Predicting Manpower Requirements for a Truck-Building Facilty Using Simulation Techniques: A Case Study

P. Wagh, Sangram Redkar, Jerry Gintz and Brad Rogers, Arizona State University

Abstract

Simulation is one of the most frequently used techniques in operations research and industrial engineering. Simulation can be applied in many critical areas and enables one to address issues before they become problems. The effective generation, verification and validation of simulation models is an important challenge. Due to the rapid increase in computing power, it is now possible to simulate significantly larger systems. In this study, simulations are used to predict the manpower requirements for a local truck-building facility. Here, the authors developed two simulation models. The first, Model I, was used to identify the bottlenecks in the facility and study their impact on truck production. Later, an interactive simulation model (model II) was built using commercially available software (Extend 6.0) to predict the manpower requirements for every station depending on the planned truck production. A time-study analysis of the facility was also conducted in order to obtain the data required for the simulation models. These models predicted the manpower requirements depending on the user's input to the model for the planned truck production and the desired operator utilization. This study served as a demand-based decision-making tool for resource allocation.

Introduction

In today's competitive environment, decision making and strategic planning are becoming more and more important. Computer simulation is one of the most important analysis tools that can help to increase operational understanding and decision making for managers [1]. Simulation is an imitation of the operation of a real-world process or system over time. Simulation is used to describe and analyze the behavior of a system, ask what-if questions about the real system, and aid in the design of real systems [2]. In the field of mechanical engineering, simulations have been used for a variety of applications ranging from evaluating airborne radar applications [3] and analyzing solar-panel efficiency [4] to path planning and navigation for unmanned surface vehicles [5].

In principle, by experimenting with different configurations of the system, engineers can evaluate and compare any number of system designs. One of the largest application areas for simulation modeling is that of manufacturing systems [6], with the first uses dating back to at least the early 1960s. Following are some of the specific issues that simulation addresses in manufacturing:

- The need and the quantity of equipment and personnel for a particular objective [7]
- Labor-requirement planning [8]
- Performance evaluation such as throughput analysis, bottleneck analysis, time-in-system for parts, utilization of equipment and/or personnel [9], [10]

Factory simulation can provide insights into various issues of a manufacturing firm before significant time and cost has been invested [11], [12].

The purpose of this research study was to develop and validate a visual interactive simulation model that represents the manufacturing flow of a local truck-body building facility. This model was used to predict labor requirements for every station depending on the truck production planned on a given day. Figure 1 presents the process flowchart describing the process used in the simulation model for this truck-building facility. The process chart is a device for recording the processes in a compact manner as a means of better understanding and improving it [12]. The chart graphically represents the separate steps or events that occur during the performance of a task. The chart begins with the raw material entering the factory and follows it through every step—such as transportation to storage, machining, assembly and inspection—until it becomes a finished product or a part of a subassembly. In the case of this study, raw materials entering the factory are truck chassis along with various parts, assemblies and subassemblies required to build a truck box. The finished product is a truck ready for dispatch to the dealers.

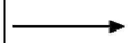
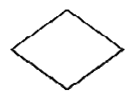
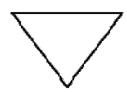
An extensive time study was conducted to get cycle times for various stations. Time-study analyses involve timing every operator for every operation. In the real world, different operators work at different paces based on their skills, ability and experience. New operators may take more time to finish their tasks than experienced, trained operators. Because of the time and scheduling constraints in conducting the time study, a time-study dataset based on a skilled operator was used in the project. The cycle-time data collected from the time study were used as an input to the simulation model.

In this paper, the authors present the development and validation of this factory simulation. The symbols used in the process chart (shown in Figure 1) are described in Table 1.

Industry Application

As stated earlier, the main objective of this study was to develop a methodology for predicting manpower requirements for every station, depending on the truck production output planned for a given day. Two simulation models using Extend 6.0 [13] were developed. First model was used to identify the bottlenecks of the facility, while the second model was used to predict the manpower requirements. For the first model, supervisor feedback about the cycle times for all stations was considered based on their knowledge and experience about the facility. The second model used data collected from time study for manpower prediction.

Table 1. Symbols Used in the Process Chart

Symbol	Name	Description
	Operation	An operation occurs when an object is intentionally changed in one or more characteristics. It represents a major step in the process and usually occurs at a machine or a work station.
	Transportation	Transportation occurs when an object is moved from one place to another, except when the movement is an integral part of an operation or inspection.
	Inspection	An inspection occurs when an object is examined for identification or is compared with a standard as to quantity or quality.
	Storage	Storage occurs when an object is kept under control such that its withdrawal requires authorization.

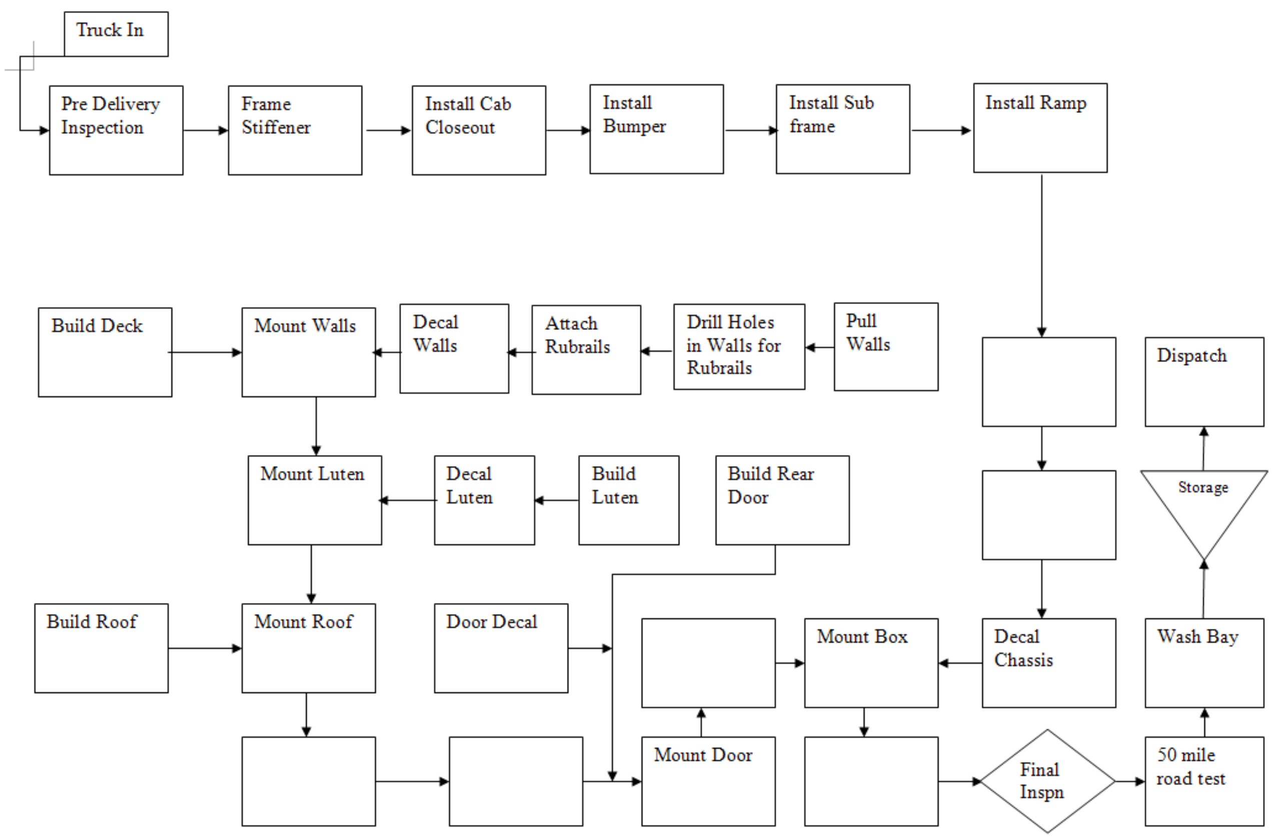


Figure 1. Process Flowchart

The next step in the project was to study processes taking place in the body building plant. This truck-building facility buys truck chassis from leading truck manufacturers. The body-building facility then builds truck boxes and installs them on the chassis. During this stage, various operations taking place at every station and sub-station were observed and recorded. With the help of this input, the process flowchart shown in Figure 1 was created and used to represent the truck-body building facility.

To construct any simulation model, the basic requirement is to have appropriate data. For the simulation model used in this study, the authors needed data such as operation sequence, operational job details, number of workers and cycle times for each and every station [6]. Since no historical data were available for the cycle times of stations, the important part of the simulation project was data collection. Operations taking place at every station were divided into small elements [14]. A document containing detailed list of activities performed at every station was prepared by the manufacturing department. This document contained a list of 372 operations performed at 22 stations. This document had information such as station name, operation number, operation performed, number of operators performing the operation and cycle time in seconds (see Table 2).

Table 2. Time-Study Format

Station Number	Station Name	Sub Station Number	Sub Station Name	Opn No.	Operations Performed	Operation Performed by # of Operators	Cycle Time in secs.	Performed by Operator No.
6	Pull Walls			68	Install hole alignment fixture and clamp	1	88	10
6				69	Drill 2 holes top of the wall	1	43	10
6				70	Un-clamp and remove hole alignment	1	31	10
6				71	Drill 5 holes in bottom of the wall	1	56	10
6				72	Lift wall and slide into wall line	1	165	10
6		5.1	Clamp Rubrails	73	Clamp rub rails into position	1	74	10
6				74	Using fixture drill holes on rub rails	1	111	10
6				75	Remove fixture and and drill 3/8" holes	1	122	10
6				76	Countersink all 40 holes	1	75	10
6				77	Make a set and put aside for later use	1	40	10

Time-study techniques were used to record the data for every station and sub-station in the format developed by the manufacturing group. The two commonly used methods for time studies are [14]:

- Continuous Timing: In this method, the observer starts the watch at the beginning of the first element and allows it to run continuously during the period of the time study. The observer records the watch reading at the end of each element. The time for each element is subsequently determined by subtraction.
- Repetitive Timing: In repetitive timing, the observer reads the watch, resets the watch, and then records the reading at the end of every element. This method gives the direct time without subtractions.

Time-study techniques used in this project followed the repetitive timing method where the operators were instructed to start performing the operation when instructed by the observer and stop when finished. This time study was performed just before providing input to simulation. Before the actual time study, operators and supervisors were briefed and asked for suggestions, and trial runs were carried out to ensure that realistic data were collected.

Model Development

Model I:

After gathering the data, the next step of the project was model development. As noted above, two simulation models were developed. Both of the models used Extend 6.0 simulation software. The first model was used to identify the bottlenecks in the facility. This model had an associated notebook that displayed information such as station utilization, number of arrivals, number of departures and average processing time for every station. The notebook also showed truck production status at given times. Stock blocks were used in the model to store parts and supply them to the respective stations as requested. Various stations in the facility were represented by using station blocks. This model used the data based on supervisor feedback about processing times for various stations. All of the station blocks operated with random processing times.

The distribution chosen for random processing was triangular. Triangular distribution is often used when little or no data are available [12]. It also has 3 parameters: minimum and maximum range definition and the more likely, or peak, value. The distribution has a triangular form (see Figure 2). It starts at the minimum value, increases linearly to peak at the mode, and then decreases linearly to the maximum value. The triangular distribution is often used in business decision makin, particularly in simulation. As an example, the batching process joins one unit of roof with one unit of luten; the assembly then travels as one item. Figure 3 shows the block representation and Figure 4 shows the input to the block. Finally, the exit block was used to count the number of trucks built at a particular time.

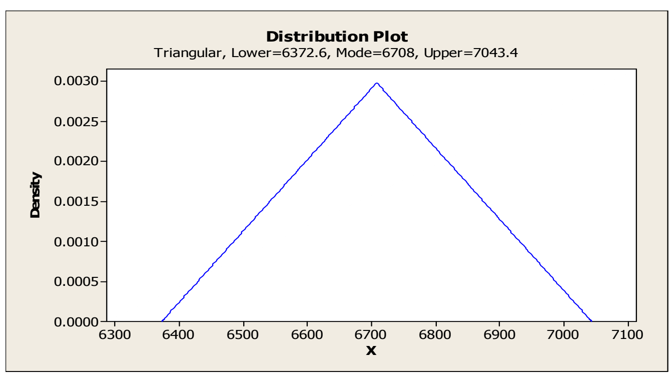


Figure 2. Example of Triangular Distribution

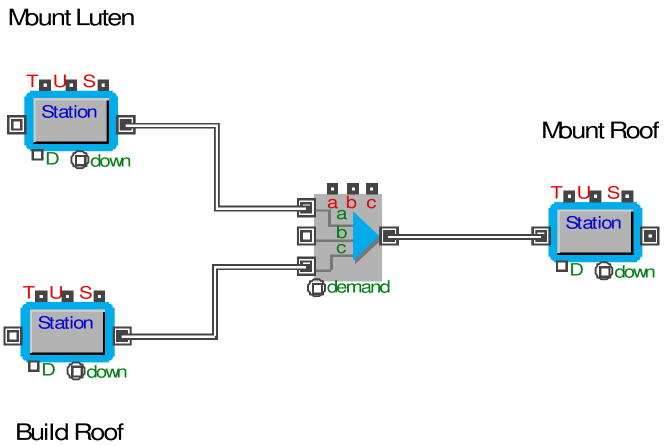


Figure 3. Example of Batch Block Used in the Model

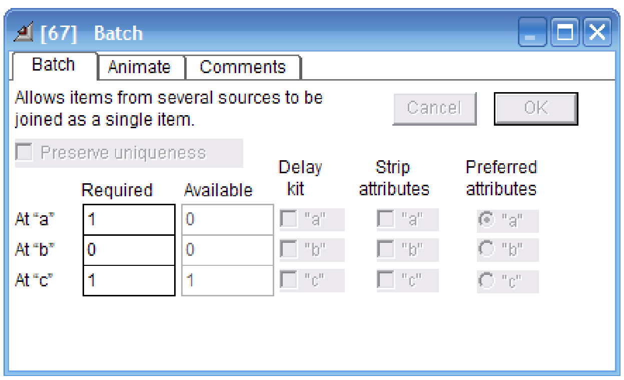


Figure 4. Batch Block Dialog

Model II:

Figure 5 shows the architecture developed for the second simulation model. Through Excel, users can give the following input (as shown in Table 3) to the simulation model: a) Planned Production per Day, and b) Desired Operator Utilization. The desired operator utilization input will be explained later.

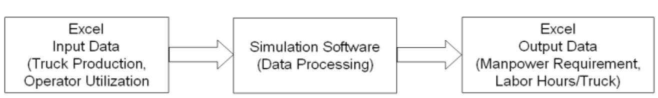


Figure 5. Model II Architecture

Table 3. Simulation Model Input Parameters

Planned Production per Day	5
Desired Operator Utilization %	70

Figure 6 shows how the different blocks are used in the second model, and represents a PDI I station used to model activities performed by operator #4. The cycle-time data collected from the time study are entered into respective blocks for respective activities of a particular station. The various activities performed at a station are represented by individual activity delay blocks. This model takes into consideration the number of workers at a particular station at the time the time study was performed. The activities performed by every worker are put into the model using separate activity delay blocks.

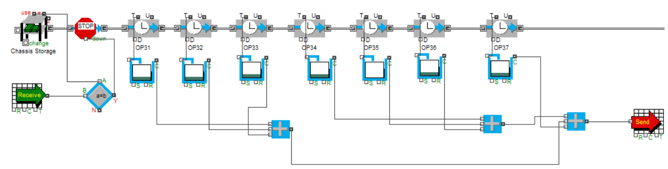


Figure 6. PDI I Station –Showing Different Blocks Used

Depending on the user input of planned production per day, the simulation model processes the data. The model calculates the total man-hours spent by every worker in the facility, based on the activities performed. These data are sent back to an Excel spreadsheet for further calculations. The Excel spreadsheet developed for manpower calculations shows the station number, station name and planned station production per day (see Table 3). It also displays information such as operator number, total time spent by the operators in performing their set of activities for building x trucks in a day, which is specified by the user. Total available hours in a day for production are also displayed. The spreadsheet then calculates the total number of man-hours required for a particular station for building x trucks in a day. It then predicts the total number of operators required for a station to achieve the desired utilization, which is entered as an input parameter by the user before running the model.

Operator utilization is calculated by the formula:

$$\text{Operator Utilization} = \frac{\text{Total Operator Hours}}{\text{Available Production Hours in a Day}}$$

Operator utilization indicates how much time per day each operator is utilized and how long he remains idle. Production hours (7.5 hours) are calculated by subtracting the lunch break of 30 minutes from the total shift time of 8 hours. The operator-utilization figure automatically changes to red if operator utilization is less than the desired operator utilization for a user-entered planned production per day. A utilization figure marked with a gold background indicates that operator utilization is greater than the desired utilization and overtime, or an extra operator, would be required in

Table 3. Excel Spreadsheet -Format for Manpower Calculation (PDI I Station)

Station Number	Station Name	Planned Station Production/Day	Operators Hours @ Planned Production				Total Man Hours for PID I Station	Total Operators Required @ Planned Production @ Desired Utilization
			OP1	OP2	OP3	OP4		
1	PDI I	5	3.5	5.0	5.5	5.33	19.3	3.7
		Available Hours in a Day	7.5	7.5	7.5	7.5	30	
		Operator Utilization @ Planned Production	**47%**	**66%**	**73%**	**71%**	**64%**	
* **Figure in red bold letters indicate that operator is underutilized for current planned production**								
*Figure marked with this background indicate that utilization of the operator is above Desired utilization (Overtime or extra operator/s needed to achieve planned production @ Desired Utilization)								

order to achieve the planned production at the desired utilization level.

Desired Utilization: A separate input tab for desired operator utilization is provided in the simulation model. The main purpose of doing so is to see how the manpower requirement changes based on the user-specified desired utilization. This gives the management a clear picture of the manpower requirement.

Based on the data received from Extend, the Excel spreadsheet calculates total man-hours required at a particular station for building x trucks in a day by adding the man-hours of all operators working on that station. Depending on the desired utilization input, the spreadsheet calculates ideal man-hours for that utilization. For example, for a desired utilization of 70%, the ideal man-hours would be (0.7*7.5) 5.25. The total number of operators required for the planned production at the desired utilization level is calculated by dividing the total man-hours for that station by ideal man-hours.

$$\text{Total Operators Required} = \frac{\text{Total Man Hours}}{\text{Ideal Man Hours}}$$

Data Analysis and Results

Model I:

Model I uses the data obtained by line supervisor feedback about the cycle times based on their experience and knowledge. The data are shown in Table 4. With the given input data, the facility was supposed to build 4 trucks per day. Simulation Model I was run for a year to observe the results. After running the model for a year, it was observed that the facility produced 963 trucks. This means that, on average, the facility produced 3.73 trucks per day. Utilization of various stations is presented in Table 5.

Table 4. Approximate Cycle Times-Supervisors Feedback

Sr.No.	Station Name	Approx. Cycle Time (min)
1	PDI Line Stations	60
2	Pull Walls	10
3	Drill Holes in Walls/ Attach Rub Rails	35
4	Decal Walls	90
5	Build Deck	45
6	Mount Walls	40
7	Build Luten/Decal Luten	50
8	Mount Luten	30
9	Build Roof	75
10	Mount Roof	40
11	Build Door	75
12	Door Decal	45
13	Mount Door	60
14	Mount Box	120
15	Decal Chassis	20
16	Cab Decals	75
17	Inspection	20

It can be seen from Figure 7 that the highest utilized station is station 17—Mount Box (99.7%)—followed by station 7—Decal Walls (75.5%). Station 5—Pull Walls (8.4%)—is the least utilized followed by station 22—Wash Bay

(12.5%). Mount Box station is the bottleneck in the facility. The following graph shows that utilization of the Mount Box station increases rapidly from the 0th hour to 241st hour. After that, the utilization remains stable to almost 100% until the end of the year. Similarly, the graph shows utilization for PDI I, Wall Decals, Build Roof and Build Door stations. The blue line represents PDI I, the red line represents Wall Decals, the green line represents Build Roof, and the gray line represents Build Door. The Wall Decals station utilization increases to 97% until the 67th hour and then stabilizes at 75%. A parallel station was added to the Mount Box station and the model was run again for a year. Now, with the additional Mount Box station, the facility produced 1,285 trucks in a year (4.98 per day). This means production could be increased by 33.4% by adding a parallel Mount Box station.

Table 5. Station Utilization

Station Number	Station Name	Station Utilization %
1	PDI I	50.3
2	PDI II	50.2
3	PDI III	50.2
4	PDI IV	50.2
5	Pull Walls	8.4
6	Drill Holes in Walls/Attach Rub Rails	29.4
7	Decal Walls	75.5
8	Build Deck	37.71
9	Mount Walls	33.4
10	Build Luten/Decal Luten	41.9
11	Mount Luten	25.1
12	Build Roof	54.15
13	Mount Roof	33.3
14	Build Door	62.59
15	Door Decal	37.6
16	Mount Door	50
17	Mount Box	99.7
18	Decal Chassis	25
19	Cab Decals	61.8
20	Inspection	16.6
21	Road Test	52.3
22	Wash Bay	12.5

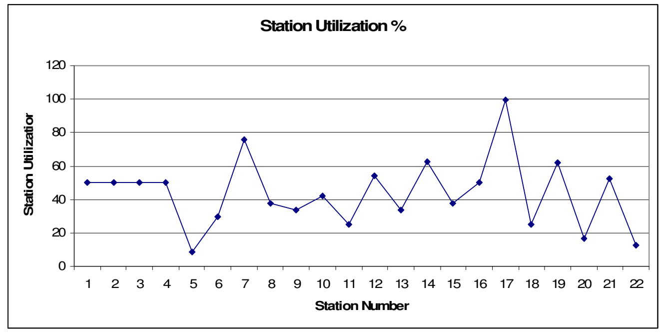


Figure 7. Station Utilization-Graphical Summary

Model II:

Model II uses the data obtained from the Time Study. The graph of Figure 8 summarizes cycle times for all of the operations performed at the various stations. It can be seen from the graph that operation number 52, which is install rear bumper/draw bar, has the highest cycle time (4,444 seconds). Some of the other higher cycle-time operations are ramp track assembly (3,265 seconds), enter the data of PDI line into computer (2,700 seconds), install rivets (Build Roof station—1,937 seconds) and install Door Decals (1,766 seconds).

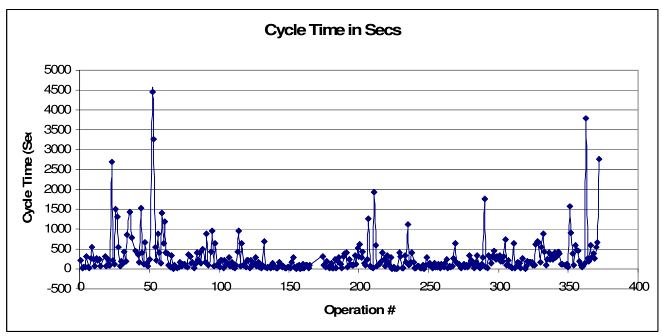


Figure 8. Cycle Times for All Operations

Simulation Model II was run for various planned truck production cycles from 1 truck per day to 20 trucks per day. After running the simulation model, a summary macro was run in order to generate the results summary in Excel. Figure 9 shows utilization of all the stations in the facility, which is calculated by effective utilization of the operators working at a particular station. Only the stations Mount Walls (115%), Build Roof (142%) and the Chassis-Van Box Decals (111%) have utilization above 80%. This means that these stations need more manpower than the currently assigned manpower in order to achieve truck production of 4 trucks per day.

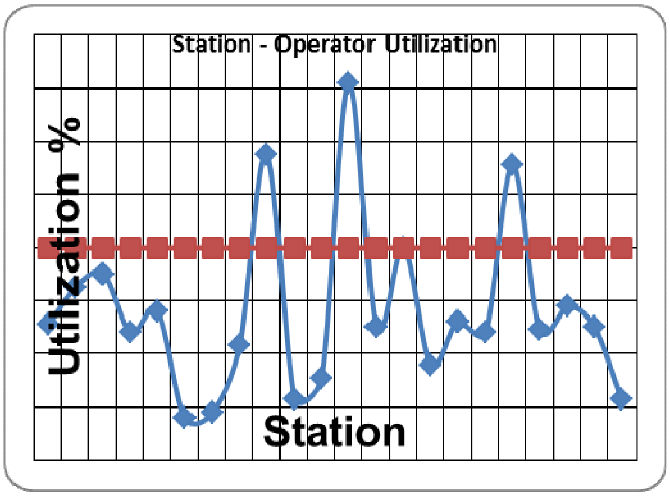


Figure 9. Station-Operator Utilization (4 trucks per day)

Figure 10 shows utilization of the operators working at various PDI line stations for truck production of 4 trucks per day. Utilization of all the operators is less than 80%, which means that PDI stations need fewer operators (4.8 ≈ 5) than the currently assigned 7 operators in order to make 4 trucks per day at 80% utilization.

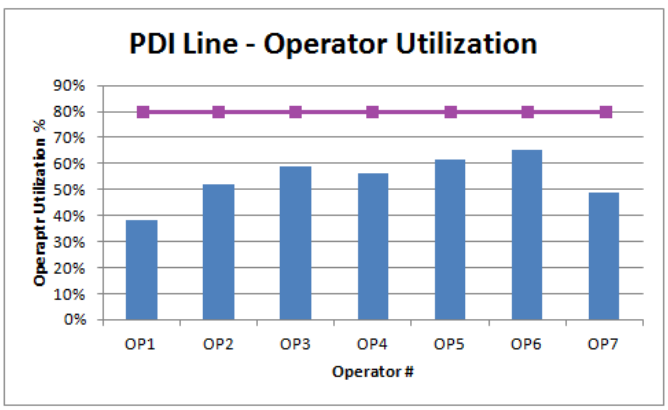


Figure 10. PDI Line Operator Utilization (4 trucks per day)

Various stations need a different number of operators depending on the work content. For building 4 trucks in a day, assuming operators are 80% utilized, the PDI I station requires 2.6 operators, whereas 1.7 operators are required at the Mount Box station, as shown in Figure 11. When this time study was conducted, 27 operators were working in the facility for building 4 trucks per day. Results provided by the simulation software showed that the facility would have needed only 21.6 ≈ 22 operators for building 4 trucks in a day at 80% utilization. The graph shown in Figure 12 summarizes the total manpower required for the body-building facility for truck production from 1 to 20 trucks per day.

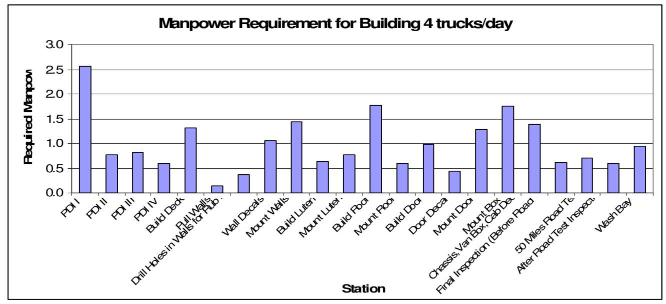


Figure 11. Manpower Requirements for Building 4 trucks per Day @ 80% Desired Operator Utilization

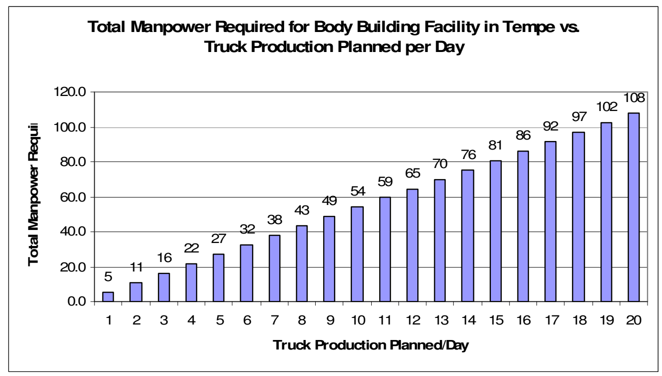


Figure 12. Manpower Requirements versus Truck Production

Verification and validation of the simulation models is an important step. There are various ways that the model could be verified. In this study, the authors used peer review for an initial verification. The models were presented in front of workers and supervisors, who were asked for their feedback. It is important to note that the feedback from the workers who have worked on particular operations was very helpful in verifying the models. Workers' feedback was studied along with the supervisors' and engineers' feedback. This exercise resulted in very positive group dynamics and helped us understand workers' concerns and answer their questions. Some sanity checks, such as consistency in input and output data, were also carried out in order to verify the models.

For validation, the authors decided to use peer evaluation, sensitivity analysis and historical input data. It should be noted that the results from this simulation matched very closely with the actual as well as historical factory production data. Interestingly, this truck-building facility has three identical manufacturing units across the United States. These plants also follow the same manufacturing flow (shown in Figure 1). The time-study analysis and simulations performed at other locations also showed similar trends. However, the bottlenecks identified at those facilities indicated by low utilization were different. The simulation models were very useful in identifying underutilized and/or understaffed stations. Based on the results of this work, the supervisors allocated the resources as indicated by this simulation at two locations which have shown substantial improvement in production and resulted in significant cost savings, operating efficiency and revenue generation. Currently, the approach presented in this case study is being developed further to improve the process efficiency.

Conclusion

This research study developed two valid simulation models of a local truck body-building facility. The company management can use these tools to assign manpower at various stations in the facility depending on the truck production planned. These models can be used to explore alternative techniques to lower production costs and increase production capability.

Simulation Model I used the data based on the production supervisor's feedback. The model was run for one year. This model identified Mount Box as the bottleneck in the facility as the utilization of this station was almost 100% throughout the year. A possibility of adding a parallel Mount Box station was explored in the model and its impact on the production was studied. Model I showed that by adding a parallel Mount Box station in the facility, truck production could be increased by 33.4%.

Simulation Model II was developed for predicting manpower requirements for the facility depending on the truck production planned and desired operator utilization specified by the user. One of the issues faced at the start was collecting the information about the total time worked by the operator and sending this information to Excel. This issue was sorted out with the use of activity delay, accumulate, add and send blocks. This model identified the maximum number of operators required at the PDI I station followed by the Mount Box station. The model also recognized that the facility had a 23% larger workforce when 4 trucks were built in a day at the time the study was done.

With the help of results obtained from Model II, manpower could be assigned to various stations in such a way that the operators were efficiently utilized. The time-study data could be used to target the operations that had maximum cycle times and explore new techniques for reducing them. It should also be noted that these simulation models have been validated and are currently being used for resource allocation. Several extensions and generalizations of the approach presented here are in progress.

References

[1] Laguna, M., & Marklund J. (2005). *Business Process Modeling, Simulation, and Design*. Upper Saddle River, NJ: Pearson/Prentice Hall.

[2] Banks, J. (1998). *Handbook of Simulation: Principles, Methodology, Advances, Applications, and Practice*. New York; Chichester England: Wiley.

[3] Lawrence, R. (2010) A Simulation environment for the evaluation of Airborne Bistatic Radar Concepts for External Hazard Detection. *International Journal of Engineering Research and Innovation, 2*(2), 72-79.

[4] Guo, H., & Mehrubeoglu, M. (2012). Analysis of Solar Panel Efficiency through Computation and Simulation. *International Journal of Modern Engineering 12*(2), 51-58.

[5] Eydgahi, A., Godaliyadd, D., & Falase, S. A. (2007). Simulation Software for Autonomous Navigation of Unmanned Surface Vehicles Using MATLAB Environment. *International Journal of Modern Engineering, 7*(2).

[6] Gogg, T. J. (1996). *Improve Quality & Productivity with Simulation.* JMI Publishing.

[7] Bazargan-Lari, Y., Gupta P., & Young, S. (2003). A Simulation Approach to Manpower Planning. *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P.J. Sanchez, D. Ferrin, and D.J. Morrice, (pp. 1677-1685).

[8] Ong, H. H. (2007). Establishing Man-Machine Ratio Using Simulation. *Proceedings of the 2007 Winter Simulation Conference*, ed. Henderson, Biller, Hsieh, Shortle, Tew, Barton, (pp. 1663-1666).

[9] Hillberg, P. A., Sengupta, S., & Van Til, R. P. (2009). A Comparative Study of the Three Predictive Tools for Forecasting a Transfer Line's Throughput. *International Journal of Industrial Engineering: Theory, Applications and Practice*, *16*(1), 32-40.

[10] Marvel, J. H., Schaub, M. A., & Weckman, G. R. (2008). Assessing the Availability and Allocation of Production Capacity in a Fabrication Facility Through Simulation Modeling: A Case Study. *International Journal of Industrial Engineering: Theory, Applications and Practice, 15*(2), 166-175.

[11] Hansen, G. A. (1997). *Automating Business Process Reengineering: Using the Power of Visual Simulation Strategies to Improve Performance and Profit*. (2nd ed.). Upper Saddle River, N.J.: Prentice Hall.

[12] Law, A. M. (2006). *Simulation Modeling and* Analysis. (4th ed.). Boston: McGraw-Hill.

[13] Krahl, D. (2003). Extend: An Interactive Simulation Tool. *Proceedings of the 2003 Winter Simulation Conference*, ed. S. Chick, P.J. Sanchez, D. Ferrin, and D.J. Morrice, (pp. 188-196).

[14] Barnes, R. M. (1980). *Motion and time study: Design and measurement of work*. (7th ed.). New York: Wiley.

Biographies

P. WAGH graduated with MS(Tech) from Arizona State University in 2008. He can be reached at pwagh@asu.edu

SANGRAM REDKAR is an assistant professor in the department of engineering at Arizona State University. He received his PhD from Auburn University in 2005. He can be reached at sredkar@asu.edu

JERRY GINTZ is a senior lecturer in the department of engineering at Arizona State University. He can be reached at jerry.gintz@asu.edu

BRAD ROGERS is an associate professor in the department of engineering at Arizona State University. He can be reached at brogers@asu.edu