AS-J6

DETERMINING THE ALLOCATION OF RESOURCES SHARED AMONG MULTIPLE PRODUCTION LINES

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ABSTRACT

The production of defense electronics requires an enormous amount of testing and inspection. In many cases, the required testing equipment proves to be quite costly, and must be shared among multiple production lines. The same sharing occurs with people resources. In a department where three production lines currently share common resources, allocating these resources becomes even more difficult when a new product is introduced. This paper will show how a simulation model was used to determine if a department can handle the addition of a new product, and if not, what additional resources are needed and at what cost.

1 INTRODUCTION

Boeing North American's Defense and Space Group in Duluth, Georgia, produces defense electronics. Recently the site had the opportunity to bid on an upcoming project. The customer wanted a closed bid to produce a new product (Product 1) at specified levels of demand over a ten-year period. Before the bid could be composed, several questions had to be answered, including:

1. Does the existing department (Department A) chosen to manufacture Product 1 have enough physical space for the additional WIP?
2. Can the current resources in Department A (people and equipment) produce the amount demanded of Product 1 without adversely affecting production of its three current products?
3. If not, what will it take, as far as resources and manufacturing methodologies, to meet the projected demand of Product 1?
4. If additional resources are required, what is the cost associated with acquiring and supporting these new resources?

Product 1 would share manufacturing space and resources with existing Products 2, 3, and 4 in Department A. Due to the complexity of the system, it was decided simulation was the best tool to use in answering these questions.

2 OBJECTIVE

Boeing's objective was to build a simulation model of Department A that would enable it to answer the questions in the previous section. In addition to answering these questions, the simulation model had to meet other requirements. The model must be:

- **User-Friendly.** Boeing wants to allow everyone the ability to use the model, not just those familiar with the simulation software.

- **Flexible.** The company wants the model to be used in answering similar questions in the future for other departments.
- **Powerful.** Such a complex model requires the manipulation of many of variables. This power must also encompass the ability to expand the model easily (add user-input variables).
- **Compatible.** Compatibility with Boeing's existing cost system is a priority. The model's output has to be organized in such a way that it can be used as input for the company's cost system.

3 SYSTEM DESCRIPTION AND SCOPE

Each of the products produced in Department A go through a similar process of kitting, assembly, inspection, and testing. All products are composed of many sub-assemblies that are built individually and then assembled together and tested as a final product. A unit or sub-assembly is inspected or tested after every assembly step. A product or sub-assembly may go through several assembly, inspection, and testing processes before completion. During inspection or testing, a unit or sub-assembly may fail and be sent back to a prior assembly step for rework. Product demand can fluctuate from as low as 87 per year to 460 per year. Following is a diagram of the process flow for products and sub-assemblies in Department A:

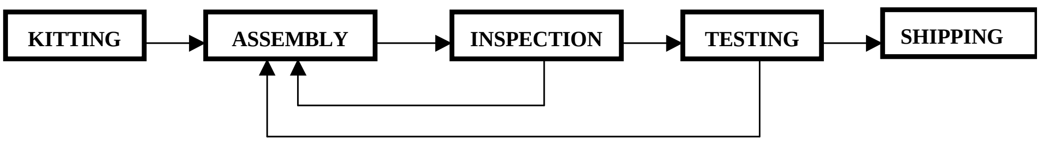

Figure 1: Process Flow in Department A

Because many resources are shared among products produced in Department A, all resources (people and equipment) must be modeled. Products and sub-assemblies produced in Department A are subject to any number of 11 different tests. However, there is only one piece of equipment for performing each test, except for Test 4 which has three test sets.

There are 14 employees working in Department A. Seven of them are qualified test technicians, four are qualified to do inspections, and eight are assembly associates. Assembly associates work on first shift, while test technicians and inspectors work first, second, or third shift. Due to the nature of the work, a learning curve is applied to all employees (i.e., process time will decrease as more experience is gained). Following is a layout of Department A:

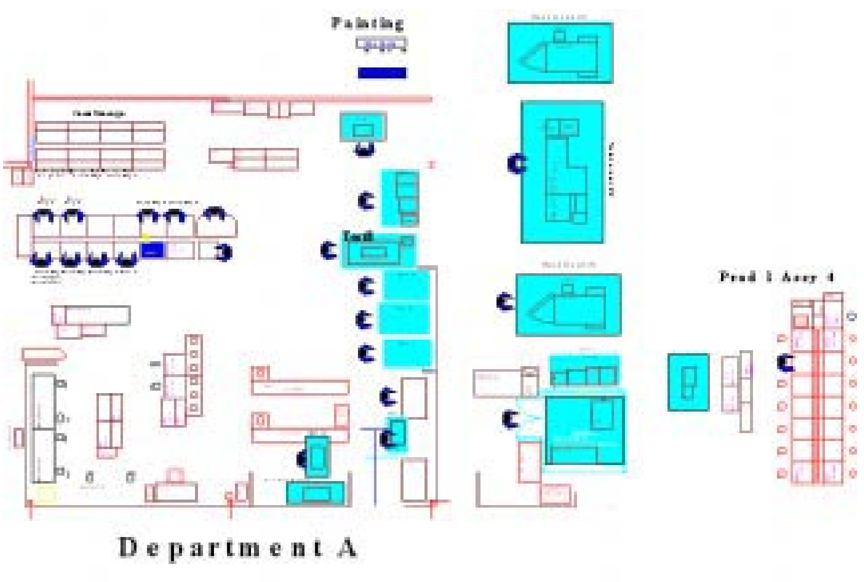

Figure 2: Layout of Department A

4 MODEL INPUT AND OUTPUT

Microsoft Excel provides a user-friendly interface to the Arena model for both model input and output. This interface allows those not familiar with Arena to input data and create new scenarios easily. Custom input screens were designed to assist the user in modifying any one of 473 input variables. The Excel interface provides a method to change model input parameters quickly and accurately, including run period, number of replications, delivery schedules, labor cost, and learning curves. Excel macros and Visual Basic modules are used to allow easy navigation within the interface. Following is an example of the model input screen:

Model Input

Press to Input Program Specific Information → Product 1 | Product 2 | Product 3 | Product 4

Return to Arena | View Latest Output

Start Month	1	(1-12)
Start Year	1998	(1998-2007)
Duration	12	(1-120) months
Replications	1	(1-20)

Delivery Schedule (# of units)

Product	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

Expected Recalls (# of units)

Product	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

Warranty Work (# of units)

Product	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

Kit Shortages

Product	% Short (1=100%)	Duration (hrs)
1	0	0
2	0	0
4	0	0

Available Hours

Jan	Feb	Mar	Apr	May	Jun
0.0	0.0	0.0	0.0	0.0	0.0
Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0.0	0.0	0.0	0.0	0.0	0.0

Labor Rates ($/hr)

Type	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Associate	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Inspector	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Technician	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00

Learning Curves

Elec/Mech Assembly: 0 (1.0 = 100%)

Figure 3: Model Input Screen

The Excel interface also allows the user to input specific processing times, Realization Factors (RF), and test and inspection failure rates at the sequence level for each product or sub-assembly. Following is an example of the screen used for inputting information specific to Product 1:

Product 1 Process and Testing Parameters

Description	Sequence #	Sequence Name	Standard Time (time in hours)	RF	% Failed (0.10 = 10%)
Prod 1 Assy 0	10	Assemble	0.0000	0.0	
	20	Test 1	0.0000	0.0	0.000
	30	Test 2	0.0000	0.0	0.000
	40	Test 3	0.0000	0.0	0.000
	50	Test 4	0.0000	0.0	0.000
	60	Test 2	0.0000	0.0	0.000
	70	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 1	10	Assemble	0.0000	0.0	
	15	Inspect	0.0000	0.0	0.000
	20	Assemble	0.0000	0.0	
	25	Inspect	0.0000	0.0	0.000
	30	Assemble	0.0000	0.0	
	35	Inspect	0.0000	0.0	0.000
	40	Test 5	0.0000	0.0	0.000
	45	Assemble	0.0000	0.0	
	50	Inspect	0.0000	0.0	0.000
	55	Assemble	0.0000	0.0	
	60	Assemble	0.0000	0.0	
	65	Inspect	0.0000	0.0	0.000
	75	Test 2	0.0000	0.0	0.000
	80	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 2	10	Assemble	0.0000	0.0	
	20	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 3	10	Assemble	0.0000	0.0	
	15	Test 6	0.0000	0.0	0.000
	20	Assemble	0.0000	0.0	
	25	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 3 Sub 1	10	Assemble	0.0000	0.0	
	15	Inspect	0.0000	0.0	0.000
	20	Bonding	0.0000	0.0	
	25	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 4	10	Assemble	0.0000	0.0	
	20	Inspect	0.0000	0.0	0.000
	30	Test	0.0000	0.0	0.000
	40	Assemble	0.0000	0.0	
	50	Final Inspect & Closeout	0.0000	0.0	0.000
Prod 1 Assy 5	10	Assembly	0.0000	0.0	
	15	Inspect	0.0000	0.0	0.000
	20	Test 7	0.0000	0.0	0.000
	25	Final Inspect & Closeout	0.0000	0.0	0.000

Figure 4: Product 1 Data Screen

With 140 output variables generated from the model, Excel provides a robust tool for generating reports and charts, and also provides the ability to save the input and output files of the various scenario runs for future reference. Following is an example of the output provided to the user after each simulation run:

Product 1 Model Ouput

Return to Model Input Form

Save Output to File

Start Month:	**1**	(1-12)
Start Year:	**1998**	(1998-2007)
Simulation Length:	**120**	(1-120) months
Number of Replications:	**1**	(1-20)

Total Throughput (# of units produced)

Product	Production	Warranty	Recall	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0

Throughput by Year

Product	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0

Cycle Time (average hours in process)

Product	Production	Warranty	Recall
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0

Total Touch Labor Hours & Cost

	Production	
Product	Hours	Cost
1	0	$0
2	0	$0
3 (Warranty)	0	$0
4	0	$0
1 (Warranty)	0	$0

Total Touch Labor Hours by Type

Staff Descripton	Hours
Assembler	0
Inspector	0
Technican	0

Figure 5: Output for Product 1

Model Output continued…

Utilization

Station Description	% Busy
Test 5	0%
Test 10	0%
Test 2a	0%
Test 2b	0%
Test 4 set 1	0%
Test 4 set 2	0%
Test 4 set 3	0%
Test 9	0%
Painting	0%
Kit Test Station	0%
Test 8	0%
Assembly 4	0%
Test 6	0%
Test 3	0%
Test 1	0%
Test 7	0%
Test 12	0%
Wire Harness Station	0%

Person Resource	% Busy
Assembler	0%
Assembler	0%
Assembler	0%
Assembler	0%
Assembler	0%
Assembler	0%
Assembler	0%
Inspector	0%
Inspector	0%
Inspector	0%
Technician	0%
Technician	0%
Technician	0%
Technician	0%
Technician	0%
Technician	0%
Technician	0%

Figure 6: Model Output

Model Output continued...

Total Rework Labor Hours

Product	Hours
1	0
2	0
3 (Warranty)	0
4	0

Queues

Description	Ave. Number
Test 10	0.0
Test 5	0.0
Test 2	0.0
Test 11	0.0
Test 9	0.0
Test 12	0.0
Test 8	0.0
Test 6	0.0
Test 7	0.0
Test 4 set 1	0.0
Test 4 set 2	0.0
Test 4 set 3	0.0
Test 3	0.0
Gimbal Assembly	0.0
Product 1 Holding Fixture	0.0
Product 2 Holding Fixture	0.0
Product 1 Assembly Fixture	0.0
Seeker Nose Assembly	0.0
Assembly Fixture (rework)	0.0

Figure 7: Model Output

4.1 The Methodology of the Arena/Excel File Organization

The flow of input and output data between the Excel Interface files and the Arena model is graphically depicted below. As shown by the bold arrows, the user moves only between the Arena model file, “ArenaSphere.doe,” and the Excel Interface files: “ArenaSphere in.xls” and “ArenaSphere out.xls.” The additional files shown for data transmission (including arena in.xls, arena in.txt and output.xls) are automatically utilized by macro commands. These files are necessary to convert the input and output data into readable formats for Arena and Excel. Also shown on this schematic are the Arena Output Analyzer and Arena Standard Summary Report. These two tools are accessed directly from the Arena model and are used to supplement the information provided by the Excel Output Report and Charts.

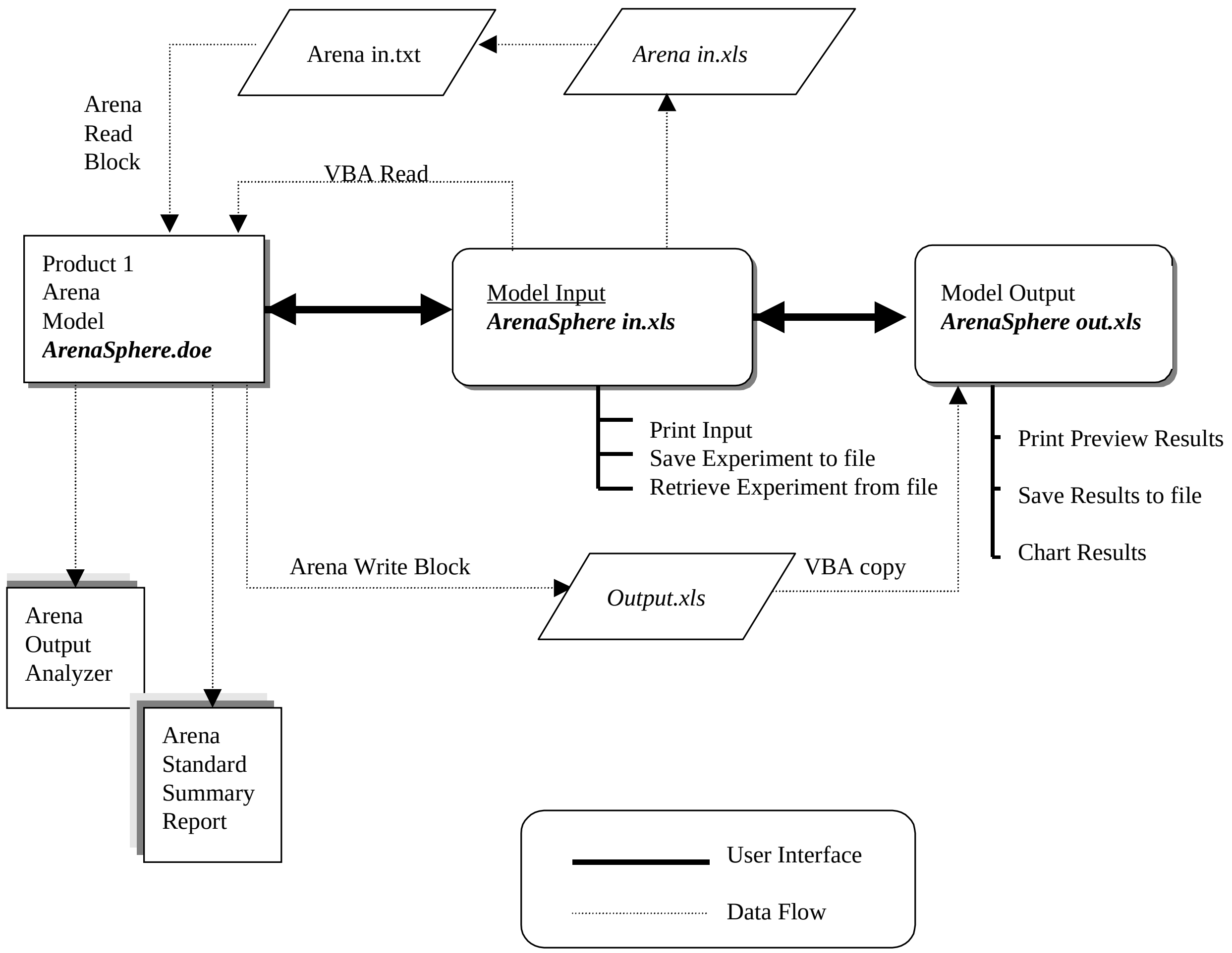

Figure 8: Flow of Input and Output Data Between Excel and Arena

4.2 Information Flow Schematic

The following flowchart illustrates at a high level the data or information flow for the model:

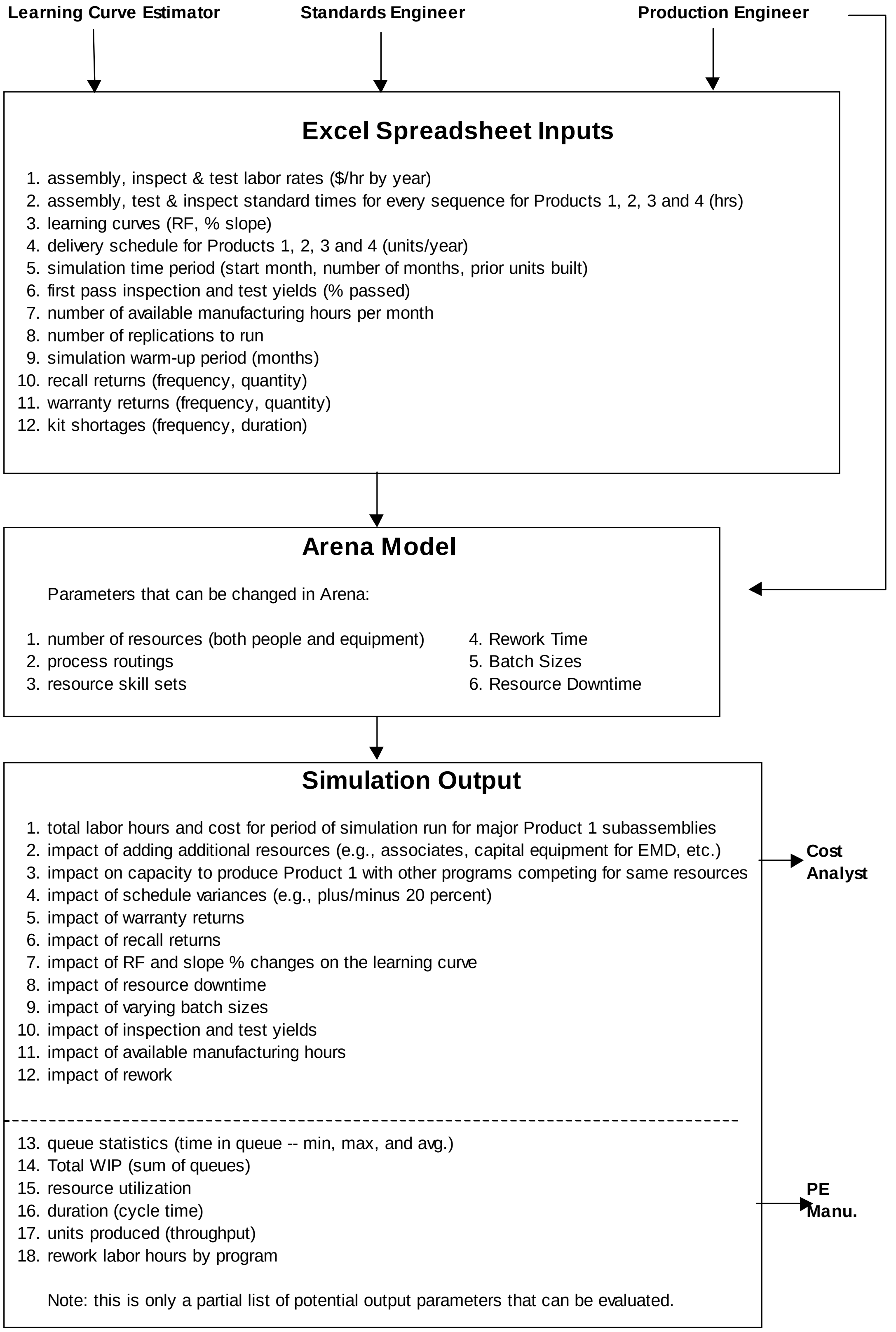

Figure 9: Information Flow Schematic

5 MODEL VALIDATION

The method used to validate the simulation model was to use input data from 1997 and compare the output from the model to actual results for 1997. Since the model is a non-terminating system, output was batched and the warm-up period truncated so that the system could be analyzed from a steady state. Statistical analysis was performed to guarantee that the model was run for a long enough period of time to provide statistical independence. In addition, sensitivity tests were run to verify that the model behaved properly when tested using extreme values for RF, test yield, learning curve, and delivery schedule.

Once it was concluded that the model accurately represented reality, it was run for 10 replications of a 10-year period to determine if Department A could meet the demand for Product 1 without adversely affecting production of Products 2, 3, and 4. Results from this test run showed that Department A, as it existed in 1997, was not capable of meeting the demand for Products 1, 2, 3 and 4 in years 1998–2007. Therefore, modifications to Department A's production environment had to be made to provide the necessary capacity to produce all projected volumes for the four products. These results answered two of the questions Boeing raised in the Introduction section of this paper.

Without changing the existing manufacturing methodology, resources (people and equipment) were added to the validated model to determine what was needed to meet demand for all products in Department A. Each scenario was run for 10 replications and its output analyzed to determine the effect these additional resources had on the results. It was discovered that the constraint was not with test equipment, but with people.

The following modifications were made to Department A to provide the capacity needed to meet customer demand for all four products over a 10-year period from 1998–2007:

- The assembly associates were cross-trained for assembly 1 and all sub-assemblies.
- No planned overtime, but technicians finish their work before leaving for breaks or the end of a shift.
- Three additional assembly associates were added for assembly 1 on second shift.
- The second and third shifts each added one technician.
- Test 4 set 2 was dedicated to Product 1 with a capacity of two.
- Test 4 set 3 was dedicated to Product 2 with a capacity of two.
- The number of assembly fixtures was increased from three to 16.
- RF values were adjusted for each product.

With the above changes, different analyses, or scenarios, can now be run on the new "base model" to determine the solution that allows Boeing to produce the required quantities of all four products at the lowest cost.

6 ANALYSES (SCENARIOS)

Meeting demand for all four products is possible using the updated "base model." The goal is to achieve the required production (throughput) at minimal cost. Cost is composed of two factors – WIP and labor. The fewer the units of WIP in the process, the lower the cost. Accordingly, the fewer the employees needed to produce the products in Department A, the lower the cost. Following are the scenarios that were run:

1. Compare using overtime vs. additional staff
2. Remove cross-training of assembly associates
3. Implement self-inspection for all assembly associates
4. Pull vs. Push manufacturing system
5. Realization Factor (RF) Sensitivity
6. Inspection and test yield sensitivity
7. Product 2 demand remains at 100/year
8. Product 1 demand increases by 20%
9. Product 1 demand decreases by 20%

6.1 Compare Using Overtime vs. Additional Staff

Question: What will be the impact on staffing of planned overtime if each assembly associate works one hour of OT per day?

Answer: If each assembly associate worked one hour of OT per day, then the number of second shift associates could be reduced from three to one with the following impacts on production:

- A 5% reduction in Product 1 throughput.
- Cycle time for Product 1 will double.
- There will be a 10% increase in associate utilization.
- The average Test 4 set 2 queue will increase from 14 to 68.
- No change in per unit touch labor cost.

6.2 Remove Cross-Training of Assembly Associates

Question: Since cross-training was added to the "base model," what would have been the impact of not adding cross-training to the "base model"?

Answer:

- Product 1 production would have been reduced by 20%.
- Product 1 cycle time would have increased from 1073 to 4192 hours.
- The average Test 4 set 2 queue would have increased from 14 to 152.
- No change in per unit touch labor cost.

6.3 Implement Self-Inspection for All Assembly Associates

Question: If all the assembly associates become trained for self-inspection, what will be the impact?

Answer:

- A 2% increase in total throughput.
- 10% decrease in Product 1 and Product 2 cycle times.
- No change in per unit touch labor cost.

6.4 Push vs. Pull Manufacturing System

Question: How does <u>pulling</u> production from the constraint vs. <u>pushing</u> production from kitting affect WIP and cycle time?

Note: the constraint is the Test 4 technicians.

Answer:

- Cycle time is cut by more than half, from 1100 to 500 hours.
- WIP is cut in half, from 249 to 142 units.
- No change in per unit touch labor cost.

6.5 Realization Factor (RF) Sensitivity

Question: How sensitive is Product 1 production to changes in RF (used to estimate the time to produce the first unit)? To test RF sensitivity, the RF for the following Product 1 sequences was changed from 7.0 to 6.0.

Description	Sequence Number	Sequence Name	Standard Time	RF
Prod 1 Assembly 0	10	Assemble	1.77	7.0
Prod 1 Assembly 1	45	Assemble	0.71	7.0
	55	Assemble	0.92	7.0
	60	Assemble	0.74	7.0
Prod 1 Assembly 3	10	Assemble	0.25	7.0
	20	Assemble	0.25	7.0
Prod 1 Assembly 3 Sub 1	10	Assemble	1.64	7.0
	20	Bonding	0.47	7.0

Answer:

- Production is quite sensitive to changes in process times (due to changes in RF value).
- Touch labor cost was reduced from $1320 to $1260/unit (5% or $135K) when the RF for the above sequences was changed from 7.0 to 6.0.
- Product 1 production increased 8% without impacting other programs.

6.6 Inspection and Test Yield Sensitivity

Question: How sensitive is Product 1 production to changes in failure rates – in this case, a 10% reduction in failure rates in Product 1 Assembly 0 tests? The following failure rate values were changed for this test.

Prod 1 Assy 0 Test	Existing Failure Rate	Failure Rate Reduced 10%
Test 1	.100	.090
Test 2	.563	.507
Test 3	.039	.035
Test 4	.357	.321
Test 2	.139	.125
Final	.100	.090

Answer:

- Product 1 production increased 10% without impacting other programs.
- There was a reduction from $1320 to $1225/unit in Product 1 touch labor cost (7% or $214K).

6.7 Product 2 Demand Remains at 100/Year

Question: What is the impact on Product 1 if Product 2 demand does not tail-off and remains at 100 units/year?

Answer:

- There is a 10% reduction in Product 1 throughput.
- Product 1 cycle time is increased by 70%.
- No change in Product 1 per unit touch labor cost.

6.8 Product 1 Demand Increases by 20%

Question: What is the result of increasing Product 1 demand by 20%?

Answer:

- There is a 7% increase in Product 1 throughput.
- Product 1 cycle time doubled to 2000 hours.
- There was an increase in the average queue for Test 4 set 2 from 14 to 48.

6.9 Product 1 Demand Decreases by 20%

Question: What happens if Product 1 demand is decreased by 20%?

Answer:

- Demand for Product 1 can be met without three additional second-shift assemblers and without adding second- and third-shift technicians (assumed in "base model").
- Product 1 cycle time increased 30% after staff reductions.
- The constraint moves from the Test 4 technicians to the Product 1 associate assemblers.

7 RECOMMENDATIONS

Boeing was successful in using simulation to meet its objectives. The simulation model revealed that the Test 4 technicians, not the test sets, were the constraint. This simple revelation alone saved Boeing from purchasing an expensive and unnecessary Test 4 unit. Following are the major findings from the simulation study:

- No need to purchase additional Test 4 unit to handle projected volumes for Products 1,2, 3 and 4 for the time period 1998-2007.
- Three additional second shift assembly associates will be required starting in year four for assembly 1.
- An additional test technician will be needed in year four for second shift and one for third shift.
- Have Test 4 set 2 dedicated to Product 1 with a capacity of two; an additional test set is needed to implement this change.
- Have Test 4 set 3 dedicated to Product 2 with a capacity of two.
- Increase the number of assembly fixtures from 3 to 16.
- The current number of holding fixtures (8) is adequate to handle the projected volumes.
- Assembly associates should be cross-trained to handle the projected volumes.
- Consider implementing a pull system (pulling from Test 4 technicians) to reduce WIP and cycle time.
- To reduce WIP, do not release incomplete kits to Department 1.
- Improve test yields and process times.

Given the aforementioned findings, following are the recommendations from the simulation study:

1. *Implement a pull system from the constraint (Test 4 technicians).*
   Instead of pushing production from kitting, pull production from the constraint. Do not release an order to Department A until a unit has completed test 4. The only excess WIP (buffer) should be in front of the constraint to keep them busy at all times. Determine the amount of WIP to be available to Test 4 technicians at all times, then manage production accordingly.

When the simulation was run using a pull system, cycle time was cut by more than half, from 1100 to 500 hours, and the average amount of WIP in the system was reduced from 249 to 142 units.

2. *Clear out all idle WIP, except at the constraint.*
   As mentioned in the previous item, the only WIP buffer should be in front of the constraint. A constraint should never be waiting for work. All WIP currently on the shop floor should be pulled back until it is needed. Again, an order should only be allowed on the shop floor when a unit has completed Test 4.

3. *Do not release kits to the shop floor with shortages.*
   Unless a kit is complete, do not release it to the shop floor. Incomplete assemblies create unnecessary WIP, which increases congestion, uses resources, and impacts throughput. In addition, kits could be damaged or parts "robbed" from kits to be used elsewhere.

8 CONCLUSION

Simulation allowed Boeing to determine that it could not meet the demand for four products in Department A without changing its manufacturing methods and without adding a few resources. Simulation is a tool that is easy for the majority of people to understand. The model provides a path to solve current as well as future problems. It provides a method by which a complex system can be contained and understood, making the answers easier to identify—and in finding the answers, works in a way that is complementary to Boeing's current cost estimating system.

The conclusions of this simulation study provided a more favorable bid to present to our customer. Boeing has plans to use the model described in this paper in future projects concerning Department A. Boeing also has plans to utilize simulation through the creation of new simulation models for existing and future programs.

REFERENCES

Arena Template Reference Guide (1994-1995), Systems Modeling Corporation, Sewickley, PA.

This guide discusses the concepts of the Manufacturing Template, which is a collection of the modules that can be combined to describe the process flow of a system. Each of the modules within the template is made up of one or more SIMAN Blocks and/or Elements.

Arena Variables Guide (1994-1996), Systems Modeling Corporation, Sewickley, PA.

This guide contains an overview of all the variables that can be used or referenced in Arena.

Developing Excel 95 Solutions with Visual Basic Applications (1995), Microsoft Press, Redmond, WA.

This book describes how to create VBA (Visual Basic Application) applications.

SIMAN Reference Guide (1994-1995), Systems Modeling Corporation, Sewickley, PA.

This guide contains descriptions of the dialogs, statements, variables, and functions composing the SIMAN simulation language, which is used by Arena.

Simulation with Arena (1997), Kelton, W. D., R. P. Sadowski, D. A. Sadowski, McGraw-Hill, New York, NY.

Overview of Arena and the science of simulation.

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