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Research Paper

CYCLE TIME REDUCTION OF A COMPOSITE PANEL MANUFACTURING LINE

Surendar Bandi[1] and Ron Lumia[2]*

Corresponding Author: **Ron Lumia, ✉ lumia@unm.edu*

This paper presents a solution for increasing the production capacity of a composite panel manufacturing line. A Unit Load Device (ULD) manufacturing company wants to increase its composite panel production capacity by at least 30% to meet anticipated demand. The manufacturing floor setup is modeled in Extend factory simulation software and analyzed for bottlenecks. Time and motion studies are captured for all the workstations and used in the simulation model. The bottleneck station is identified and several alternative configurations are proposed and simulated using Extend to minimize the cycle time. Cost analysis of each alternative is performed to justify an economical solution. The Net Present Value (NPV) method along with breakeven analysis is used in the cost analysis to validate the optimal solution. Three configurations are highlighted in this paper that meet the desired cycle time. Configuration A proved to be an optimal solution out of the three eligible configurations analyzed with 38.8% increase in production capacity, a high NPV of $3,950,830 over a period of five years and requires least number of ULDs (991 units) to break-even.

Keywords: Unit load device, Line cycle time, Extend simulation, Production capacity

INTRODUCTION

Advanced Composite Structures (ACS) is in the business of manufacturing composite based Unit Load Devices (ULD) used by air carriers all over the world. There are different types of ULDs used in the industry that conform to different contours of an airplane. ACS manufactures AKE and DPE type ULDs widely used in the lower deck of airplanes for carrying baggage, mail and cargo. The AKE type ULD forms the majority of the company's revenue. With rising aviation fuel costs, air carriers are shifting towards ULDs that are lightweight and have low serviceability rate to reduce operating costs. ACS ULDs provide the lowest repair rate (1/6th the industry standard) in the industry and weighs 23% less than the traditional aluminum ULDs. ACS forecasts a sharp

[1] Advanced Composite Structures, LLC 1026 Legrand Blvd, Charleston SC 29492.
[2] Department of Mechanical Engineering, MSC01-1150, University of New Mexico, Albuquerque, NM 87131.

increase in demand for these ULDs based on the product value generated in the industry and is therefore planning to increase the production capacity by at least 30% to meet the anticipated demand. The annual production capacity of the existing composite panel production line for a standard AKE version ULD is roughly 9000 ULDs. A typical fit of an AKE type ULD in the lower deck of an airplane is shown in Figure 1.

Figure 1: Typical ULD Fit in an Airplane

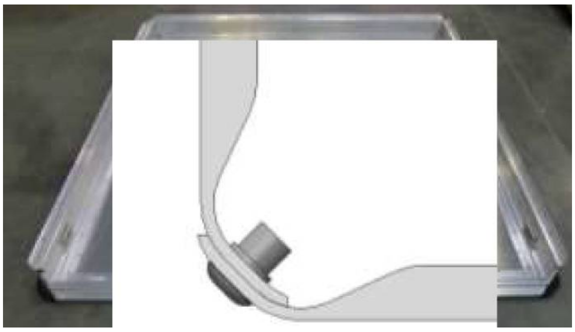
Product Description

The AKE ULD (Figure 2) is basically an assembly of lightweight thermoplastic composite panels supported on an aluminum base assembly. The thermoplastic composite

Figure 2: ALE Type ULD

panel is basically a fiberglass/polypropylene skin laminated on both sides of thermoplastic honeycomb core. All the panel edges are formed to have a specially shaped edge profile which helps in securing one panel to another with the help of a special type of fastener called Lock bolt and Collar. A typical construction of a panel mating edge is shown in Figure 3. There are six panels of different shapes and sizes used in the ULD. The panels are assembled in sequence on top of the aluminum base assembly using Lock bolt and Collars to form the structure of the ULD.

Figure 3: Panel Mating Joint



The aluminum base assembly, which forms the base of the ULD, is made of aluminum rail extrusions attached to the edges of a thick aluminum sheet using semi-tubular rivets. There are corner bumpers

Figure 4: ULD Base Assembly

attached to each corner of the base assembly to protect the corners against impact. Tie down cleats are installed on specific locations along the base edge rails to restrain cargo motion. A typical aluminum base assembly is shown in Figure 4.

The panel edges along the door side of the ULD are reinforced with door rails using Lock Bolt/Collar fasteners. Gussets are attached on both upper and lower corners on the door side to provide stability to the ULD. A flexible door made of spectra or vinyl material is used for ease of access and for securing the cargo. There are six replaceable straps that connect the flexible door to the ULD. There are four Pull Straps attached to the ULD along the four corners of panel mating edges for ease of ULD handling by the operators.

Problem Statement

The goal of this work is to achieve a 30% minimum increase in production capacity of composite panel manufacturing line.

Air carriers are shifting towards ULDs that are lightweight and have low serviceability rate to reduce operating costs. The ACS ULD weighs roughly 20 kg less than the traditional aluminum ULDs in the market. With the use of composite technology, ACS ULDs serve both purposes of being lightweight and resistant to severe field damages. ACS provides these two major benefits much better than all its competitors. ACS sees an increase in demand for these ULDs with increased awareness of these benefits. Therefore the company would like to increase production capacity by at least 30% based on forecast projections. The ACS manufacturing line operates 4 days a week with a 10 hour shift and currently manufactures 46 ULDs per day. The shift includes two mandatory breaks of 15 minutes each for production workers. Therefore true available time per shift is 9.5 hours. This translates to about 12.39 minutes cycle time per ULD set of panels. Taking a 9.5 hour shift a day and 196 business days in a calendar year excluding the holidays, ACS has an annual production capacity of about 9017 ULDs. Using the same work schedule, an increase of 30% in production capacity would yield 11722 ULDs per year. This translates to a 9.5 minute cycle time, which is the goal of this project.

PANEL PROCESS FLOW

Panel Parts Line

The Aerobox ULD of standard version AKE-4SC is made up of thermoplastic honeycomb panels supported by aluminum extrusions and the aluminum base subassembly. ACS has two manufacturing lines – Composite Panel Processing line and Base Assembly line. ACS purchases the raw panels from an outside source and converts them into finished composite panels in house.

ACS panel manufacturing line uses multiple operations to produce finished composite panels needed for the assembly of the ULD. The basic operations involved in the panel manufacturing line are Blanking, Edge forming and Trimming and Drilling. The finished panels are then inspected by the Quality Assurance department and then tagged for the next stage. All the conforming parts are then further examined by a Designated Airworthiness Representative (DAR), a Federal Aviation Administration representative, who issues 8130-3 forms authorizing the product as airworthy. The accepted product is then released to the shipping department for packaging in the form of kits. The equipment used in the manufacturing line is described briefly in Table 1.

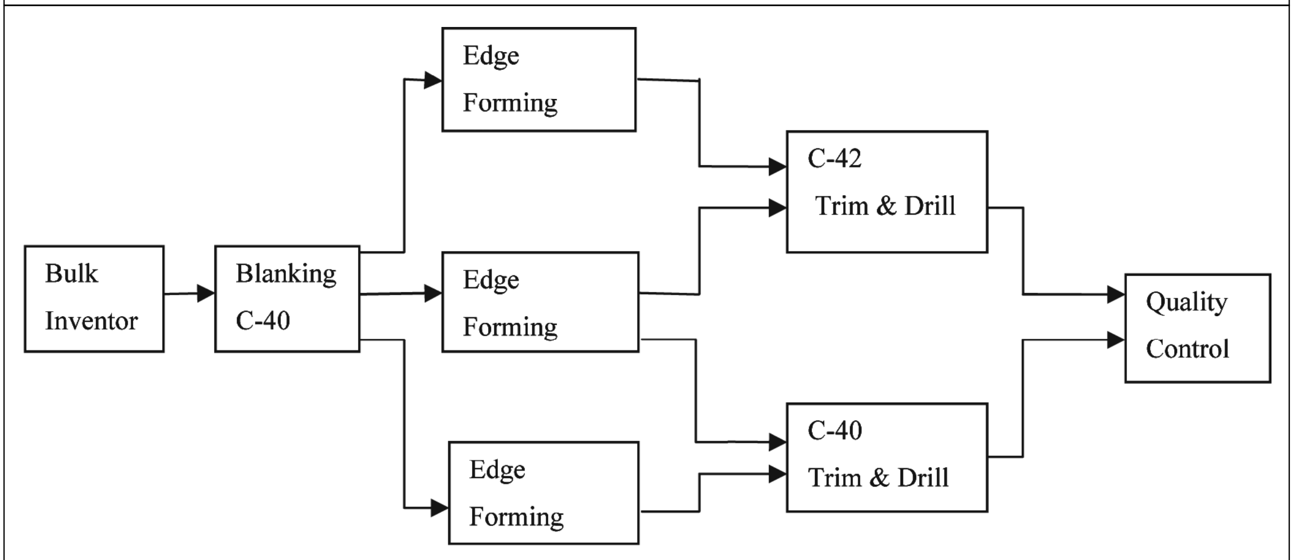
General Process Flow

Figure 5 shows the general process flow of the panel parts. The raw panels are procured and a constant supply is maintained in the bulk inventory. The raw panels first sent to a blanking operation at C-40 workstation. The blanking operation involves converting raw panels to different panel shapes and sizes. It takes three raw panels to produce one set of ULD panels. They are identified as Top, Aft, Inboard, Shear, Lower Outboard and Upper Outboard panel. The second stage involves edge forming of different blank panels using Edge Forming Machines (EFM) with the help of specially shaped die profiles. A 2-inch wide doubler, made of fiberglass polypropylene skin is attached to along the panel edges using a sonic welder prior to forming the edges. This reinforces the panel edges to meet minimum edge shear out strength. The blanked panel with the doubler material is then formed using dies under heat and pressure. Each EFM workstation press forms two panels at a time producing edges shown in Figure 3. The edge formed panels are inspected for consolidated edge thickness as part of the in-process inspection. The third stage involves trim and drill operation of panels to produce completely

Table 1: Equipment

S. No.	Machine	Description	Operation
1.	Thermwood 40 (C-40)	CNC Router Table	Blanking
2.	EFM-1, 2 and 3	Edge Forming M/C	Edge Forming
3.	Thermwood 42 (C-42)	CNC Router Twin Table	Trim and Drill
4.	Thermwood 40 (C-40)	CNC Router Table	Trim and Drill

Figure 5: Process Flow of Panel Parts



finished panels with holes, notches and trimmed edges. The final stage involves quality inspection of panels. The actual machine path for all the panels is defined in Table 2.

Table 2: Machine Path

S. No.	Part Name	Machine Path
1.	Raw Panel	Blanking (C-40)
2.	Top Panel	Inventory/C-40, Blanking/EFM-2/C-42, Trim and Drill
3.	Aft Panel	Inventory/C-40, Blanking/EFM-1/C-42, Trim and Drill
4.	Inboard Panel	Inventory/C-40, Blanking/EFM-3/C-40, Trim and Drill
5.	Lower Outboard Panel	Inventory/C-40, Blanking/EFM-2/C-40, Trim and Drill
6.	Upper Outboard Panel	Inventory/C-40, Blanking/EFM-3/C-40, Trim and Drill
7.	Shear Panel	Inventory/C-40, Blanking/EFM-1/C-42, Trim and Drill

TIME STUDY DATA

Time and motion study data for all the workstations are shown in Table 3. The time study data of processing time, loading and unloading time, in-process inspection time and additional operator task times are captured.

EXTEND SIMULATION

The ACS panel parts manufacturing line is simulated using Extend Simulation Software developed by Imagine That, Inc. (http://www.imaginethatinc.com/). Extend is factory simulation software used for modeling actual processes to explore alternatives in order to improve line productivity. Extend has different modules to simulate different types of processes. The Operation Research (OR) module is used in the simulation of ACS manufacturing line, as it is a discrete process. Time study data, collected from each workstation, forms the basis of the simulation to analyze the capacity of the manufacturing line. An introduction to simulation and the role of Extend software are discussed below.

Simulation is a powerful tool for analyzing, designing, and operating complex systems. It enables one to test the proposed process without having to implement it, which saves time and money. It is a cost-effective means of exploring new processes, without having to resort to creating prototypes.

A model is a logical description of how a system performs. Simulations involve designing a model of a system and carrying

Table 3: Time and Motion Study Data

S. No.	Machine	Operation	Cycle Time in Minutes
1.	C-40, CNC Router	Blanking	3.66
2.	EFM-1	Edge Forming	8.5-9.0
3.	EFM-2	Edge Forming	8.5-9.0
4.	EFM-3	Edge Forming	8.5-9.0
5.	C-42, CNC Router	Trim and Drill	12.0-12.25
6.	C-40, CNC Router	Trim and Drill	11.5-12.0

out experiments to achieve a specific goal. The model predicts how a real-world activity will perform. The models are useful in testing hypotheses at a fraction of the cost of actually undertaking the activities. One of the principal benefits of a model is that one can begin with a simple approximation of a process and gradually refine the model as needed. This enables the simulator to achieve good approximations of very complex problems. As the refinements are added, the model becomes more and more accurate.

Simulation Assumptions

The following are the general assumptions made in the manufacturing line simulation.

- The stock in the bulk inventory was assumed to be available at all times.
- A buffer is used between workstations.
- All the parts are assumed to be zero-defective upon completion of the process.
- The operator resources dedicated to the manufacturing line are always available.

Variability is introduced in the model at each process to simulate variations in the actual process due to operator handling. The actual process time study data varies between maximum and minimum value. This variation is used in the simulation model. A triangular distribution with minimum, maximum and most likely value is used in the simulation model to generate this variability.

There is no data history on Machine Time Between Failures (MTBF) and Machine Time to Repair (MTTR). Therefore all the machines are assumed to operate in good working condition.

All the fixtures, tools and measuring devices are assumed to operate in good working condition.

General Process Approach

A model simulating the ACS panel manufacturing line from the bulk inventory stage to the finished panel was built in Extend. The following steps explain the approach involved in analyzing the manufacturing line using the Extend simulation tool:

- The simulation model of the original line setup was compared to the actual process to verify it simulates the actual process.
- All the time study data for different machines were used in the simulation model.
- Simulation runs were analyzed to identify the bottleneck.
- The bottleneck station cycle time was analyzed and improved by using a new approach.
- Simulations were rerun to see if the required cycle time was achieved.
- If the simulation model did not meet the desired goal, the configuration is discarded. A new configuration is proposed and modeled using a different approach.
- The simulation model was iterated until the appropriate cycle time was achieved.
- The simulation model iteration process involves incorporating several different approaches to reduce line cycle time including:
  – Change tool feed rates.
  – Use new tools, e.g., double spindle tool.
  – Analyze tool path for an efficient machining sequence

– Analyze operator tasks to remove non-value added time, etc.
– Shift work to underutilized machines to balance the line.
– Move operations to different shift.

PROCESS ANALYSIS

The time between two successive completed units at the end of the production line must be 9.5 minutes or less in order to meet the goal of 11722 ULDs per year. Each series workstation in the production line must have a cycle time less than or equal to the cycle time of the production line. A number of panel manufacturing configurations were analyzed in this effort, but only three configurations met the desired cycle time.

Original Configuration

The original panel manufacturing configuration for AKE type ULD was simulated in Extend as executed at ACS factory floor. The simulated manufacturing line starts from bulk inventory of panels through C-42/C-40 trim and drill operation. The simulation was run with 46 ULD sets of panels. Six finished panels make one ULD set and it takes 3 raw panels to produce 6 finished panels. Therefore it requires 138 raw panels to produce 46 ULD sets of panels. Figure 6 shows the throughput time for 46 ULD sets of panels, which is 569.38 minutes. Therefore the line cycle time is 12.37 minutes. Each exit item in the second column from Figure 6 refers to a set of 46 panels of one kind. The Extend simulation model of original configuration is shown in Figures 7 and 8.

Figure 6: Simulation Plot of Original Configuration

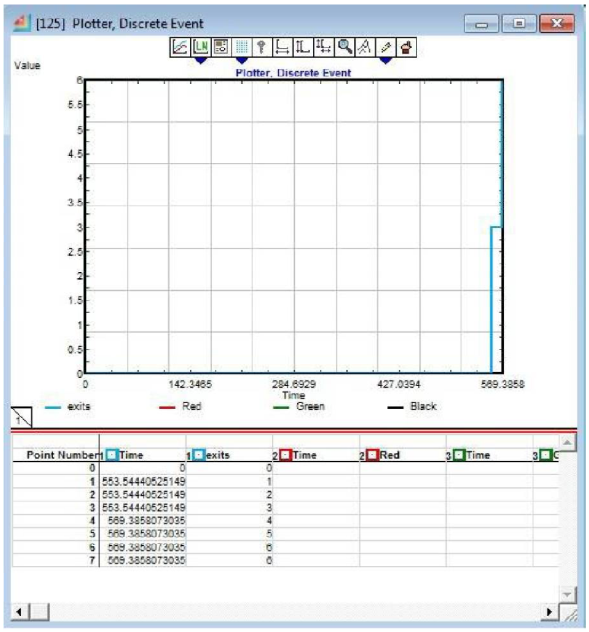


Figure 7: Simulation Model - Original Configuration, Part A

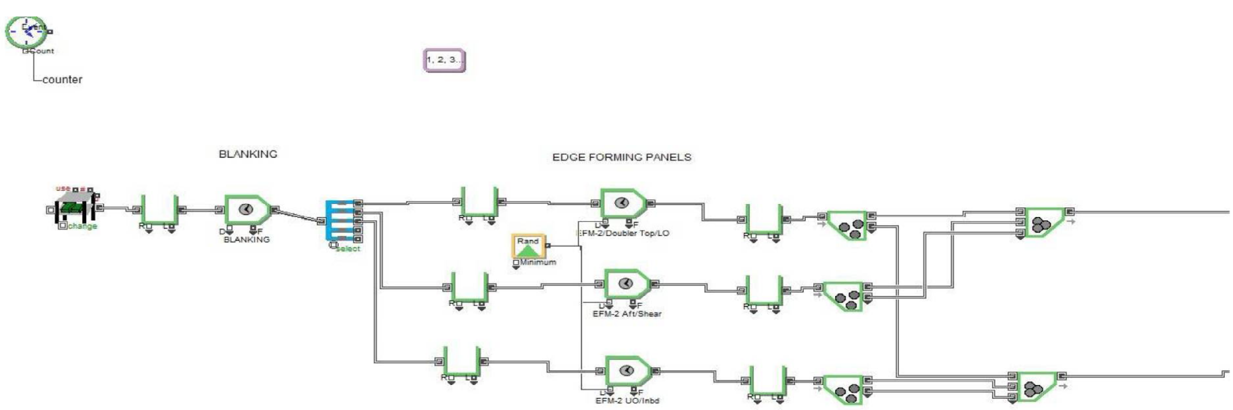
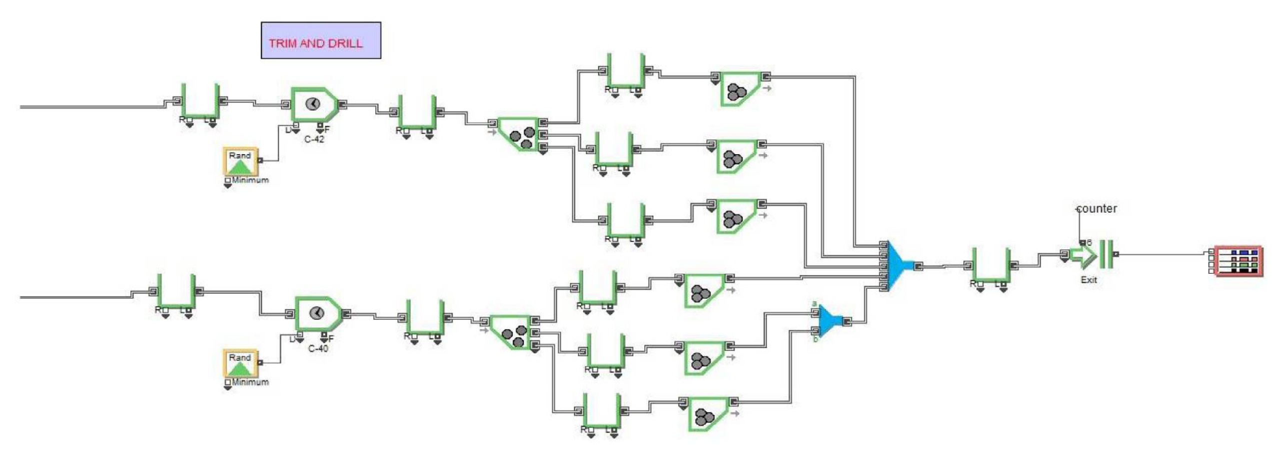


Figure 8: Simulation Model, Original Configuration, Part B



The utilization of different workstations is obtained from the simulation model as shown in Table 4. C-42 and C-40 CNC router workstations at 98/95% utilization are the bottlenecks for the original configuration. The simulated line cycle time is about 12.37 minutes, which is very close to the actual line cycle time of 12.39 minutes.

Table 4: Workstation Utilization

Workstation	Panels	Utilization	Comments
C-40 – Blanking	All	0.29	
EFM-1	Aft, Shear	0.71	
EFM-2	Top, Lower Outboard	0.70	
EFM-3	Upper Outboard,Inboard	0.70	
C-42 – Trim and Drill	Top, Aft Lower Outboard	0.98	Bottleneck
C-40 – Trim and Drill	Upper Outboard, Inboard, Lower Outboard	0.95	Bottleneck
Simulated Line Cycle Time	12.37 minutes		

Configuration A

Edge Forming Machines in this configuration. Table 5 In the original configuration, the C-42/C-40 trim and drill workstations were the bottlenecks. The following process changes are incorporated to reduce line cycle time a) Move Blanking operation to a previous shift and supply blank panels to the regular shift b) Move Shear and Lower Outboard panel Trim/Drill operation from C-42/C-40 Trim and Drill workstation to C-40 Blanking Table workstation in the regular shift.

The Extend simulation model of Configuration A is shown in Figures 9 and 10. The simulation was run with 138 raw panels yielding 46 ULD sets of panels. Figure 11 shows the throughput time for 46 ULD sets of panels, which is 410.8 minutes. Therefore the line cycle time is 8.93 minutes. Each exit item in the second column from Figure 11 refers to a set of 46 panels of one kind. It requires 6 of them exiting in the simulation model to end the simulation run.

Table 5: Workstation Utilization

Workstation	Panels	Utilization	Comments
C-40 – Blanking	Only Trim and Drill of Lower Outboard/Shear	0.68	Blanking Performed in Another Shift
EFM-1	Aft, Shear	0.98	Bottleneck
EFM-2	Top, Lower Outboard	0.97	Bottleneck
EFM-3	Upper Outboard, Inboard	0.98	Bottleneck
C-42 – Trim and Drill	Top, Aft	0.86	
C-40 – Trim and Drill	Upper Outboard, Inboard	0.76	
Simulated Line Cycle Time	8.93 minutes		

Figure 9: Simulation Model – Configuration A, Part A

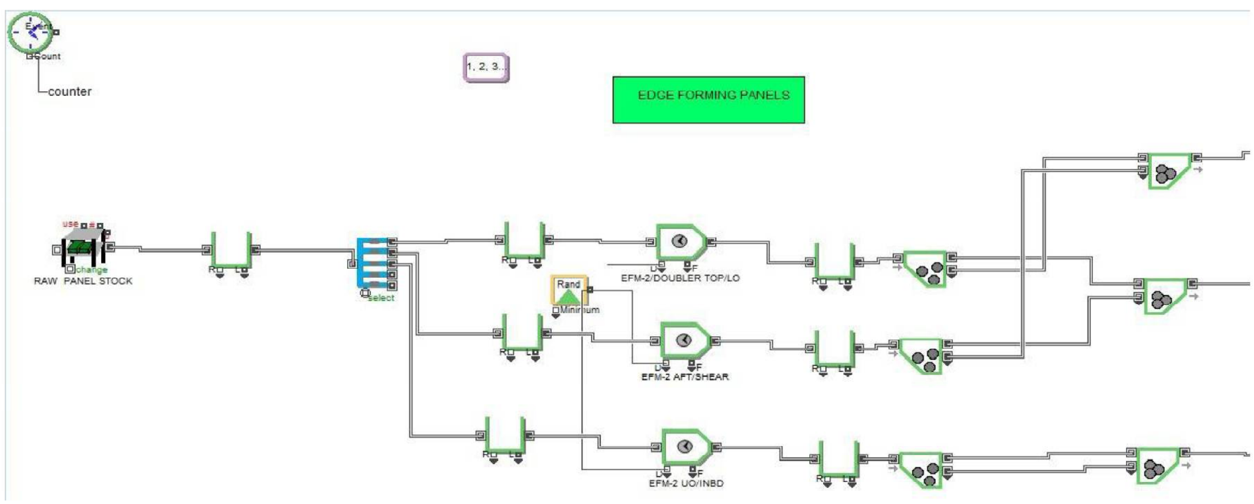


Figure 10: Simulation Model, Configuration A, Part B

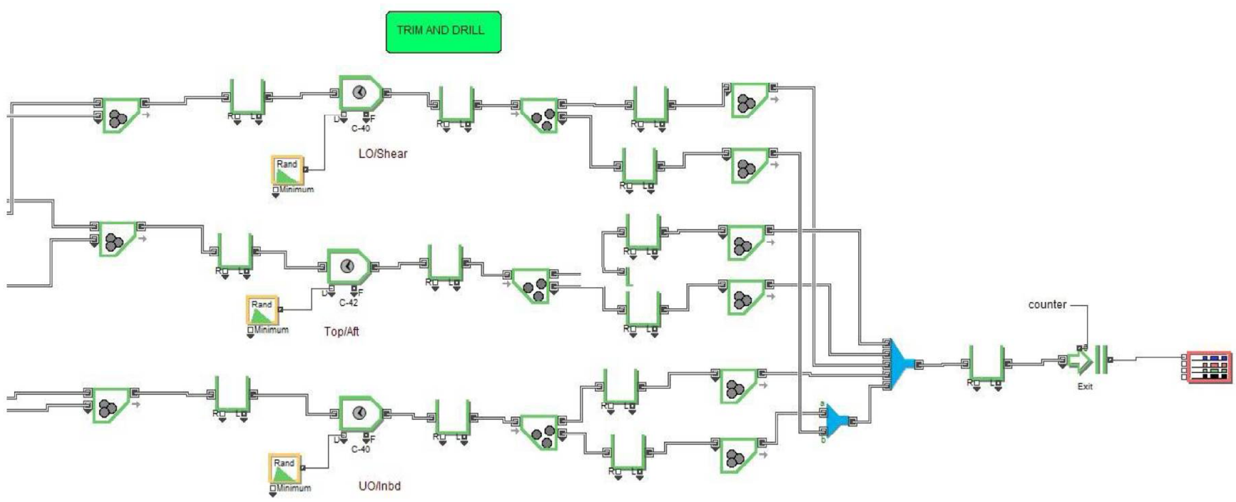
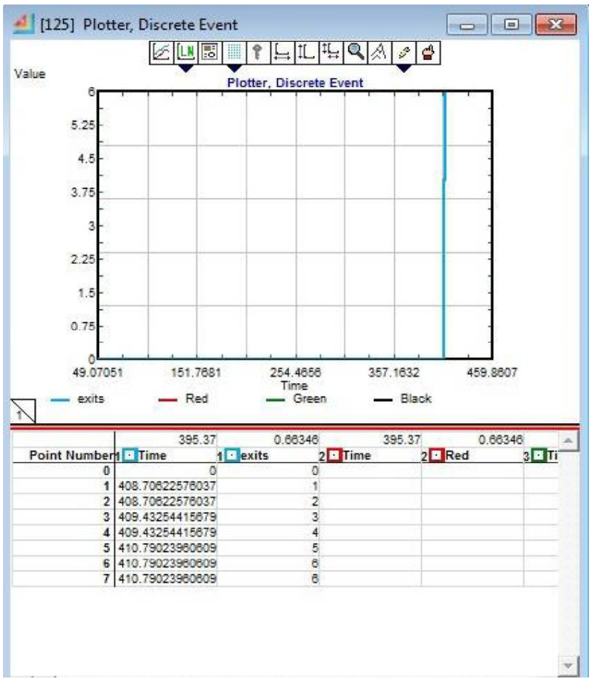


Figure 11: Simulation Plot of Configuration A



The line cycle time has improved significantly by moving the blanking operation to a previous shift and moving the trim and drill operations of Shear and Lower Outboard panel to the C-40 Blanking table. The line cycle time of the updated simulation model is about 8.93 minutes, which meets the desired goal of 9.5 minutes or less. The bottleneck moved as shown by the utilization of workstations from the simulation model.

Configuration B

The dual Spindle Aggregate Head Tool is introduced at C-42/C40 Trim and Drill operation and routing operation of all the panels shifted from C-42/C-40 to C-40 Blanking table in this configuration. Table 6 shows the utilization of each workstation for this configuration.

Table 6: Workstation Utilization

Workstation	Panels	Utilization	Comments
C-40 – Blanking	Blanking + Routing Operation of All Panels	0.94	
EFM-1	Aft, Shear	0.94	
EFM-2	Top, Lower Outboard	0.94	
EFM-3	Upper Outboard, Inboard	0.95	
C-42 – Trim and Drill	Top, Aft	0.96	Dual Spindle Tool Used
C-40 – Trim and Drill	Upper Outboard, Inboard	0.93	Dual Spindle Tool Used
Simulated Line Cycle Time	9.24 minutes		

Detailed Process Changes are as follows:

- Panel edge cleanup using pneumatic pad sander instead of hand sander at C-42/C-40 trim and drill workstations.
- Utilizing panel check fixtures for in-process inspection instead of manual checking using calipers at C-42/C-40 trim and drill work stations.
- C-42/C-40 CNC Machine Program optimization to improve machining efficiency.
- Dual Spindle Aggregate Head Tool is used in place of existing Aggregate Head Tool in the C-42/C-40 -Trim and drill workstation.
- Move routing operation from C-42/C-40 Trim and Drill Table to C-40 Blanking Table.

The Extend simulation model of Configuration B is shown in Figures 13 and 14. The simulation was run with 138 raw panels yielding 46 ULD sets of panels. Figure 12 shows the throughput time for 46 ULD sets of panels from the simulation model, which is 424.9 minutes. Therefore the line cycle time is 9.24 minutes. Each exit item in the second column from Figure 12 refers to a set of 46 panels of one kind. The simulation terminates when 6 sets of 46 panels are produced.

Configuration C

Another alternative to minimizing cycle time is to reduce loading and unloading time of C-42/

Figure 12: Simulation Plot, Configuration B

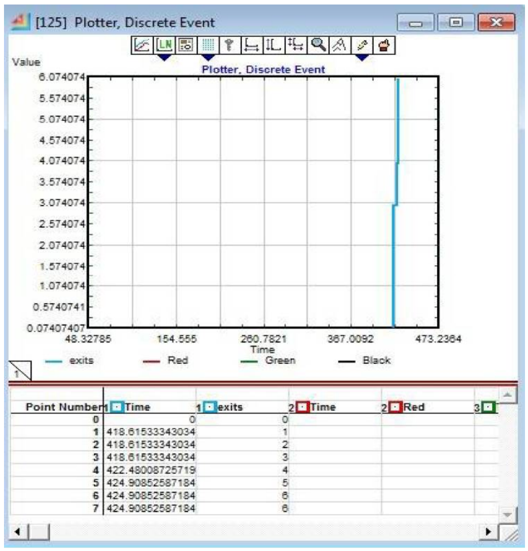


Figure 13: Simulation Model, Configuration B, Part A

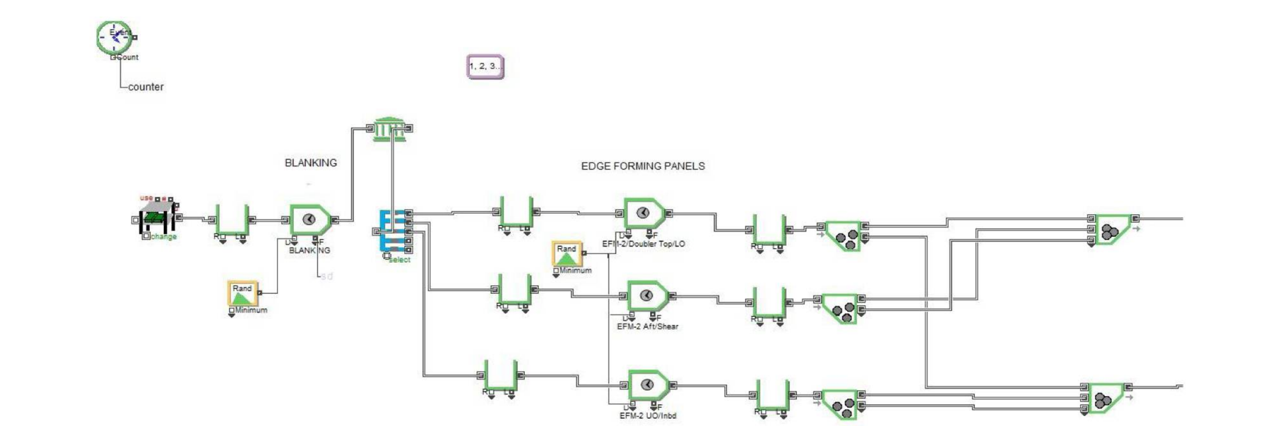
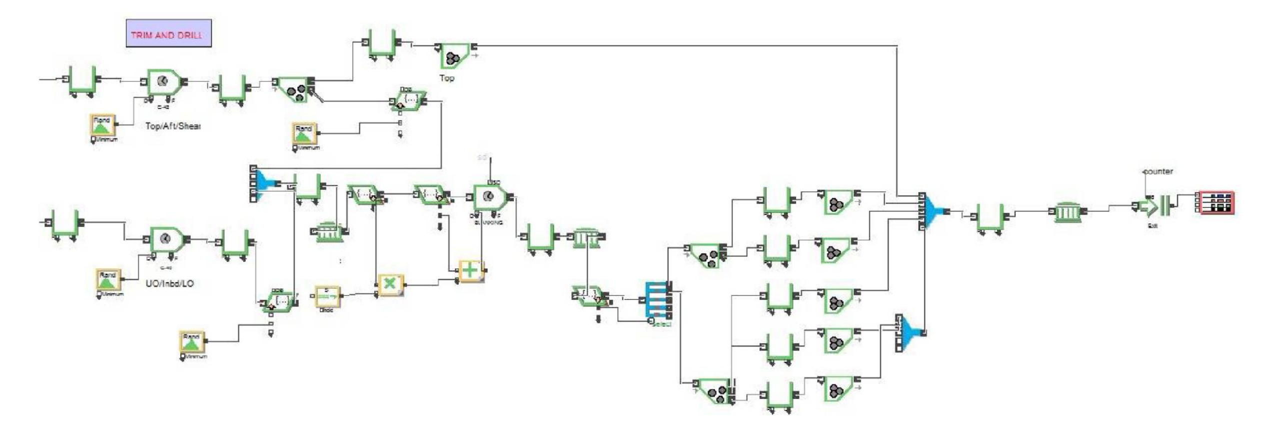


Figure 14: Simulation Model, Configuration B, Part B



C-40 Trim and Drill workstations. The panel is loaded on the table and located using datum locators. The existing loading and unloading time is about 1.25 minutes for the C-42 workstation and 1.8 minutes for the C-40 Trim and Drill work station. Minimizing the loading and unloading time by utilizing an upside down panel locating fixture is another alternative to reduce the machine cycle time. The upside down fixture makes use of the panel profile to locate the panel thereby eliminating the need for repeated using of datum locators by the operator. Process Changes involve:

- Panel edge clean up using pneumatic pad sander instead of hand sander at C-42/C-40 trim and drill workstations.
- Utilizing panel check fixtures for in-process inspection instead of manual checking using calipers at C-42/C-40 trim and drill work stations.
- C-42/C-40 CNC Machine Program optimization to improve machining efficiency.
- Upside down panel locating fixture used during locating the panels on the table.

The Extend simulation model of Configuration C is shown in Figures 16 and 17. The simulation was run with 138 raw panels yielding 46 ULD sets of panels. Figure 15

Figure 15: Simulation Plot of Configuration C

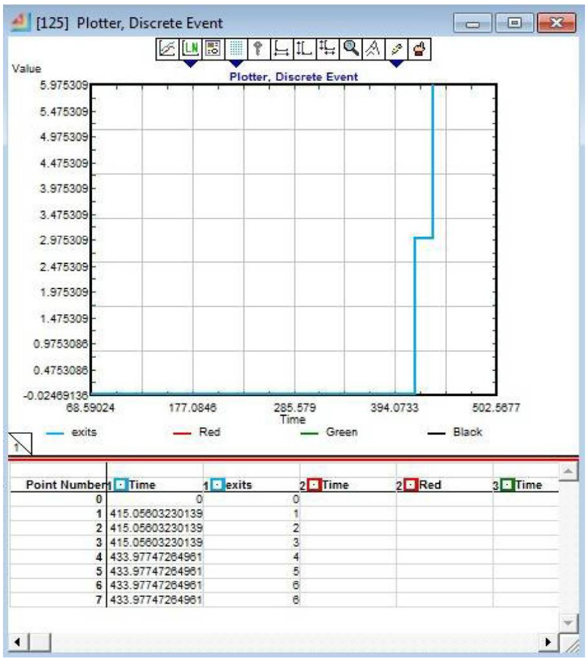


Figure 16: Simulation Model, Configuration C, Part A

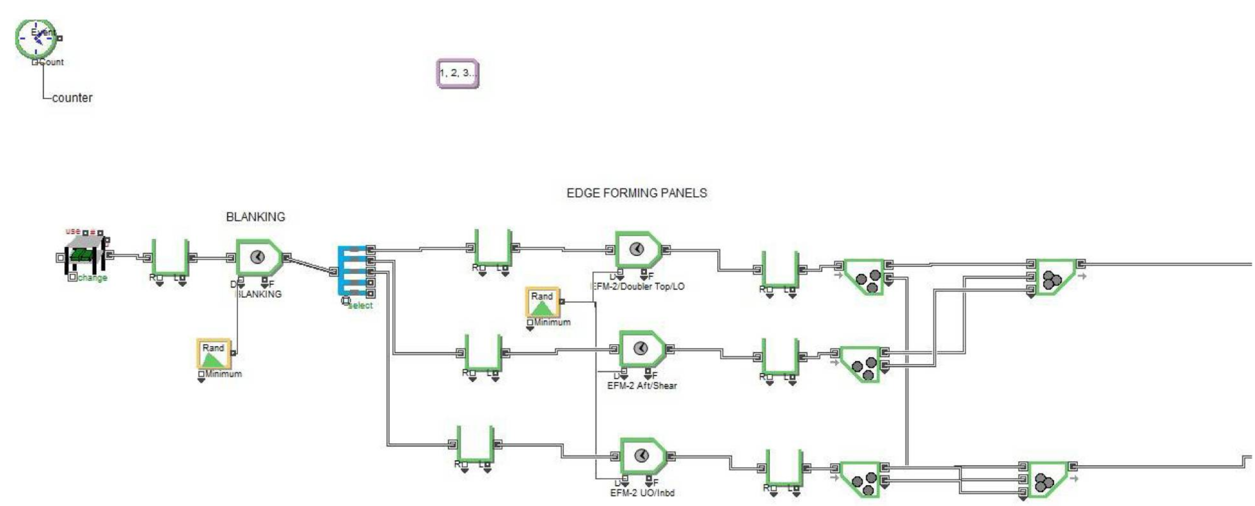
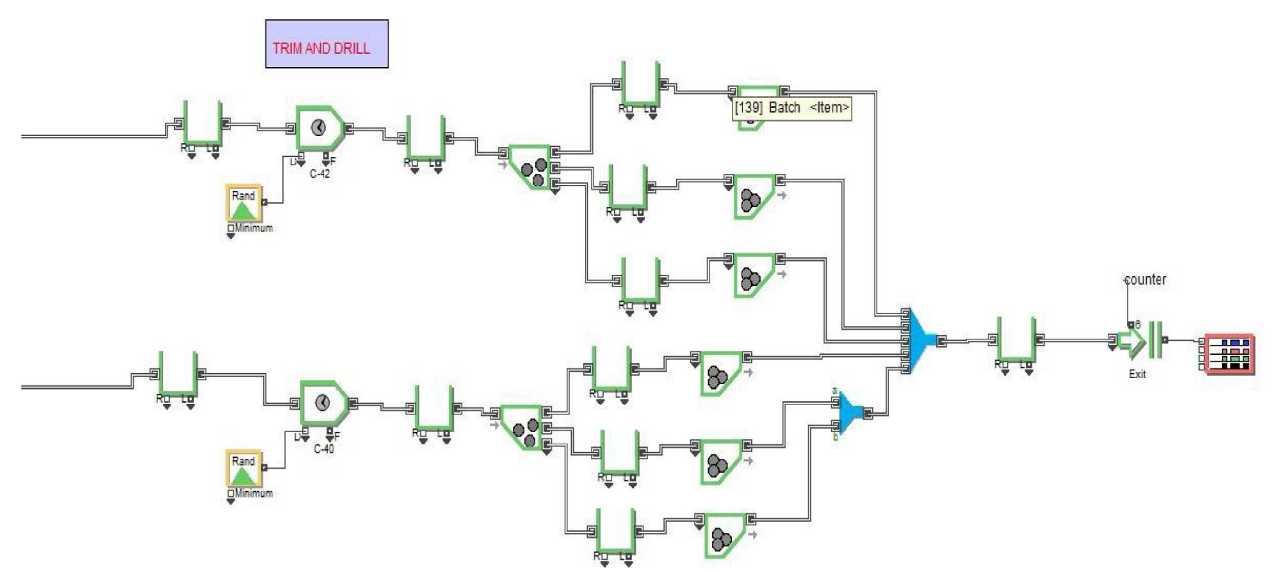


Figure 17: Simulation Model, Configuration C, Part B



shows the throughput time for 46 ULD sets of panels from the simulation model, which is 433.97 minutes. Therefore the line cycle time is 9.43 minutes. Each exit item in the second column from Figure 15 refers to a set of 46 panels of one kind. The simulation requires 6 sets of them to terminate the run. The line cycle time is reduced to 9.43 minutes based on the updated simulation model. Table 7 shows the utilization of each workstation.

Table 7: Workstation Utilization

Workstation	Panels	Utilization	Comments
C-40 – Blanking	Blank all Panels	0.42	
EFM-1	Aft, Shear	0.92	
EFM-2	Top, Lower Outboard	0.92	
EFM-3	Upper Outboard, Inboard	0.92	
C-42 – Trim and Drill	Top, Aft, Shear	0.97	Dual Spindle Tool and Upside Down Fixture
C-40 – Trim and Drill	Upper Outboard, Inboard	0.90	
Simulated Line Cycle Time	9.43 minutes		

COST ANALYSIS

Multiple configurations were analyzed using simulations of the panel manufacturing line. Only 3 configurations met the desired goal of 9.5 minutes or less in cycle time. An economical viable configuration must be chosen from these three configurations. The Net Present Value method (Donald *et al.*, 2004) is used in all of these cases to determine financial impact.

The Net Present Value (NPV) method is used as an indicator in determining how much value an investment adds to the company. It is the sum of present values of individual cash flows. A five-year period is used in this process to determine the impact of the investment. The

Table 8: Eligible Configurations

S. No.	Configuration	Cycle Time in Minutes	Production Capacity	Increase in Capacity
1.	A	8.93	12511	38.8%
2.	B	9.24	12091	34.1%
3.	C	9.43	11847	31.4%

NPV method is applied to the three configurations to determine the best option. Table 8 refers to the three eligible configurations and the capacity level comparisons.

The Net Present Value is the sum of present values of the individual cash flows. Each cash inflow/outflow is discounted back to its Present Value (PV) by.

$$\frac{R_t}{(1+i)^t} \quad \text{...(1)}$$

where R_t is the net cash flow at time t, i is discount rate, t is time of cash flow. The NPV is then the sum of all terms. Given the (period, cash flow) pairs (t, R_t) and the total number of periods N, the net present value is given by:

$$NPV = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t} \quad \text{...(2)}$$

NPV of Configuration A

Configuration A involves running a partial shift of panel blanking and moving Trim and Drill operation of Shear and Lower Outboard Panel to the blanking table in the regular shift. Configuration A is compared with the original configuration to determine the labor savings. A Net Present Value of $3,950,830 over a period of 5 years is realized for a discounted rate of 10% for Configuration A.

NPV of Configuration B

Configuration B uses a dual spindle tool and moves Trim and Drill operation of Shear and Lower Outboard Panel to the blanking table in the regular shift. Configuration B is compared with the original configuration to determine the labor savings.

Net Present Value of $3,482,492 over a period of 5 years is realized for a discounted rate of 10% for Configuration B. Again, the NPV of Configuration B is a positive value.

NPV of Configuration C

Configuration C utilizes dual spindle tool and upside down panel fixtures and is compared with the original configuration to determine the labor savings. The Net Present Value of $3,190,398 over a period of 5 years is realized for a discounted rate of 10% for Configuration C.

NPV Summary

The Net Present Values of all the three configurations are positive. Configuration A has the highest NPV of $3,950,830. Configuration C has the lowest NPV of $3,190,398. Since the configuration with the highest NPV is the best choice, Configuration A is chosen.

Break-Even Analysis

To verify the result shown in NPV Summary a break-even analysis is also performed on all the three configurations to see how many ULD units the company must produce in order to break-even for the investment against each configuration. Cost of ULD is obtained from the company based on current costing. Additional labor costs per ULD and fixed cost are calculated for different configurations.

Configuration A requires 991 units to break even while it takes 1013 and 1017 units to break-even for Configuration B and Configuration C respectively. The break-even analysis verifies that Configuration A is the best choice.

CONCLUSION AND RECOMMENDATIONS

The production capacity of ACS composite panel manufacturing line is analyzed for different scenarios to increase the capacity based on simulation runs. Multiple configurations were simulated for the panel manufacturing line based on standard AKE type ULD. An increase in annual production capacity of over 30% is achieved in three different simulation models. They are Configuration A with 39%, Configuration B with 34% and Configuration C with 31% increase in annual production capacity compared to the original configuration. Configuration A is the best of the three scenarios to implement in terms of NPV over a period of 5 years. In addition, Configuration A also requires the smallest number of units (991) to break-even. It takes 1013 units to breakeven for Configuration B and 1017 units to breakeven for Configuration C. ACS has decided to implement Configuration A based on the analysis of this study.

ACKNOWLEDGMENT

Advanced Composite Structures LLC sponsored this work.

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APPENDIX

Abbreviations and Acronyms

ULD	–	Unit Load Device
FAA	–	Federal Aviation Administration
FAR	–	Federal Aviation Regulation
DAR	–	Designated Airworthiness Representative
ACS	–	Advanced Composite Structures
EFM	–	Edge Forming Machine
MTBF	–	Mean Time between Failures
MTTR	–	Mean Time to Repair
NPV	–	Net Present Value