SIMULATION IMPROVES MANUFACTURE AND MATERIAL HANDLING OF FORGED METAL COMPONENTS

Teresa Lang
Edward J. Williams
Onur M. Ülgen
Industrial & Manufacturing Systems Engineering Department
College of Engineering, Engineering Complex, University of Michigan - Dearborn
4901 Evergreen Road
Dearborn, MI 48128 U.S.A.
(tmlang | williame | ulgen)@umd.umich.edu

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ABSTRACT

As competitive pressures increase within the manufacturing sectors of economies worldwide, and especially within the automotive sub-sector, the importance of achieving operational efficiencies to reduce costs and thence to increase profits while keeping and attracting customers steadily increases. Simulation, time studies, and value stream mapping have long been key allies of the industrial engineer assigned to find and progress along the often difficult and challenging road leading to such efficiencies. The presentation here, and undertaken collaboratively between the university and the company involved, concentrates primarily on the use and achievements of discrete-event process simulation in improving the manufacture and material handling of forged metal components sold in the automotive and industrial manufacturing marketplace.

INTRODUCTION

Historically, the first major application area of discrete-event process simulation was the manufacturing sector of the economy (Miller and Pegden 2000). With the passage of time, simulation has become more closely allied with other industrial engineering techniques such as time and motion studies, value stream mapping, ergonomics studies, and "5S" examinations used concurrently to improve manufacturing operations (Groover 2007). Illustrative examples of simulation applications to manufacturing and industry appearing in the literature are: analysis of pig iron allocation to blast furnaces (Díaz et al. 2007), construction of a decision support system for shipbuilding (Otamendi 2005), and layout of mixed-model assembly lines for the production of diesel engines (Steringer and Prenninger 2003)

In the application documented here, simulation was applied to reduce manufacturing lead times and inventory, increase productivity, and reduce floor space requirements. The client company was and is a provider of forged metal components to the automotive light vehicle, heavy lorry [truck], and industrial marketplace in North America. The company has six facilities in the Upper Midwest region of the United States which collectively employ over 800 workers. Of these six facilities, the one here studied in detail specializes in internally splined (having longitudinal gearlike ridges along their interior or exterior surfaces to transmit rotational motion along their axes (Parker 1994)) shafts for industrial markets. The facility also prepares steel for further processing by the other five facilities. Components supplied to the external marketplaces are generally forged metal components; i.e., compressively shaped by non-steady-state bulk deformation under high pressure and (sometimes) high temperature (El Wakil 1998). In this context, the components are "cold-forged" (forged at room temperature), which limits the amount of re-forming possible, but as compensation provides precise dimensional control and a surface finish of higher quality.

OVERVIEW OF PROCEDURES AT THE FORGING FACILITY

As mentioned, the facility examined in this study specializes in internally splined shafts for one dedicated customer in the industrial marketplace, and in steel preparation processes for two colleague plants within the same company. Therefore, this particular plant has exactly three distinct customers. The figure below shows a typical forging produced here:

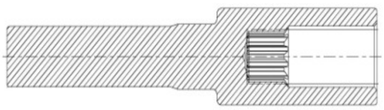

Figure 1. Typical Forging

The major production equipment used at this facility comprises:

1. Eight hydraulic presses (150-750 tons, single station, manually fed)
2. Eleven tank coating lines with five traveling tumblers

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3. Two saws
4. One "wheelabrator™" (trademark name of equipment used for shot blasting)
5. Eight small and two large heat treatment areas, with five bell furnaces.

The overall layout of these operations is shown in the Appendix (Figure 4).

Having three dedicated customers, this facility produces parts in three distinct families, each with its own process routing. Parts of family #1 go first to shot blast (a cleaning process to remove surface scale and dust from the parts or billets) at the "Wheelabrator," a manually operated machine; then to lubrication at the coating line, and then to the outgoing dock for weighing and shipping. Families #2 and #3 have longer itineraries, summarized in the following tables:

Table 1. Process Routing for Production Family #2

Operation	Workcenters
Saw cutting	Saw 1 and Saw 2
Shot blasting	"Wheelabrator"
Annealing	Heat treat
Lubricating 1	Coating line
Weighing and shipping	Outgoing dock

Table 2. Process Routing for Production Family #3

Operation	Workcenters
Saw cutting	Saw 1 and Saw 2
Shot blast	"Wheelabrator"
Annealing	Heat treat
Lubricating 1	Coating line
Cold Hit 1/Inspect	390T, 490-2T, 500T
Stress relief	Heat treat
Lubricating 2	Coating line
Cold Hit 2/Inspect	150T, 490-1T, 490-2T
Final audit	Final audit
Weighing and shipping	Outgoing dock

At the saw cutting process, bar stock is received in 5-ton bundles 30 feet long. A bundle is loaded onto the saw using a crane; only then is the bundle broken open and fed into the saw. Although the saw routinely cuts every piece to an exact length (vital), it is more difficult, and equally vital, to control the weight of the billet (bar after cutting). The two saws share, and are run by, one operator.

Two varieties of heat treating are used. Spherodize annealing converts strands of carbon in the steel to spheroids before forging, rendering the steel more formable and hence capable of being forged at room temperature. Stress relieving, done after forging, relieves the stresses accumulated in the steel during forging, thereby permitting distortion-free carburizing of the internal splines. This carburizing is done at customers' sites. These two heat-treat operations share one operator, who is responsible for loading the parts into "heat treat pots" (Figure 2 below) to be placed in the furnace and unloading the parts afterwards. Since the parts expand during heat treat, the unloading times are 50% longer and also have triple the standard deviation of the loading times.

Figure 2. Heat-treat Pot

After final heat treat, the parts are coated in a zinc-phosphate and soap lubricant; this requires that they be dumped into tumblers (Figure 3 below) which can be rotated and submerged in the lubricant, and then lifted and rotated again to drip excess solution. This work also requires operator intervention.

Figure 3. Tumbler

After lubrication, those parts destined for either of the two corporate downstream plants are ready for final inspection, weighing, and shipment thereto; the lubrication prepares them for further cold-forging there. Parts destined for the external customer are cold-forged locally subsequent to inspection, weighing, and shipment to the customer.

DATA COLLECTION AND INPUT ANALYSIS

As usual, data collection consumed a significant percentage (about 35%) of time invested in this process improvement study (Carson 2004); educators must gently explain to students that simulation studies are unlike Exercise 4 in the textbook, with "givens" such as "the machine cycle time is gamma distributed with parameters…." Much of the data collection work simultaneously supported both the value stream mapping and the simulation analyses. Historical data on the arrival times and quantities of raw material, which occurred approximately daily at 9am by truck, was readily available. The quantities of raw material delivered were approximately normally distributed, as verified by the Anderson-Darling goodness-of-fit test available in the Minitab® statistical software package (Ryan, Joiner, and Cryer 2005) and the Input Analyzer of the Arena® simulation software. Machine cycles, such as the lubricant immersion time, the shot blast time, or the required length of heat-treat time, were well known, but operator intervention times, such as time to load or unload the heat-treat pots or the tumblers, had to be collected by traditional time-&-motion study stopwatch measurements (Mundel and Danner 1994). The stopwatches made the workers uneasy at first, raising the specter of the Hawthorne effect; data collection needed to be as quiet and unobtrusive as possible (Czech, Witkowski, and Williams 2006). Two significant aids in this data gathering were: (1) it occurred across *all* manually assisted operations – hence no *one* operator or group of operators felt threatened by special vigilance, and (2) labor-management relations at the company were and are historically favorable. Downtime frequency of occurrence, downtime duration, and scrap rate data were conveniently available from historical records, a commendable situation described vividly in (Weiss and Piłacińska 2005).

CONSTRUCTION, VERIFICATION, AND VALIDATION OF THE SIMULATION MODEL

Owing to ready availability within both academic and industrial contexts, and ample software power to both simulate and animate the production processes in question, the Arena® simulation modeling software (Kelton, Sadowski, and Sturrock 2007) was used. The animation was basic and, given the time limitations of this study, only two-dimensional, but these limitations were of little importance to the client management. Arena® provides direct access to concepts of process flow logic, queuing disciplines (e.g., FIFO), modeling of processes which may be automated, manual, or semi-automated, use of Resources (here, the various machines and their operators), definition of shift schedules, constant or variable transit times between various parts of the model, extensibility (in its Professional Edition) via user-defined modules (Bapat and Sturrock 2003), and an Input Analyzer (used as discussed in the previous section to verify distributions).

Verification and validation techniques used included a variety of methods such as tracking *one* entity through the model, initially removing all randomness from the model for easier desk-checking, structured walkthroughs among the team members, step-by-step examination of the animation, and confirming reasonableness of the preliminary results of the model with the client manager by use of Turing tests (Sargent 2004). For the "one-entity" tests, an entity of each product type for each of the three customers was used in succession. Since the facility has maintained accurate and complete inventory data over a lengthy period of time, the inventory and work-in-process levels predicted by the model furnished an excellent "test bed" for validation. Comparison of localized performance data pertinent to each work center (e.g., machine utilization and length of queue preceding the machine) with model results was also helpful to the validation effort. Validation of the first model built – the "current operations model" was considered complete by both the analysts and the client when machine utilizations, operator utilizations, inventory levels, and throughput all correctly matched recent historical data to within 6%.

RESULTS AND OPERATIONAL CONCLUSIONS

The simulation model representing current operations was specified to be terminating, not steady-state, because this manufacturing process, unlike most, "empties itself" each night (here, at the last of three shifts) and resumes work the next day with the delivery of new raw material (Altiok and Melamed 2001). Therefore, warm-up time was always zero. Results and comparisons between the current and proposed systems were based on ten replications of the current-state model and on thirty replications of the proposed-state model (described next, and of higher intrinsic variability) each of length five working days (one typical work week). The number and duration of replications were chosen based on the helpful Arena® capability of predicting confidence interval widths for performance metrics on their standard deviations among replications run.

The initial model vividly exposed the inefficiencies in material handling already suspected of existing in the production system. Each time parts are dumped into or out of any container, they are at risk of dings and dents. The dumping that occurs in the coating line (into and out of the tumblers) is necessary – these tumblers are attached directly to the coating line, are made of stainless steel to withstand the caustic chemicals used in this operation, and have mechanisms permitting their rotation to "spin-dry" the parts as mentioned above. Therefore, the tumblers, costing about $60,000 each, represent a significant capital investment. On the other hand, the dumping into and out of containers – the heat-treat pots – seemed wasteful. Certainly the parts must be stacked in containers to be heat-treated, but the processes immediately upstream (shot blast and/or forging) and downstream (coating) from heat-treat presume the parts to be in some type of container already. Therefore, a second model was built in which these material handling operations were revised under the hypothesis that parts would be put in heat treat pots instead of other containers for all operations up to (but not including) the actual coating process. Under this new scenario, day-to-day operations would certainly need more heat-treat pots, and this second model was used primarily to answer the question "How many more heat-treat pots would be needed to avoid excessive work-in-process inventory and delays?"

Point estimates and confidence intervals built at the 95% level, using the Student-*t* distribution (since population standard deviation was estimated from sample standard deviation) for the current system predicted the following:

- Mean number of heat-treat pots in use in the current system is 93 during any one work week.
- Maximum number of heat-treat pots in use in the current system at any time during any one work week is 191.
- In the proposed system (material-handling revision) the mean number of heat-treat pots in use is between 308 and 316 with 95% confidence.
- In the proposed system (material-handling revision) the maximum number of heat-treat pots in use is between 422 and 435 with 95% confidence.

Hence the simulation results were summarized for management as a recommendation to buy 225 heat-treat pots (there being currently 204 heat-treat pots on hand). The disadvantage: this recommendation entails a capital expenditure of $225,000 ($1,000 per pot). The advantages are:

1. One heat-treat dumping operator on each of the three shifts is no longer needed (annual savings $132,000).
2. Less material handling (dumping parts into and out of pots) entails less risk of quality problems (dings and dents).
3. The work to be eliminated is difficult, strenuous, and susceptible to significant ergonomic concerns.

Hence, from a financial viewpoint, the alternative investigated with this simulation study has a payback period just under 1¾ years, plus "soft" but significant benefits.

INDICATED FURTHER WORK

Further work to be investigated next via simulation involves balancing the schedule so that parts do not, as they do now, "flood" into either the heat treatment or the coating departments. The saw cuts one job at a time, and the order in which those jobs are run is discretionary. Saw cycle time is highly variable (from one to seven hours) based on the number of workpieces per box fed to a saw. Simulation may be able to prove that having all short jobs run on one saw and all long jobs run on the other saw will smooth the flow of parts downstream. If so, the gap between mean and maximum number of heat-treat pots in use can perhaps be narrowed with detriment to neither work-in-process inventory nor work-in-process time. Then the number of pots to be purchased will decrease and the payback period will likewise decrease, thereby making the operational alternative suggested by the simulation study even more attractive.

OVERALL CONCLUSIONS AND IMPLICATIONS

Taking a longer view, the benefits of this study extend beyond the improvement of manufacturing and material handling in one facility of one moderate-sized company in the automotive sector. Publicity accorded to the study by the senior professor in charge of the simulation course (as is routinely done for many "senior projects" or "capstone projects") has drawn beneficial local attention to the ability of simulation (and by implication, other analytical methods [e.g., the value-stream mapping used here] within the discipline of industrial engineering) to help local companies increase their competitiveness. Such help is particularly pertinent to the beleaguered automotive and manufacturing industry, especially in Michigan, which is currently the 50^{th} of the 50 United States economically (Morath 2007). Additionally, the success of this study has increased the willingness of local business and management leaders to welcome and provide project opportunities for advanced undergraduate students. This willingness stems partly from the short-term attraction of having useful industrial-engineering work done, and partly from the long-term attraction of making an investment in the experience level of students who will shortly be entering the labor market as industrial engineers (Black and Chick 1996). A student who, within the auspices of this simulation course, understands the "connection between the physical activities and the consequential financial flows" (Ståhl 2007) is well prepared to make both technically sound and financially valuable contributions at his or her place(s) of career employment.

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AUTHOR BIOGRAPHIES

TERESA LANG is a student of Industrial and Systems Engineering at the University of Michigan - Dearborn campus. She expects to be graduated with a Bachelors of Science after the winter 2008 semester. She currently holds a 3.12 overall grade-point average and a 3.48 in her engineering discipline (maximum = 4.0). She was drawn to industrial engineering due to her passion for creating efficient systems, satisfaction in creating organization out of chaos, and enjoyment of statistical analysis. She has been an employee in the forging industry for the past seven years, where she has worked as a Product and Process Engineer, Tooling Coordinator, Customer Service Engineer, and Program Manager. Currently she is working as the Quality and Engineering Coordinator / Lean Promotion Officer / TS Management Representative, responsible for development of new business, maintenance of the quality management system, and improvement of plant operations through elimination of waste and reduction of variability. She is a six-sigma black belt, a certified lead TS auditor, and certified lean champion. She specializes in cold forging and die design, statistical analysis, and program management.

EDWARD J. WILLIAMS holds bachelor's and master's degrees in mathematics (Michigan State University, 1967; University of Wisconsin, 1968). From 1969 to 1971, he did statistical programming and analysis of biomedical data at Walter Reed Army Hospital, Washington, D.C. He joined Ford Motor Company in 1972, where he worked until retirement in December 2001 as a computer software analyst supporting statistical and simulation software. After retirement from Ford, he joined PMC, Dearborn, Michigan, as a senior simulation analyst. Also, since 1980, he has taught evening classes at the University of Michigan, including both undergraduate and graduate simulation classes using GPSS/H™, SLAM II™, SIMAN™, ProModel®, SIMUL8®, or Arena®. He is a member of the Institute of Industrial Engineers [IIE], the Society for Computer Simulation International [SCS], and the Michigan Simulation Users' Group [MSUG]. He serves on the editorial board of the *International Journal of Industrial Engineering – Applications and Practice*. During the last several years, he has given invited plenary addresses on simulation and statistics at conferences or seminars in Monterrey, México; İstanbul, Turkey; Genova, Italy; Rīga, Latvia; Göteborg, Sweden; and Jyväskylä, Finland. He has served as Program Chair of the 2004, 2005, and 2006 Summer Computer Simulation

Conferences, and also for the 2005 IIE Simulation Conference. His university web page is: http://www-personal.umd.umich.edu/~williame.

ONUR M. ÜLGEN is the president and founder of Production Modeling Corporation (PMC), a Dearborn, Michigan, based industrial engineering and software services company as well as a Professor of Industrial and Manufacturing Systems Engineering at the University of Michigan-Dearborn. He received his Ph.D. degree in Industrial Engineering from Texas Tech University in 1979. His present consulting and research interests include simulation and scheduling applications, applications of lean techniques in manufacturing and service industries, supply chain optimization, and product portfolio management. He has published or presented more that 100 papers in his consulting and research areas.

Under his leadership PMC has grown to be the largest independent productivity services company in North America in the use of industrial and operations engineering tools in an integrated fashion. PMC has successfully completed more than 3000 productivity improvement projects for different size companies including General Motors, Ford, DaimlerChrysler, Sara Lee, Johnson Controls, and Whirlpool. The scientific and professional societies of which he is a member include American Production and Inventory Control Society (APICS) and Institute of Industrial Engineers (IIE). He is also a founding member of the MSUG (Michigan Simulation User Group).