lower than what overtime is currently costing. \$400,000 annual cost compared to a \$4 million dollar annual cost is a significant cost savings that can be plugged back into the system and spent on improvements elsewhere, perhaps product quality, another issue causing overtime. We realize a finished goods inventory would not entirely eliminate overtime cost but it would significantly reduce it and is worth the investment.

If Boeing wanted to implement a finished goods inventory they would need to set up some business rules to determine the average number of parts to keep in inventory per part. The larger the inventory the larger the cost, the smaller the inventory the greater risk of stock out and additional overtime to create another part. We recommend keeping more inventory than less. The costs are still in favor and it also reduces the headaches that kitting and shipping managers have to deal with when being short on parts. Overall it reduces stress of the entire system by having finished goods inventory.



## Appendices

Exhibit 1

|                       |                       | Total Year Demand | % of total | Control Model Hours between A/P arrival | 0% Overtime Arrival | 25% Overtime Arrival | 50% Overtime Arrival |
|-----------------------|-----------------------|-------------------|------------|---|---------------------|----------------------|----------------------|
| <b>737</b>            | <b>700</b>            | 46                | 9.563410%  | 139.8804348                             | 121.7934783         | 126.3152174          | 130.8369565          |
|                       | <b>800</b>            | 296               | 61.538462% | 21.73817568                             | 18.92736486         | 19.63006757          | 20.33277027          |
|                       | <b>900ER</b>          | 28                | 5.821206%  | 229.8035714                             | 200.0892857         | 207.5178571          | 214.9464286          |
|                       | <b>P-8A</b>           | 2                 | 0.415800%  | 3217.25                                 | 2801.25             | 2905.25              | 3009.25              |
| <b>747</b>            | <b>FRTR</b>           | 15                | 3.118503%  | 428.9666667                             | 373.5               | 387.3666667          | 401.2333333          |
| <b>767</b>            | <b>300ER&amp;FRTR</b> | 12                | 2.494802%  | 536.2083333                             | 466.875             | 484.2083333          | 501.5416667          |
| <b>777</b>            | <b>B200ER</b>         | 5                 | 1.039501%  | 1286.9                                  | 1120.5              | 1162.1               | 1203.7               |
|                       | <b>2LR</b>            | 10                | 2.079002%  | 643.45                                  | 560.25              | 581.05               | 601.85               |
|                       | <b>300ER</b>          | 50                | 10.395010% | 128.69                                  | 112.05              | 116.21               | 120.37               |
|                       | <b>FRTR</b>           | 17                | 3.534304%  | 378.5                                   | 329.5588235         | 341.7941176          | 354.0294118          |
|                       |                       | 481               | 1          |   |                     |                      |                      |
| total hours in year = |                       |                   |            | 6434.5                                  | 5602.5              | 5810.5               | 6018.5               |
| hours per day =       |                       |                   |            | 17.6287671232877                        | 15.3493150684932    | 15.9191780821918     | 16.4890410958904     |



