SIMULATION HELPS EVALUATE AND REDESIGN SEAT ARMREST ASSEMBLY

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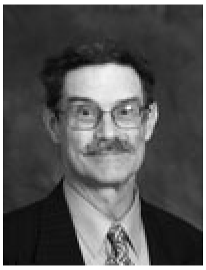
Abstract

A multifaceted industrial engineering approach, using simulation, ergonomic analyses, facility layout and material handling assessments, and quality control and enhancement, was applied to the assembly of personal-vehicle passenger seats. The company assembling these seats is a Detroit [Michigan]-area company with a checkered history dating back nearly a century; the company is now a Tier I automotive supplier. In this paper, we describe the role played by simulation in process improvement, particularly the utilization of operators, and the collaborations between simulation analysis and the other analytical techniques of industrial engineering used.

Keywords: discrete-event simulation, manufacturing simulation, Arena®.

Presenting Author's biography



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1 Introduction

Simulation has long been a significantly valuable tool for process evaluation and improvement, and historically, its first widespread use was within the manufacturing sector of the economy [1]. Furthermore, simulation used in concert with other industrial engineering techniques (e.g., ergonomic analysis, facility layout and material handling assessments, quality and process control, or value-stream mapping) yields strongly synergistic process improvement benefits [2], as was the case here.

The company whose operations were simulated and studied was founded in Detroit, Michigan, U.S.A. about ninety years ago. In recent years, the company has prospered and expanded dramatically in its role as a Tier I automotive-industry supplier (a supplier which supplies vehicle manufacturers directly – recursively, a Tier II supplier supplies a Tier I supplier, etc.). Inasmuch as the United States automotive industry is shrinking and becoming increasingly competitive, first-tier (not to mention second-tier, third-tier, etc.) automotive suppliers must continually increase their efficiencies to withstand competitive pressures on price, timeliness of delivery, and flexibility [3]. The expansions of this client company include "going public" (becoming traded on the New York Stock Exchange) in 1994, broadening supplier service from seats alone to other vehicle interior systems (e.g., flooring, door panels, instrument panels), and significant overseas penetration (the company now has facilities in 33 countries). Analogous examples of simulation analysis in the service of manufacturing and assembly operations appear in [4] (simulation to implement and operate a digital factory), in [5] (simulation to support decision-making within an assembly line fabricating components of ships), and in [6] (sequencing jobs on a single machine within a semi-automated production process).

The focus of this project was a seat-manufacturing plant undergoing recent and current expansion in the metropolitan Detroit area. This plant produces seats for three different vehicle lines, two made by one automotive company and one made by another. A total of 84 different seating styles are available to these three automotive companies collectively.

2 Overview Of Seat Assembly And Armrest Assembly Operations

The seat assembly process receiving detailed study and analysis must produce a total of 84 different seating styles for three different vehicle lines and two different vehicle manufacturers. Distinguishing features among the 84 styles include:

Color of seat and style of seat trim used

Type of armrest, if any, between the driver's seat and the front passenger's seat (about 30%, at prevailing market mix, of the vehicles assembled require an armrest supplied by the subassembly line; it is vital that the main assembly line not be delayed for want of a needed armrest)

Whether OCM [Occupant Classification Module] and TPS [Track Position Sensor] are installed (these systems help determine the pressure used to deploy the airbag)

Whether the seats are heated

Whether the seats maneuver manually or with power.

The summer before this project was undertaken, the number of seats rejected due to problems with their armrests increased, so plant executives and managers desired an in-depth analysis of the armrest assembly process to improve quality, improve resource utilization, and reduce waste. Accordingly, the offline armrest assembly area received direct attention during the simulation phase of the project.

Of the 84 seat styles, 51 require inclusion of an assembled armrest. Assembly kits for these armrests are received at docks, and subsequently replenished through pick lists at an in-line storage as required for each style. These pick lists must sequence the armrests to match the sequence of seat styles within which the armrests will be incorporated. The actual assembly requires three operators. First, Operator X receives upper portions, sequenced, from the pallets delivered by the picking carts. The armrest may be of storage style (i.e., an armrest with a flip-up lid covering a storage space for small items carried by the driver and/or passenger during travel in the vehicle). In this case, Operator X retrieves a matching lid and attaches it to the storage bin. In either case, this operator places the partially assembled upper portion of the armrest onto a conveyor for delivery to Operator Y. Operator Y then attaches brackets to each side of the upper portion and then places the armrest upper portion with attached brackets onto a conveyor for delivery to Operator Z. The bracket attachment operations performed by Operator Y require care, particularly in tightening nuts within narrow torque tolerances. Operator Z then, with the help of the newly attached brackets, marries the upper portion received via conveyor with a lower portion subassembly. In doing this, Operator Z must ensure that the lower portion trim color matches the color of the upper portion, and that wrinkles in the trim (present because the trim was folded in storage) are carefully ironed into oblivion. Operator Z then places the completed armrest subassembly onto a belt conveyor feeding the downstream main assembly line for vehicle seats. The overall process flow involving Operators X, Y, and Z is summarized in Fig. 1, Appendix. It was this subassembly line that the client wanted to examine with particular attention to assessment and improvement of the operator utilizations. The client management and the simulation analysts agreed that the fundamental required input data to model the armrest subassembly model were: pallet interarrival times, seat style distribution, chute and conveyor capacities, and cycle times for each of the three operators. Since pallets circulate between this subassembly line and the main subassembly line, pallet interarrival times increase when the amount of downtime on the main assembly line increases, and vice versa.

3 Data Collection And Analysis

Data collection for this project was time-consuming and difficult. The subassembly line supervisors did not already have much of the pertinent data required for the simulation study; in particular, the operator X, Y, and Z cycle time data and the interarrival times of pallets to Operator X were unavailable. After delicate conversations with the client and with the (unionized) operators, these data were collected by direct observation. To avoid the Hawthorne effect [7], since cameras were forbidden, the data gatherers came at times known only to management and carefully concealed themselves (e.g., behind pillars or equipment, or on a mezzanine) while gathering these data. The four data sets thus obtained (interarrival times and cycle times for each Operator) were then analyzed by curve-fitting software to assess whether their analogue in the simulation model should be an empirical distribution or a closed-form distribution [8]. Since the interarrival time, Operator X cycle time, and Operator Y cycle time data sets were not only of high variance but also bimodal or multimodal, they were represented by empirical distributions. The discovery of multimodality in these empirical data sets was in and of itself of incremental value to the client (similar events are described in [9]): this discovery prompted the question "why the multimodality?" and hence provoked subsequent detailed examination of work design at these two operations. The Operator Z cycle time data set was well characterized by an Erlang distribution. In this last case, the *p*-value for rejection of H_0: "suggested closed-form distribution is a good fit" was greater than 0.4.

4 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 system in question (although the animation was two-dimensional only, an issue of trifling consequence), the Arena® simulation modeling software [10] was used. This software 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 Operators), definition of shift schedules, extensibility (in the Professional Edition) via user-defined modules [11], an Input Analyzer (used as discussed in the previous section to choose between empirical and closed-form distributions), and a Process Analyzer to automate the successive running of multiple scenarios.

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 managers by use of Turing tests [12]. These precautions contributed greatly to the credibility of the model also. Runs of the initial (base case) model corresponding to current operational conditions produced surprisingly low utilizations for the operators. After examining the verification and validation steps taken for completeness and correctness, both client management and the analysts accepted them as correct to within 4%. Re-examination of actual production work revealed the disconcerting facts that the operators were overproducing some parts, and also taking unduly long and frequent breaks.

5 Results And Indicated Further Work

The simulation model was specified to be steady-state, not terminating, because this manufacturing process, like most, does not "empty itself" during off-shifts or weekends [13]. Each scenario studied was run for a warm-up time of one day followed by a statistics-gathering period of five production days, and for three replications.

The base case model, as mentioned in the previous section, corresponded to the then-current state of the offline armrest assembly area. Key performance metrics predicted by the model at various levels of vehicles needing armrests (the row corresponding to the current level of 30% is highlighted in gray) are summarized in Tab. 1 (Appendix); these results confirmed and quantified the following, all of high interest to the client:

1. Utilization of the first two operators is markedly lower than desired.
2. Even at workload levels of "70% of vehicles need armrests," the subassembly line will not force the main assembly line to stop (such stoppages are expensive and disruptive to the point of being completely unacceptable).
3. Total production count is hence nearly independent of the percentage of vehicles requiring armrests, but does decline if the main line does need to stop.

Next, the base model was run on the assumption that the final assembly line it supplies never goes down, since this (unrealistic) situation is the one placing most extreme demand on the ability of the subassembly line to supply it without pause. This scenario continued to exhibit poor utilization (under 50%) of the first two operators even when 50% (far greater than current or anticipated market mix) of vehicles needed armrests. Also, until the proportion of vehicles needing armrests reached nearly ½, the main assembly line was still never stopped due to temporary starvation.

Accordingly, study of this system directed attention next to the possibility of eliminating one operator. Since operators X and Y had markedly lower utilizations than operator Z, the next scenario examined the effect of consolidating their work into one hypothetical operator XY (actually the original operator X) who requires two seconds to walk from work location X to work location Y (or vice versa), while operator Z's work duties remain unchanged. Results appear in Tab. 2 (Appendix) for observed levels of main assembly line downtime. These results show that:

1. Utilization of the newly consolidated ("XY") operator improves markedly, while the utilization of operator Z remains essentially unchanged.
2. Overall throughput remains essentially unchanged.
3. The process retains its ability to avoid stoppage of the main line even if 70% of the vehicles require armrests.

Next, as was done for the base case scenario, this one was run under the "stress" assumption that the main line never pauses for downtime. Under this condition, the subassembly line remains capable of not starving the main line until nearly 50% of the vehicles require armrests.

The client then requested exploration of the alternative "only one operator is used, and this operator requires two seconds to walk between work location X and work location Y, two seconds to walk between work location Y and work location Z, and four seconds to walk between work location X and work location Z (walk times again symmetric)." Results of this scenario are shown in Tab. 3 (Appendix) for typical main assembly line downtime rates. The single operator would be barely able to support the main line without interruption under current conditions, but would become unable to do so under either a slight increase in percent of vehicles needing armrests and/or a slight decrease in main line downtime. Indeed, a check similar to the ones undertaken above proved that if the main line downtime were hypothetically removed, the single operator could not support the main line without stoppages.

Accordingly, the client decided (successfully, in retrospect) to reassign one operator to other work and reallocate the subassembly line work to operators "XY" and Z. During discussions of this proposal with the client, it was confirmed that the operators' skill mixes were broad enough, and the skill demands of operations X, Y, and Z similar enough, that no degradation of quality in the final product appeared. Hence, neither an increase in workload at downstream inspection stations nor a decrease in customer satisfaction occurred.

Toward the close of this project, discussions and investigations with the client also addressed the question "What if the seat volume and/or variety demanded collectively by our customers were to increase sufficiently to overload the newly reassigned operators?" As United States businesspeople often say colloquially, "This would be a good problem to have" – but the client needed to be prepared. Experimental runs with the model, incorporating both the reassignment of operators and the hypothetically increased market demand, were therefore made and analyzed. These runs provided the client with highly comforting thresholds (presented as a [highly confidential] summary of contingency) indicating at what points of demand increase an operator would need to be "hired back" to the operations in question. Therefore, client management consolidated the operator assignments, as described above, secure in the existence in a well-defined "path of return."

Viewing this project from a broader perspective, it accomplished additional goals. It helped draw local business managers' attention to the capabilities of simulation and the benefits of collaborations with the university and its allied consultants. Additionally, the project invested in the experience level of industrial engineering students soon to enter the labor market as industrial engineers [14].

6 Acknowledgments

The authors gratefully acknowledge the help of project participant Kathryn Peacock; colleague, industrial engineer, and project leader Marcelo Zottolo, of PMC; and the suggestions of anonymous referees which contributed greatly to the clarity and presentation of this paper.

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8 Appendix

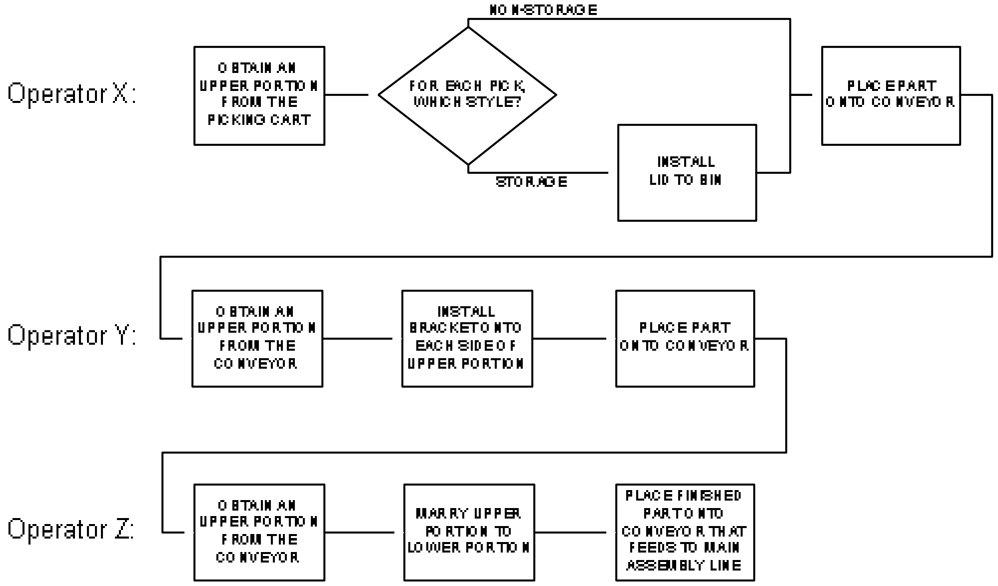

Fig. 1 Armrest Subassembly Manual Operations

% Main Line Vehicles Needing Armrest	Resource Utilizations			Five-Day Production Count	Starvations at Main Assembly Line in Five-Day Run	
	Operator X	Operator Y	Operator Z		Number of Stoppages	Average Duration
20%	87%	16%	25%	5030	0	0
30%	12%	24%	38%	5043	0	0
40%	16%	32%	50%	5047	0	0
50%	19%	39%	62%	5035	0	0
60%	24%	48%	75%	5067	0	0
70%	28%	56%	88%	5091	0	0
80%	31%	63%	99%	5021	1161	0.8 minutes

Tab. 1 Key Performance Metrics for Base Case

% Main Line Vehicles Needing Armrest	Resource Utilizations			Five-Day Production Count	Starvations at Main Assembly Line in Five-Day Run	
	Operator XY	Operator Y	Operator Z		Number of Stoppages	Average Duration
20%	23%	---	25%	5034	0	0
30%	35%	---	37%	5043	0	0
40%	47%	---	50%	5038	0	0
50%	59%	---	63%	5034	0	0
60%	71%	---	75%	5065	0	0
70%	83%	---	87%	5028	0	0
80%	93%	---	99%	5016	821	0.8 minutes

Tab. 2 Key Performance Metrics for Operators X and Y Consolidated

% Main Line Vehicles Needing Armrest	Resource Utilization			Five-Day Production Count	Starvations at Main Assembly Line in Five-Day Run	
	Operator XYZ	Operator Y	Operator Z		Number of Stoppages	Average Duration
20%	47%	---	---	5062	0	0
30%	73%	---	---	5057	0	0
40%	94%	---	---	4998	97	1.7 minutes
50%	100%	---	---	4154	1313	1.7 minutes
60%	100%	---	---	3446	1831	1.9 minutes
70%	100%	---	---	2957	2007	2.0 minutes
80%	100%	---	---	2582	2057	2.1 minutes

Tab. 3 Key Performance Metrics for All Operators Consolidated