Proceedings of the 2007 Winter Simulation Conference
S. G. Henderson, B. Biller, M.-H. Hsieh, J. Shortle, J. D. Tew, and R. R. Barton, eds.

PRODUCTIVITY IMPROVEMENT IN APPLIANCE MANUFACTURING

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ABSTRACT

Simulation can be a useful tool when analyzing complex manufacturing systems to help sort through cause-and-effect relationships and gain a better understanding of what is actually causing a particular problem in the system. Once cause-and-effect relationships are identified, changes for improvement can be made more intelligently and then verified using simulation. This paper describes an application in which simulation was used to identify the bottleneck of a dishwasher tub manufacturing line. Engineers were then able to determine and verify a solution to the bottleneck which resulted in an annual cost savings of $275,000.

1 INTRODUCTION

A manufacturer of dishwashers was experiencing an imbalance in production between two areas of the production system. Specifically, throughput from the dishwasher tub line was not keeping pace with demand from the final assembly area. In order to increase the tub line throughput, management decided to add an extra partial shift that would cost $275,000 a year. Engineers reluctantly went along with this decision but had a gnawing suspicion that something must be wrong with the process itself since none of the operation times for the tub line was greater than the required takt time at final assembly (the maximum tub-line operation time was 10 seconds). Table 1 shows the actual, required and theoretical throughput of the tub line.

Table 1: Tub line throughput (actual, required and theoretical) based on a maximum cycle time of 10 seconds.

Throughput	Actual	Required	Theoretical
Per Shift	1,692	2,248	2,736
Per Hour	280	350	360
Pct. of Theoretical	61.8%	82.2%	100%

As can be seen, theoretically, there should be ample capacity in the tub line as only 61.8% of the theoretical capacity is being used. Of course cycle time variation and operational interdependencies will prevent the system from reaching its full theoretical capacity. But one would think that it could certainly achieve a higher utilization of capacity than 61.8%.

Having only conducted a cursory investigation of the situation, engineers were unable to put their finger on the source of the problem and consequently they continued to be baffled by the inability of the line to meet takt time. In order to get at the bottom of the problem and explore possible solutions, a simulation model was built and analyzed. Following is a description of the process, key modeling decisions, analysis of the output results and proposed solution that was ultimately implemented.

2 SYSTEM DESCRIPTION

A dishwasher tub is the inner box that holds the dish racks and washer arms. It is a single piece that is injection-molded in the plant. Tubs are made of calcium-reinforced poly-propylene plastic which is known for its durability and resistance to chemicals. Parts are assembled to molded tubs creating a tub subassembly which is then assembled to the pump, the door and other components in a final assembly.

As shown in Figure 1, molded tubs are presented to the tub assembly line in carriers on an overhead conveyor (4 tubs per carrier). Tubs are removed from the carrier one at a time by a robot and placed on an assembly conveyor. The robot unload time is 10 seconds. Tubs move on the assembly conveyor through several assembly operations while the carriers from which the tubs were unloaded move on to the output area to wait for the tubs to complete their assembly. When tub assembly is completed, finished tub assemblies are reloaded onto carriers which are then transported to one of two final assembly areas.

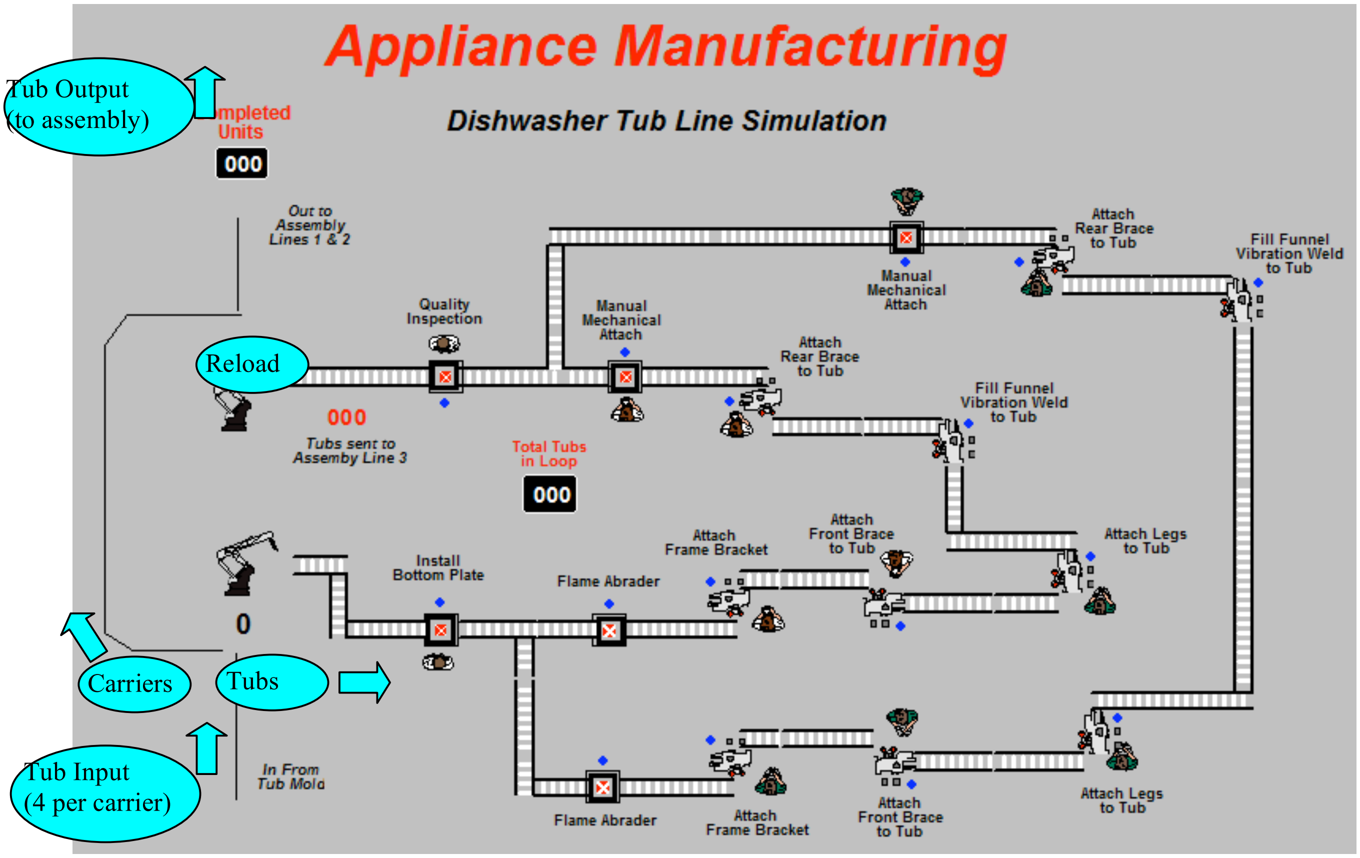


Figure 1: Layout of tub assembly line

When tubs are unloaded from the carrier, the first operation performed is a manual installation of a bottom plate. The average operation time is 10 seconds. After this operation, tubs are fed to one of two parallel assembly lines in an alternating fashion. All seven operations in each of the parallel lines have cycle times that are between 8 and 9.5 seconds. Five of the operations are manually performed and therefore have some variation in their cycle times. After the last assembly operation on each parallel line, the tubs merge onto a common conveyor for manual inspection.

Following inspection, tubs queue up to be loaded back onto a carrier (four per carrier) and sent to final assembly where the tubs are assembled into dishwashers.

The line operates for two 7.6 hour shifts per day and workers are cross-trained to fill in for each other during breaks. The line shuts down for a half-hour lunch period.

3 MODELING CREATION AND VALIDATION

Engineers with help from ProModel first built an "as-is" model to see if they could identify the real constraint. ProModel was chosen because of its ease of use and modeling flexibility. It had also been used extensively in other facilities of the company. The model excluded operations upstream and downstream from the tub line since parts were always available at the beginning and were never blocked by downstream operations at the end. The finished model is what is shown in Figure 1.

A list of critical model assumptions includes the following:

- There is always a carrier ready to be unloaded at the unload station (the tub line is never starved).
- Reloaded carriers are free to move on to final assembly (the tub line is never blocked).
- Operators are always available during the 7.6 hour period (a half hour lunch break was taken by everyone and cross-trained floaters filled in on staggered breaks).
- The system has essentially a 100% yield (rejects are reworked off-line and reintroduced at the appropriate station).
- There are no significant equipment failures.
- Component parts were always available at each assembly station.

The model was run under these operational assumptions and found to be a valid representation of the actual system producing essentially the same throughput as the actual system. Engineers familiar with the process further watched the animation to confirm that the model accurately reflected what was actually going on in the tub line.

4 SIMULATION EXPERIMENTATION & ANALYSIS

The base model was run for 7.6 hours (the length of a shift) with a 1 hour warm-up period. Key statistical variables were reset at the end of the warm-up period. Only a single replication was run since there were enough tubs produced during the shift to establish a fairly precise expected value for the throughput.

The simulation allowed the engineers to stand back and look at overall system performance in compressed time. Contrary to intuitive expectations, no bottlenecks were found at the individual assembly stations, nor in the material handling system which delivers raw tubs to the assembly line. However, a closer review of the material handling system showed that the loading process for placing tubs on the start of the conveyor line was constrained by a lack of space for empty carriers moving downstream to the "tub-to-final-assembly" reloading station

Though somewhat subtle, it became apparent that there was actually a dual constraint in the system: the carrier waiting area and the overall tub line. The carrier waiting area didn't have sufficient capacity to hold all of the carriers being unloaded. This constraint restricted the number of tubs that could be introduced into the tub line. On the other hand, the tub line wasn't getting tubs through fast enough to free up space in the carrier waiting area.

As shown in Figure 2, the empty conveyor area quickly filled up to its capacity (9 carriers) and was never available thereafter when an empty carrier was ready to enter. Hence, there was always some blocked time before carriers could unload their tubs and move into the empty carrier queue.

Two solutions presented themselves: either the cycle time for tubs in the line could be reduced thereby shortening the waiting time (hence the number) of empty carriers, or the buffer size for empty carriers could be increased to avoid blockage of the unloading operation. Since it would be impractical to reduce the processing time for tubs, it was determined that increasing the buffer size for empty carriers was the only viable solution.

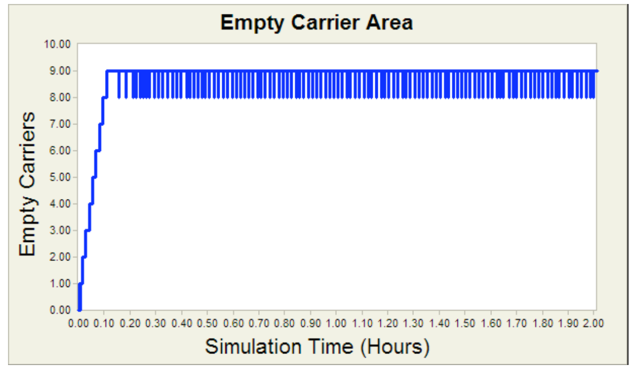


Figure 2: Queuing of empty carriers

Simulation experiments were run to determine the optimum buffer size to relieve the bottleneck. Through running iterative trials, it was determined that a buffer size of at least 16 would be sufficient to keep the unload station from being blocked.

5 SOLUTION PROPOSAL AND PROOF OF CONCEPT

Since the company already had a recirculation loop conveyor that currently wasn't being used, the engineers decided to put it to use to increase the buffer size. Figure 3 shows the revised layout with the recirculation conveyor.

The loop allowed additional empty carriers to queue between the tub unloading station and the finished tub reloading station. This increased the buffer capacity for empty carriers from 9 to 18 which should keep enough tubs entering the tub line to meet demand.

The engineers wanted to see how this recirculation conveyor would interact with the rest of the system and verify that it would increase throughput, so a simulation was run and analyzed.

The addition of the recirculation conveyor effectively supplied more inventory to the parallel tub assembly lines, thereby increasing the utilization of the assembly stations and increasing the tub-line throughput by 35% or from 1,692 tubs per shift to 2,280 tubs per shift (see Figure 3). This turns out to be just 1.4% higher than the required throughput and shows that the solution would work.

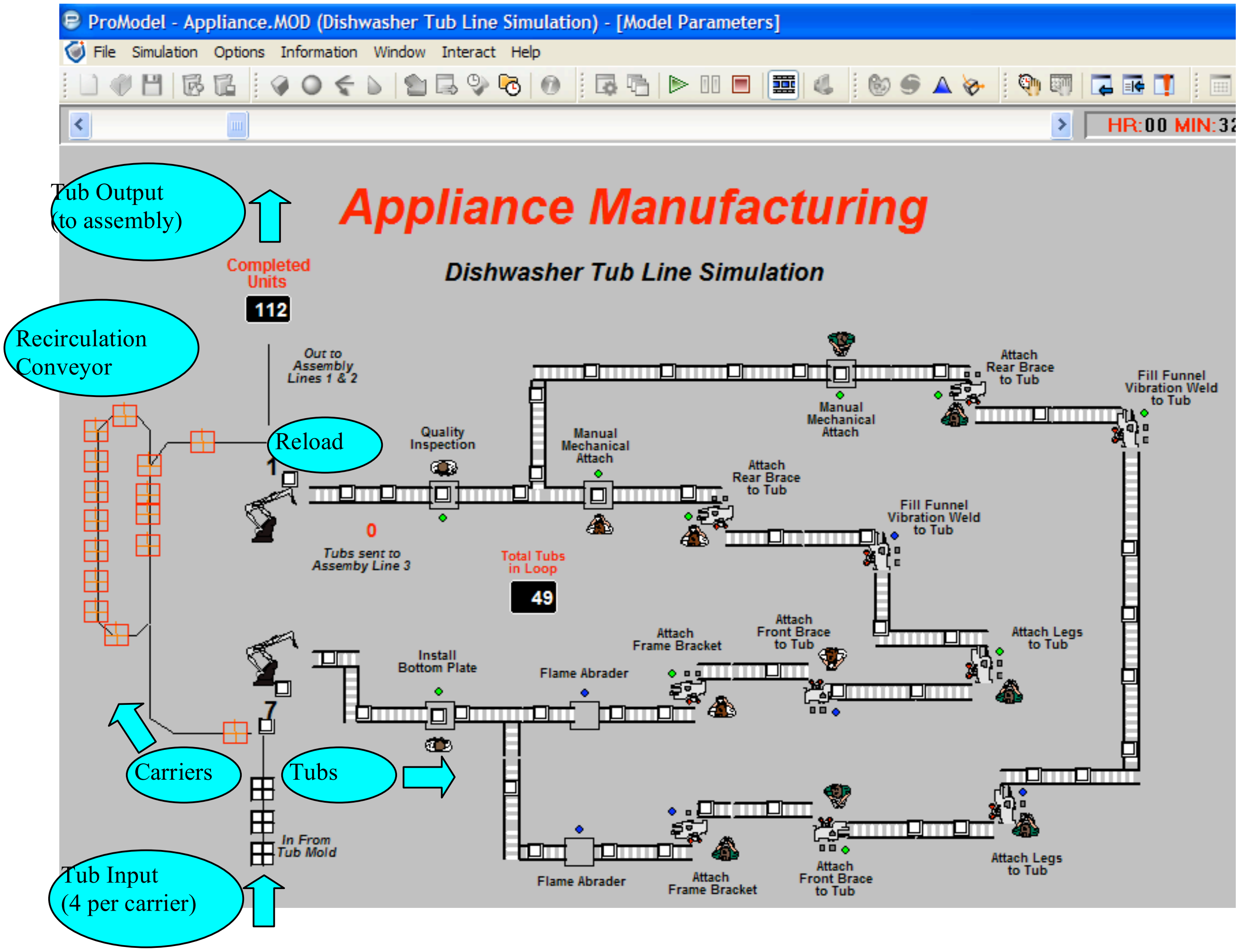
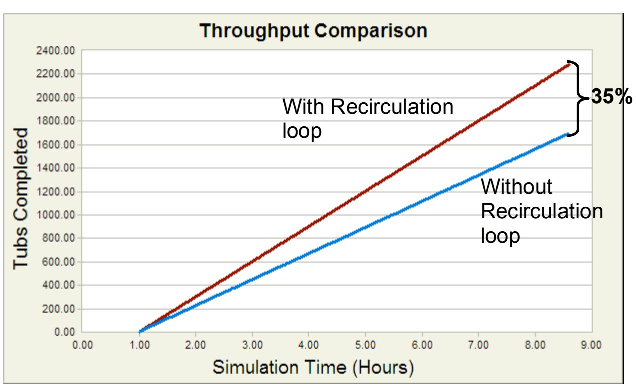


Figure 3: Revised layout showing recirculation conveyor



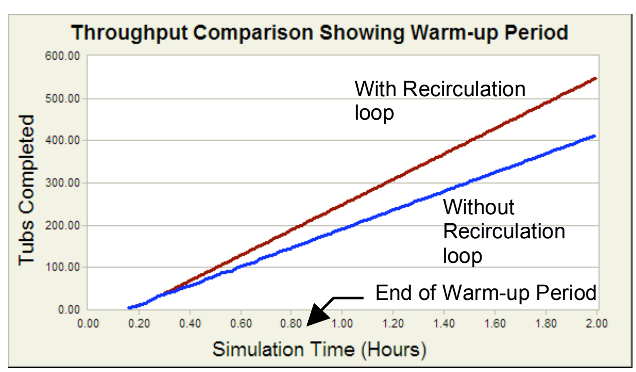


Figure 4: Throughput comparison

Figure 5: Throughput comparison showing warm-up period

With the addition of the recirculation conveyor, the required system Takt time could be met while eliminating the need for the additional partial shift.

The impact of the recirculation conveyor becomes apparent during the first hour. Notice in Figure 5 how throughput is initially the same for both scenarios but then quickly begins to drop off for the non-recirculation loop after about the first 20 minutes

As explained, the increase in throughput was accomplished by providing more empty carrier storage which, in turn, allowed more tubs to be processed at the same time in the tub assembly area. This is obviously going to increase the tub WIP. Figure 6 shows that the average tub WIP increased from 36 units to just over 48 units which is about a 34% increase.

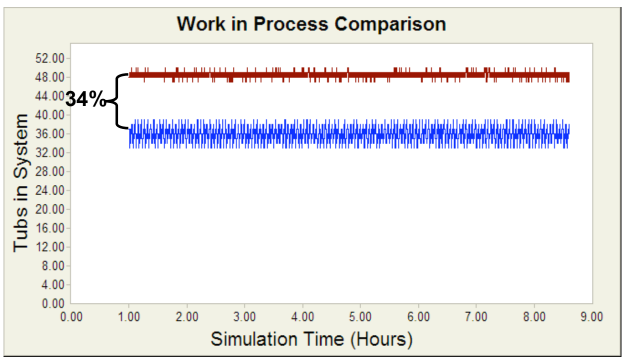


Figure 6: Work-in-process comparison

This project was completed in two weeks using ProModel software and services. By eliminating the additional partial shift, the company realized an annual savings of $275,000. The ROI in the first year alone from this project was 1,100% and the payback period was less than 2 months.

AUTHOR BIOGRAPHIES

CHARLES HARRELL is an associate professor in the Ira A. Fulton college of Engineering and Technology at Brigham Young University. His area of interest is manufacturing systems design and simulation. He was the original developer of ProModel simulation software and is currently technology advisor for ProModel Corporation. At BYU he teaches courses in manufacturing systems, manufacturing simulation, and manufacturing information systems. He is the principal author of several simulation books and has given numerous presentations on manufacturing system design and simulation. He is a Senior member of IIE and SME.

BRUCE GLADWIN is vice president of consulting services for ProModel Corporation. He has been with ProModel for 12 years, and has nearly 20 years experience in simulation of manufacturing, logistics and service systems. Bruce has also worked for the aerospace industry and spent five years at GE where he was involved in Six Sigma projects using simulation. He also worked in the Mfg and Business Process Lab at GE's Global Research Center. Bruce is a GE Certified Six Sigma Black Belt and a member of the American Society for Quality.