

USING AUTOMATION FOR FINISHING ROOM CAPACITY PLANNING

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ABSTRACT

Capacity planning of a furniture finishing system using both deterministic analysis and stochastic simulation is conveniently performed with the aid ActiveX Automation. Users interactively build a complete model of a finishing system with an Excel interface, which creates a deterministic model. The spreadsheet de-couples data input from the simulation model construction and execution, and provides a user-friendly tool for analyzing a finishing system. Using the spreadsheet, simulation data is provided to the deterministic model, and an Arena simulation model and animation of individual finishing line operations is constructed through ActiveX automation. A manufacturing manager unfamiliar with modeling techniques can use the interface to plan the finishing system and conduct simulation experiments with various input parameters such as line loading techniques, operations balancing, and line speeds. Through the interface, results from the simulation can be used in an iterative process to analyze and refine design parameters of the finishing line.

1 INTRODUCTION

Capacity planning is needed in the design of a finishing system to determine the number and configuration of individual stations and to balance the line to meet the performance expectations. Unlike traditional machining areas in a production process, where extra machines can be added to increase capacity, it is very hard to add capacity to a finishing system once it has been implemented.

There are many costs associated with the development of a finishing system (Culbreth 2000; Prak, Anco and Thomas Myers 1981). Fixed costs include the facilities costs and the equipment costs including the conveyors, spray booths, ovens, material delivery equipment, and spray guns. A typical casegoods furniture finishing system

can cost well over a million dollars. The operational costs include labor, material handling, finishing materials, and energy consumption.

There are several factors to be considered in the design and installation of a finishing system (Stauffer 1993). During the design stage, it is important to remember that the system needs to be flexible in order to accommodate new product lines and new finishing materials. The finishing system should be designed to synchronize and balance all operations while meeting the production requirements. System capacity is measured in pallets per shift. In order to meet production goals, a certain throughput level must be maintained. Estimating the capacity and setup of a finishing room can be a very difficult and time-consuming process. However, it is a process that must be completed whenever planning for a new finishing room, re-designing an existing finishing room, or preparing a finishing room for a new and different product line.

In this paper we provide an automation-based tool to assist in the design and analysis of a finishing system. The tool consists of a stochastic simulation model that communicates with an Excel spreadsheet. The Excel spreadsheet is used for data input and subsequently used to drive the simulation. The spreadsheet is used to generate overall design parameters and accepts information for an entire finishing system. The simulation model uses information from the spreadsheet to simulate one of the finishing operations. Both the spreadsheet model and the simulation model can be operated independently if desired.

2 THE SPREADSHEET INTERFACE

A template for a deterministic analysis in the form of a spreadsheet has been created using Microsoft[®] Excel 97 with Visual Basic[®] for Applications (VBA). This Excel/VBA interface accepts and stores input planning information related to overall finishing system performance

measures. The spreadsheet has a light green background with white cells indicating where user input is required. When using the spreadsheet solely for a deterministic analysis, the user only needs to complete part 1 of the spreadsheet as seen in Figure 1. However, the user must complete the second part of the spreadsheet as well (as seen in Figure 2) if it is to be used to drive the simulation.

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Figure 1: Excel Template for Deterministic Analysis

Within the Excel spreadsheet, VBA is used to validate input and determine overall design parameters for the finishing system. Specifically, as the user enters data, VBA code examines the input to be sure it is valid (i.e., non-negative, numeric, etc.). Excel then uses cell formulas to compute design parameters internally based on deterministic relationships. Furthermore, the spreadsheet uses several user forms invoked from VBA to guide the analysis.

2.1 Data Input

After entering some generic information, name and date at the top of the spreadsheet, the user fills in the required input for the “Planned Production” section of the spreadsheet as seen in Figure 1. Using this information, the spreadsheet to automatically calculate the required number of pallets per shift using a spreadsheet formula. Once the “Planned

Production” portion is complete, data can be input into the “Shift Duration” and “Conveyor Specifications” portions of the spreadsheet. Required information for the “Shift Duration” portion includes minutes per shift and minutes required for breaks/cleanup, which is used to calculate the available minutes per shift by simply subtracting time lost to breaks/cleanup from the shift length. Once the required pallets per shift and available minutes per shift are known, the conveyor rate, normal speed, and closepac speed are automatically calculated in the “Conveyor Specifications” portion of the spreadsheet using other spreadsheet formulas. Finally to complete the conveyor specifications, the estimated return distance for the conveyor and the estimated percentages of time that a pallet will stay in closepac and in normal mode is entered. All of this information will be used to automatically drive the simulation.

Year:	2000	Simulation Replications:	1					
Line Loading								
<input checked="" type="checkbox"/> Use Discrete Distribution		<input type="button" value="Enter Discrete Distribution"/>						
Pallet Load	Percentage							
Empty	25%							
Small	25%							
Medium	25%							
Large	25%							
Sum	100%							
<input checked="" type="checkbox"/> Use Planned Sequence		<input type="button" value="Enter Planned Sequence"/>						
Sequence	Pallet Load	Sequence	Pallet Load					
1	Small	11	Large					
2	Medium	12	Empty					
3	Large	13	Small					
4	Empty	14	Medium					
5	Small	15	Large					
6	Medium	16	Empty					
7	Large	17	Small					
8	Empty	18	Medium					
9	Small	19	Large					
10	Medium	20	Empty					
"Small" Operation Time (mins)			"Medium" Operation Time (mins)			"Large" Operation Time (mins)		
Triangular Distribution			Triangular Distribution			Triangular Distribution		
Minimum	Mode	Max	Minimum	Mode	Max	Minimum	Mode	Max
0.25	0.30	0.35	0.30	0.35	0.40	0.35	0.40	0.45
0.28	0.33	0.38	0.31	0.37	0.57	0.51	0.69	0.93
0.16	0.34	0.45	0.16	0.34	0.45	0.35	0.55	0.68
0.65	0.72	1.20	1.20	1.92	2.72	3.02	3.02	5.24
0.30	0.38	0.43	0.45	0.51	0.68	0.82	0.98	1.10
0.99	1.05	1.11	1.50	2.25	3.32	2.48	3.00	3.76
0.15	0.20	0.25	0.38	0.52	0.74	0.38	0.52	0.74
0.65	0.72	1.20	1.20	1.92	2.72	3.02	3.02	5.24
0.13	0.22	0.30	0.40	0.43	0.88	1.09	1.29	1.50
0.25	0.30	0.35	0.30	0.35	0.40	0.35	0.40	0.45

Figure 2: Excel Template for the Stochastic Analysis Number of Products per Pallet.

The user then adds operations to complete the deterministic model of the finishing schedule. Since the load, unload, and return operations are part of every finishing line, they are included in the model by default. To overwrite existing information, data can be entered directly. This information is then used to create the conveyor schedule and required work envelope for that operation.

The return operation simply transforms the estimated return distance into minutes and adds it to the conveyor schedule, requiring no inputs.

Operations are added to the spreadsheet as part of a time-based materials schedule (e.g., flash off, oven dry, and cooling) or they are defined as part of the operation schedule, (e.g., spraying, sanding, wiping, and inspecting). Operations belonging to the materials schedule require the user to input the operation name and the average number of minutes required for that operation. The spreadsheet automatically calculates the conveyor schedule for that operation. For drying operations, the conveyor schedule is often split into a normal and closepac component. Values for the approximate percentage of time spent in each category must be provided with typical values for normal and closepac equal to 20 percent and 80 percent, respectively.

To add an operation that is part of the materials schedule, the user simply clicks on the “Add Operation” button located under the caption “Materials Schedule.” See Figure 1. When the user clicks this button, a user form is invoked from VBA and requests information about the operation to be added. All operations must be placed between the load and unload operations. When the information is complete, the user clicks on the “Add Materials” button and the operation is added to the finishing schedule.

2.1.1 Operations Schedule

All operations contained in the operation schedule require the user to provide the operation name and the time required to perform the operation. To add an operation that is part of the operations schedule, the user simply clicks on the “Add Operation” button located under the caption “Operations Schedule” as seen Figure 1. Then, a user form will appear requesting information about the operation to be added. The user form for the operations schedule is illustrated in Figure 3.

Operation Schedule (minutes)	Calculated Number of Workers	Work Envelope (Pallets)	Row to Insert Before
0	0	1	45

	Minimum	Mode	Maximum
Small	0	0	0
Medium	0	0	0
Large	0	0	0

Figure 3: User Form for the Operation Schedule

Using the minimum, mode, and maximum estimates of the time, an average time for the operation is calculated, using a triangular distribution. The number of workers is calculated automatically after the average operation time is computed. The user can then estimate a work envelope for the calculated number of workers. The user also has the option of entering distribution parameters for the operation time based on different sizes of furniture articles. The deterministic model uses only the mean to characterize the operation times, while the simulation uses the entire distribution. When the information is complete, the user clicks on the “Add Operation” button (see Figure 3) to insure the operation is added to the finishing schedule.

2.1.2 Line Loading

The Excel spreadsheet also gives the user the option of entering a line loading pattern which will be used by the stochastic model. Line loading can be accomplished by assigning either a discrete distribution or a planned sequence. Clicking either the “Enter Discrete Distribution” button or the “Enter Planned Sequence” button, invokes a VBA user form that provides appropriate data entry.

Selecting the discrete distribution allows the user to assign probabilities to each type of pallet load being selected (empty, small, medium, or large). The stochastic model will then use these probabilities to assign loads to each pallet that enters the system. The user is asked to provide percentage values for the discrete distribution option. For the planned sequence option, the user is prompted to enter an ordered sequence of pallet loads. Selections from choices presented in a combination box creates an ordered list of pallet loads. The simulation will read this list until it encounters a blank space. It will then loop and repeat the same pattern continuously. The user should be aware that there is a selection for an empty pallet and that a blank space is not representative of an empty pallet.

The simulation model will use the line loading radio button to decide which line loading technique to use in the simulation. If data exist for both line loading techniques, toggling the radio button on and off will select either technique. To make changes to a line loading technique after it has been entered, the user overwrites the information by clicking on the proper line loading technique enter button.

3 SIMULATION/SPREADSHEET INTERACTION

By first completing the Excel spreadsheet deterministic analysis, much of the required input for the simulation is readily available, and can be used to input data directly into the simulation model. With the use of VBA within Arena, the simulation model provides the option of using the Excel spreadsheet to obtain relevant data. Instead of manually entering data, the user can conveniently select

the proper Excel file with the required information. Once the proper Excel file is opened inside of Arena, the user simply selects the desired finishing operation to simulate by clicking on the row number. The simulation will then retrieve the appropriate data on the spreadsheet and update itself. A benefit of the spreadsheet is that it allows the user to simulate specific operations, but does not require the extra logic to be placed into the model. The user retains the ability to enter data directly into the simulation, for users who are familiar with the Arena simulation software.

There are several advantages gained by de-coupling the data input from the simulation. The primary and most obvious advantage is that it simplifies the user interaction with the simulation. The logic of a detailed computer simulation can be very complex and may limit the use of the simulation to people with an understanding of simulation. Using the spreadsheet to drive the simulation eliminates this need, thus, allowing almost anyone to use the simulation with only simple directions.

Another advantage of the spreadsheet is that it clearly specifies all required input data. The spreadsheet acts as a template that accepts data for both a deterministic and stochastic analysis. All of this data is contained on a single spreadsheet, and relevant data is automatically placed into the logic modules of the simulation when the simulation begins. Without this automation, the user would have to manually change data in several logic modules each time a simulation of a different workstation was performed.

The spreadsheet also provides a tool for a closed-loop interactive analysis with the simulation. The user is able to enter data into the spreadsheet examine global deterministic implications, and then simulate a scenario based on this data. The simulation provides results that can then be used to evaluate and modify the system. Therefore, the user has the ability to use the spreadsheet model and simulation model as tools in an iterative procedure to analyze and improve the finishing system as seen Figure 4.

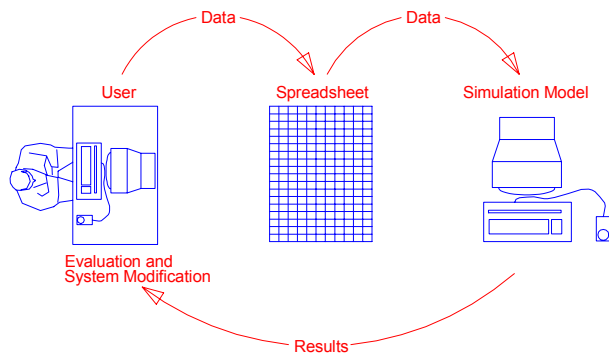


Figure 4: Interaction between the User, Spreadsheet, and Simulation

The Excel spreadsheet also gives the user the ability to quickly adjust distribution parameters and line loading pat-

terns. The deterministic analysis uses only average operation times. The simulation provides a stochastic model that results in a more accurate model of operation capacity in a finishing room. The triangular distribution was chosen to model operation times because, for many operations, there is often little available data concerning operation times in the finishing room. The triangular distribution is used in many such situations where a person familiar with the operation may be able to make an educated guess for the minimum, mode, and maximum values. The final reason is that the triangular distribution is bounded and eliminates the possibility of obtaining extreme operation times.

The simulation uses the line loading pattern that is selected on the Excel spreadsheet. By default, four types of pallet loads can enter the simulation. Pallets can be empty or they can carry large, medium, or small articles of furniture. The option of changing the line loading pattern allows several production schedules to be evaluated within the simulation.

The spreadsheet requires the user to enter in the desired number of simulation replications for statistics collection. In every simulation, the number of replications should be great enough to ensure the confidence interval half-width meets a certain precision requirement. One way to determine the number of replications required for obtaining a specified half-width is through the use of multi-stage execution (Kelton, Sadowski, and Sadowski 1998). First, perform several pilot simulation runs and check to see if the half-width of the confidence interval is acceptable. If the half-width is small enough, then no more replications are needed. However, if the half-width is not acceptable, another set of simulation replications should be made and the value checked again. This process should continue until the half-width converges and an acceptable half-width is obtained.

Based on our experience, the user should make at least 20 replications to obtain acceptable statistics. The 20 replications are equivalent to simulating the finishing operation for 20 work shifts. The only variability in the system is the operation times and the sequence of pallets entering the system. Because of the low variability in the system and the length of the simulation run, 20 replications should be adequate for most statistics collection.

4 THE SIMULATION MODEL

The simulation model provides a tool to analyze and visualize how proposed finishing systems will behave using different line loading techniques, different product lines, or different line speeds. The primary goal of the simulation is to verify and refine the adequacy of the estimated workstation sizes obtained from the deterministic analysis. Statistics obtained by simulating different scenarios allow the user to state with a certain amount of confidence what the ideal workstation size for an application will be. The

simulation can also be used to test possible solutions for a problematic workstation on an existing finishing line. By changing the variables mentioned above, the system could be continuously improved through experimentation.

The simulation software used in this study is Arena 3.0 with SIMAN. The simulation model considers only one instance of each unique workstation in the finishing room. This single workstation model is only concerned with finishing operations that are specified in the operation schedule, e.g., spraying, sanding, wiping, and inspecting. Operations that require nothing but the passage of time, such as flash off and oven drying, are not considered in this model since these operations require no operator involvement and have deterministic times. An image of the complete model logic can be seen in Figure 5. The Arena model uses VBA and ActiveX Automation to communicate with the Excel spreadsheet and obtain data for the simulation. The Arena simulation also uses several user forms invoked from VBA.

4.1 Obtaining Data from the Spreadsheet

A generic simulation model has been written previously which will be dynamically changed through VBA to fit the exact scenario described in the Excel spreadsheet, e.g., the booth length, the conveyor speed, etc. will be used as the values in the stochastic simulation. When the Arena “play” button is selected, a user form appears prompting the user to obtain information from the appropriate Excel spreadsheet or to run the simulation with the current information. Selecting the “Obtain Information from Spreadsheet” button will bring up a dialog box prompting the user to select the desired Excel file. Once the file is opened, the user is then prompted to select the row of the desired operation. The user selects the correct row by clicking on the row number at the left-hand side of the Excel window. Another prompt will ask the user if the selected operation is correct.

When the user selects the desired operation, VBA and ActiveX Automation technologies work together to allow the simulation to obtain all of the information (e.g., the simulation run length is automatically set to the value of the shift duration found) relative to that operation from the spreadsheet. If the user wishes to run the simulation for a longer period of time, he or she should make an initial run using the shift duration value. After the simulation run is complete, the user can adjust the simulation length in the Simulate module found in the logic portion of the model. The user can then re-run the simulation using the current information. The simulation automatically collects statistics on the time the operator works outside the workstation envelope and the number of conveyor starts and restarts. The user has the ability to collect other statistics by adding desired information into the “Statistics” module.

4.2 Simulation Logic Description

The development of the simulation model was restricted by the need to have an animation that presented a dynamic view of the model behavior (see Section 4.4). Therefore, the modeling the operator movement along the conveyor was critical. Thus the operator was modeled as an Arena transporter, operating in a guided network. The simulation begins with the creation of a single pallet entity that moves to an “Assign” module (see “Arrivals” in Figure 5). Here the entity is assigned an attribute that defines its payload, which can be empty or a small, medium, or large article of furniture. The entity is also assigned a corresponding picture. After the “Assign” module, the entity goes through a branch of logic that is used to loop the planned sequence array when the planned sequence is being used. The pallet entity then enters an “ASSIGN” block where the conveyor speed is set to normal speed. The pallets then access the finishing conveyor. Since the basic model is concerned only with single workstations, pallets access the conveyor at an arbitrary point in front of the workstation, which may represent the exit of the pallets from a previous operation.

After the pallets access the conveyor, the pallet entity is conveyed a distance equal to the center-to-center pallet spacing bringing it to a “Station” module. Here the pallet entity is duplicated. The duplicate entity is sent back to the first “Assign” module while the original entity continues along the conveyor to the beginning of the workstation. This logic is used to create a type of pull system. This type of system will prevent entities from entering the system when the conveyor is stopped.

After duplicating itself, the original pallet entity travels along the finishing conveyor at normal speed until it reaches a “Station” module that corresponds to the start point of a workstation. Here the pallet entity duplicates itself again with the original entity, which is animated as a pallet continuing along the finishing conveyor. The duplicated entity is sent through a logic series in which the entity triggers the operator, causing the operator to transport the duplicated entity along side of the original pallet entity that is traveling on the conveyor. When animated, the operator looks to be performing an operation on the pallet entity, however, the operator is actually transporting the duplicate entity. In the first step of this logic, the duplicated entity is sent to an “Assign” module where it is given a time attribute for the time that it enters the workstation. It is also given an operation time attribute taken from the distribution of times for the operation being simulated. This operation time is translated into an operation distance attribute using the distance formula: $AINT(Operation\ Time * Normal\ Speed + 1)$. This formula returns an integer value for the distance the operator travels while performing the operation on the pallet that is moving at normal speed. The duplicated entity is then sent to an “ASSIGN” block where the speed of the operator is set to the normal conveyor

length. The home point for the operator is the first zone on the transport link, which corresponds to the beginning of the workstation. Once the duplicated entity requests the operator, the operator locates the duplicated entity using the location formula: $Link(1, AINT((TNOW - Enter Workstation) * Normal Speed) + 1)$.

The operator begins work as soon as the entity enters into the first zone if the operator is idle and waiting at the first zone. If the operator is busy when the duplicate entity sends its request, the operator finishes the current work and moves to the location of the duplicate entity based on the location formula. This formula assumes that the operator speed is infinite or high enough that the time to travel between pallets is negligible. This assumption is acceptable since most humans walk comfortably around 250 ft./min and the typical finishing conveyor runs at speeds between 12 and 20 ft./min. The difference in speeds, along with the short distance the operator must travel between pallets, makes the travel time insignificant.

The operator is seized by the duplicate entity when the operator reaches the location of the duplicate entity. The entity is then sent to an “Assign” module. The entity is assigned an attribute called Past Workstation. This attribute determines the final location of the pallet and operator when the operation is complete. The entity is sent to another “Choose” module to determine if the distance it takes to perform the operation exceeds the workstation envelope. These decisions are “look-ahead” decisions that alert the simulation of the correct logic branch the entity should follow. The first decision determines if the final location of the operator after completing the required work is past the workstation envelope but does not exceed the envelope by more than the center-to-center spacing. The simulation permits work to occur in this region, but it is not desirable for the operator to work in this area. This region is called Zone M (marginal zone) and can be seen in Figure 6.

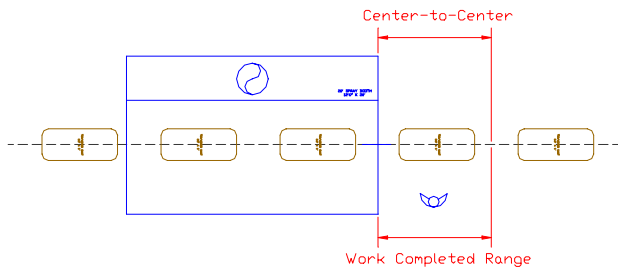


Figure 6: Work Completed in Zone M (Outside Envelope but still Permitted)

If this decision occurs, statistics are collected on the amount of time the operator is outside of the workstation. The formula calculates the distance the operator travels outside the workstation and transforms the distance value into a time value. Statistics are kept on the number of times the operator exceeds the workstation limits and the average and maximum times spent outside of the workstation.

The second decision determines if the final location of the operator after completing the required work exceeds the workstation envelope by more than the center-to-center spacing. The simulation will not permit work to occur beyond this point, therefore, this region is called Zone U (unacceptable zone), as shown in Figure 7.

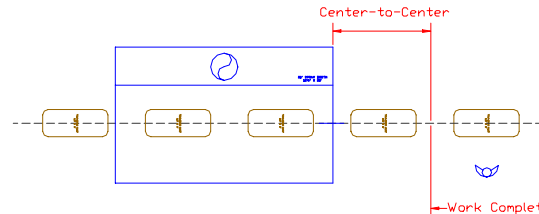


Figure 7: Work Completed in Zone U (Outside Envelope + Center-to-Center)

If the logic for this decision is true, the operator continues working until reaching the point that is center-to-center spacing past the envelope.

When this point is reached, the conveyor is stopped until the operator completes work on the current pallet and all pallets in the work envelope. When the operator has completed all work and reaches the beginning of the workstation, the conveyor is restarted. Statistics are kept on the number of conveyor stops and restarts.

The final decision determines if the operation can be completed within the workstation envelope. This region is called Zone A (acceptable zone), seen in Figure 8.

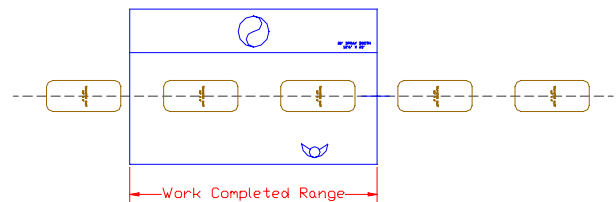


Figure 8: Work Completed in Zone A (within Workstation Envelope)

The logic following the first and third decisions is similar. The operator transports the duplicated entity along the transport link for the required operation distance. This step is mainly for animation purposes. As the original pallet entity is traveling along the finishing conveyor, the operator is transporting the duplicated entity along the transport link. The operator travels along side the conveyor for the distance required by the operation. The operator is freed by the duplicated entity, which is then disposed. The operator travels back along the transport link until encountering another duplicated entity or the beginning of the workstation. The logic, shown in the “Operator and Pallets Requests” in Figure 5, gives the appearance that the operator is working along side the pallet traveling on the conveyor since the operator moves at the same rate as the conveyor and the original and duplicated entities are coincident to each other.

The logic following the second decision is more complex because the operator is sufficiently beyond the workstation envelope to require a conveyor stop. The operator transports the duplicated entity along the transport link to a “Station” module, which is the center-to-center spacing beyond the workstation envelope. After the duplicate entity reaches this station, it stops the conveyor and increments the conveyor stop count by one. The entity delays the operator at the station until the work on the pallet is completed. The formula for this delay time is: $(Past\ Workstation - (((TNOW - Enter\ Workstation) * Normal\ Speed))) / Normal\ Speed$.

The entity is assigned an attribute called “Operator Next Location” where the value is the operator’s current location minus the center-to-center spacing. The operator moves to the location of the following pallet. Here the current duplicated entity is disposed, and the next duplicate entity seizes and delays the operator for the required operation time. This continues until the operator completes all work in the envelope and reaches the beginning of the workstation. Once the Operator Next Location is equal to the beginning of the workstation, the operator is freed, the conveyor is restarted, and the conveyor restart count is incremented by one. See “Conveyor Stops” in Figure 5.

4.3 Simulation Model Animation

The animation is meant to visually help users in their assessment of the finishing operation being simulated. It allows users to see the operation as it is being simulated and to observe the behavior of the operator under different operating circumstances.

By observing the animation, the user is able to visually determine if the workstation size and the workload is adequate. If the finishing operator exceeds the workstation limits numerous times during the simulation run, the user can conclude that either the workstation size is not adequate or the workload is too heavy for the line speed. A balanced workload is desired because it allows the operator to work in an oscillating pattern, therefore, constraining work at a workstation. A heavy workload that does not give an operator a chance to recover from a long operation will cause the operator to steadily move toward the workstation end. The user must then make adjustments to the workload if the operator is to maintain the work inside a workstation. If not, the work may need to be split between multiple employees. If conveyor stops occur even with a balanced workload, the workstation size may be underestimated and adjustments should be made accordingly.

The major components of the animation are the pallet entities, the operator, the workstation, and the counters. The entities entering the system are the pallets, and they are animated as either an empty pallet or a pallet carrying a small, medium, or large article of furniture. The operator is modeled as a transporter and is represented by a picture of a worker. When the operator is busy, the picture

changes slightly in order to illustrate the operator performing an operation. The workstation is drawn using bold, black lines. The sole purpose of animating the workstation is to allow the user to visualize the beginning and end of the workstation. The animation also includes counters for each type of pallet exiting the system and the conveyor stops and restarts. The user can use these statistics to ensure that daily production requirements are being met and there are no occurrences of conveyor stops.

The model animation is useful for making an initial analysis of the finishing operation being simulated. The animation allows the user to visualize the proposed finishing operation and the operator actions. The simulation model is somewhat constrained due to the animation. The animation is also important since it allows a user to visually verify the model is working as expected. An image of the simulation animation can be seen in Figure 9. Once the user is certain the model is running as expected, the animation may be turned off so that the simulation executes faster. This is especially beneficial when making numerous simulation replications.

4.4 Simulation Output

The simulation should be used as part of an iterative process in which the simulation output is reviewed, adjustments are made to the parameters and physical features in the spreadsheet, and the operation is re-simulated. Useful output from the simulation includes the number of times the operator exceeded the workstation limits, the average duration time spent outside the workstation, and the maximum amount of time spent outside of the workstation. This information, collected over several simulation runs, allows the user to see how large the workstation should be to prevent the operator from exceeding the workstation limits. Multiplying the time spent outside the workstation by the line speed gives the distance the operator travels outside of the work envelope. The user has the ability to run the simulation with heavy workloads to plan for worst-case scenarios. Because of the expense involved with each square foot of workstation space, it may be desirable to determine the minimum work envelope required for a particular operation.

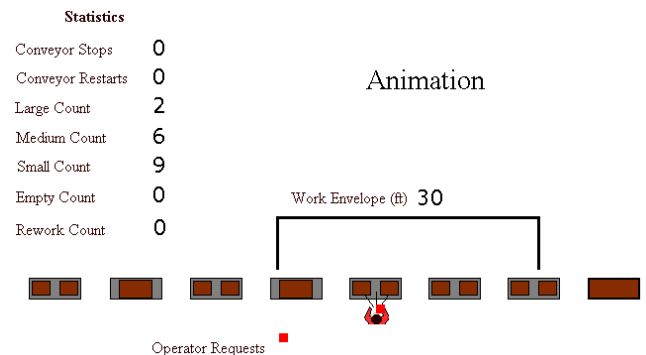


Figure 9: Simulation Animation

Other useful information is the number of conveyor stops and restarts. If there is a high number of conveyor stops, it is because the workstation is under capacitated and the operator cannot complete the work inside the work envelope. Remedies for this situation include staggering the line loading pattern, reducing the line speed, adding additional workers to the station, and increasing the workstation size.

From the Arena Output Analyzer the user may wish to state with a certain level of confidence that the operator does not exceed the limits of a particular workstation. The model has several default statistics that are sent to an output file. These include the pallet counts, conveyor stops and restarts, time between conveyor stops, observations outside of the workstation, and operator utilization.

5 SUMMARY AND CONCLUSION

The simulation model complements the deterministic planning model of the spreadsheet by allows user to focus detailed analysis on finishing line operations. The spreadsheet-to-simulation interface acts as a tool that allows a user with limited simulation experience to easily experiment with several input parameters on the spreadsheet such as line loading techniques, required daily production, and workstation sizes. This ability to quickly change input parameters allows an iterative effort to obtain the best design for a finishing system. This same methodology can be used in many cases where the user has limited simulation experience and needs to use a simulation to perform some calculation or analysis.

REFERENCES

- Adams, Larry and John Iwanski. 2000. U.S. Economy Pushes Wood Products Industry Onward and Upward, *Wood and Wood Products*, Vance Publishing, Lincolnshire, IL, January, pp. 49-52.
- Culbreth, C. T. 2000. Furniture Manufacturing Systems Design Draft. North Carolina State University. Raleigh, NC.
- Kelton, David, Randall Sadowski and Deborah Sadowski. 1998. *Simulation with Arena*. McGraw-Hill Companies, Boston, MA, p. 129.
- McCluckie, Don. 1996. Designing a Conveyor for Finishing, *Products Finishing*, Gardner Publications, Inc., March 1, p. 1,
- Prak, Anco and Thomas Myers. 1981. *Furniture Manufacturing Processes*. Department of Industrial Engineering, NCSU, Raleigh, NC, p. XII-5.
- Stauffer, J. L. 1993. *Finishing Systems Design and Implementation*. Society of Manufacturing Engineers. Dearborn, MI, p. 311.

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