DEVELOPMENT AND USE OF A GENERIC AS/RS SIZING SIMULATION MODEL

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ABSTRACT

As usage of simulation analyses becomes steadily more important in the design, operation, and continuous improvement of manufacturing systems (and historically, manufacturing was the sector of the economy first eagerly embracing simulation technology), the incentive to construct generic simulation models amenable to repeated application increases. Such generic models not only make individual simulation studies faster, more reliable, and less expensive, but also help extend awareness of simulation and its capabilities to a wider audience of manufacturing personnel such as shift supervisors, production engineers, and in-plant logistics managers.

In the present study, simulation consultants and client manufacturing personnel worked jointly to develop a generic simulation model to assess in-line storage and retrieval requirements just upstream of typical vehicle final assembly operations, such as adding fluids, installing seats, emplacing the instrument panel, and mounting the tires. Such a final assembly line receives vehicles from the paint line. The generic model permits assessment of both in-line vehicle storage [ILVS] requirements and AS/RS [automatic storage/retrieval system] configuration and performance when designing or reconfiguring vehicle paint and/or final assembly lines. The AS/RS is the physical implementation of the ILVS. These assessments, at the user's option, are based upon current production conditions and anticipated future body and paint complexities.

1. INTRODUCTION

Manufacturing systems represent perhaps both the most frequent and the oldest application areas of simulation, dating to at least the early 1960s (Law and McComas 1998). Questions asked of a simulation model now go far beyond "Will the manufacturing system reach its production quota?" [often expressed as "JPH" = "jobs per hour]. With ever-sharpening competition driving management demand for *lean* efficient operation (2010), simulation analyses are now being called upon to not only achieve production quotas, but also to minimize inventory (both in-line and off-line) and the time and resources to access that inventory whenever necessary.

Furthermore, the accelerating pace of change, often driven by both fickle marketplace demands and by competitive pressures, have increased interest, on the part of both managers and production engineers, in the availability of generic adaptable simulation models. These models, when feasible, represent attractive improvement relative to "We wish the world would stop evolving while we await the building, verification, and validation of a custom-built simulation model for answering our pressing questions." This interest is hardly new – the software tool "GENTLE" [GENeralized Transfer Line Emulation], which allowed quick study of a common type of automotive manufacturing line via a model built in GPSS (Schriber 1974), dates back nearly two decades (Ülgen 1983). As the attractions of such generic models become more widely known, their development is becoming more frequent. For example, (Legato et al. 2008) describes the development and use of a generic model for the study of maritime container terminals. Still more recently, (Zelenka and Hájková 2009) describes the development and use of a generic model for the study of road traffic.

The generic model described here permits examination of the ILVS capacity requirements interposed between the paint line and the final assembly line within vehicle assembly plants. Such examination demands high flexibility relative to volatile production conditions, future market demand, and particularly variations in vehicle resequencing. Vehicles typically exit the paint line in a sequence very different from that anticipated by the final assembly line operators. Perhaps shockingly, occasionally fewer than 5% of the

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vehicles arriving at final assembly are in "correct" (i.e. expected) sequence. Therefore, the ILVS must be capable of short-term storage so the operator can shunt one vehicle aside to attend to another arriving later but originally expected earlier. We first provide details of the project objectives and the key performance metrics to be tracked each time the generic model is used. Next, we describe the methods of obtaining and cleansing input data for a typical scenario using the model. Next, we describe the structure of the generic simulation model itself. Last, we show the results from a typical application of this model, and indicate directions for future work and enhancements to the model.

2. PROJECT CONTEXT AND OBJECTIVES

The goal of this simulation study was quantitative assessment of the in-line storage requirements between the paint line and the downstream final assembly line in the automotive manufacturing process. Ideally, vehicles exit the paint line in strict accordance with a previously planned production sequence. This ideal sequence is determined by production scheduling engineers using a standard optimization program. This program minimizes (almost always succeeds in setting to zero) the number of violations of long-standing production rules. Examples of these rules are "Avoid scheduling two moonroof-equipped vehicles consecutively" or "Avoid scheduling two vehicles with identical engine-powertrain configurations consecutively." If this optimized sequence could actually be maintained in production practice (veteran production managers in the industry might cynically grumble "Perhaps on some distant planet."), these storage requirements would remain at or near zero – the right parts for the exiting vehicle next in line would themselves be next at the assembly line. For example, the seats poised to be installed in the vehicle would be the correct seats for that vehicle type and paint color. In actuality, due to inevitable production plan changes (such as revisions to the proportions of different models demanded by the marketplace) and other transient problems in the paint shop (and indeed in other operations upstream of the paint shop), vehicles never arrive in the originally planned sequence. This simulation study sought to examine, relative to various performance metrics, the extent of ILVS needed to install the right parts in vehicles at assembly, and the amount of labor needed to access those parts from the storage. The client and consultant managers reached consensus that the model would be generic in that it could accept data from typical automotive plants having body, paint, and final assembly in that order, as almost all such plants do. Such plants, when run at fewer than three shifts per day, will inevitably have non-zero storage requirements even in the limiting case, mentioned above, when no sequence changes occur. Therefore, the model developed is also generic in the sense that it can readily be run with no sequence violations but on one or two shifts, thereby allowing client engineers and managers to assess "background" storage requirements.

To introduce and explain these metrics, let us consider the situation in which vehicles originally scheduled in order 1, 2, 3, 4, 5 leave the paint shop in order 1, 4, 5, 2, 3. A vehicle is considered "in sequence" if its sequence number exceeds that of all vehicles which have preceded it. In this example, the first 3 of the 5 vehicles are in sequence, giving a "percent in sequence" of 60%.

Now, let us consider the actions of the worker, at a specific workstation, responsible for installing the front passenger seat (one of the four seats per vehicle) relative to the stored parts when vehicle 4 arrives. Each front passenger seat comes from a separate storage rack – and these seats arrived from a supplier in a specified sequence. For example, the supplier received advisory "A white seat must be first, then a gray one, then a dark blue one, in accordance with our planned production schedule." When vehicle 4 arrives, the operator must remove the front passenger seat intended for vehicle 2 and the front passenger seat intended for vehicle 3 from the appropriate racks , and set them aside (in the "set-aside rack"). The "set aside" metric is then 2. This incremental work for the operator (an occasion of moving parts around, which is muda [non-value-added activity]) represents one "dig." By contrast, installing the seats in the recently painted vehicle is a value-added activity. Relative to this dig, the operator removed 2 seats from each storage rack (for example, he or she removed front passenger seats for vehicles 2 and 3 to access ("get at") the front passenger seat for vehicle 4. Hence, this dig has a "dig depth" of 2. The set-aside metric and the dig depth metric are closely correlated with the "spread" of the sequence – the maximum difference between sequence numbers of adjacently arriving vehicles. In this arrival sequence 1, 4, 5, 2, 3; the spread is 3 (between vehicles 1 and 4).

In this context, this simulation study sought to specify the proper ILVS size (vehicle capacity) relative to current and anticipated production conditions, particularly the amount of "complexity" – the product of the number of vehicle varieties and the number of paint color choices. Additionally, the study investigated two key in-transit production times:

1. Time-in-system vehicles spend between match-point (the milestone in body-&-assembly (upstream of painting) where a vehicle receives its vehicle identification number [VIN] and all its features are defined, and hang-to-paint (where a vehicle leaving body-&-assembly is suspended from a conveyor-carried hook and carried into the paint shop)
2. Time-in-system vehicles spend between hang-to-paint and entry to the AS/RS constituting the ILVS, at which time they are painted and await final assembly.

3. INPUT DATA – SOURCE AND CLEANSING

One of the most vital, though often unheralded, phases of any analytical simulation project is obtaining (and equally important, checking and cleansing) the input data required (Williams 1996). In this project, the existing process already had equipment installed for extensive data collection. Accordingly, the data necessary to build and validate (after verification) this model came from a database which automatically recorded more than a dozen date/time stamps on each vehicle passing through the process. These data, pertaining to approximately 11,000 vehicles, each identified by its VIN [vehicle identification number], were obtained from the database. The data were uploaded first to a large Microsoft Excel® workbook. There, the data were cleansed by visual inspection, by using Excel®'s data validation techniques, and by inspecting a variety of quickly and easily generated plots. Once ensconced in Excel®, the data could readily be input into the simulation model to control arrival times and/or for use in validating the simulation model against actual production.

As an example of important information obtained from these data, Figure 1 (Appendix) shows the empirical distribution of transit times between the body-&-assembly match point and entry into the ILVS AS/RS system between the painting and final assembly operations. These data are strongly positively skewed (right-skewed): although fewer than one-sixth of the observations are greater than 20 hours (performance goal), the mean time is 17.2 hours and the maximum time 41.1 hours. The 20-hour threshold (elapsed time from match point to completion of painting should not exceed this value), chosen by high-level production management of the client company, represents an attempt to keep the AS/RS inline storage requirements small. When this transit time exceeds 20 hours, excessive AS/RS capacity represents a palliative for inefficiencies in the body and/or the paint operations.

4. SIMULATION MODEL CONSTRUCTION, VERIFICATION, AND VALIDATION

After discussion of alternatives, client personnel and the simulation analysts agreed on the use of the SIMUL8® simulation software tool (Hauge and Paige 2001) to build the model. Like its numerous competitors, SIMUL8® provides built-in constructs for the modeling of buffers and conveyors, both of significant importance to this model. Figure 4 (Appendix) is a screen shot of this model. Furthermore, this tool affords convenient importation of large blocks of data from Excel® workbooks. After examination of sample data, appropriate distributions (usually exponential or Erlang) were chosen for process times using a distribution fitter – a specialized software tool which examines an empirical data set and chooses a suitable statistical distribution for its characterization (Law and McComas 2002).

Verification and validation of this model used traditional techniques. These techniques included informal inspections and walkthroughs among the model developers, step-by-step execution while watching the animation, removing all randomness from the model temporarily, allowing only one entity into the model, and directional testing (Sargent 2004). After errors (e.g., mismatched time units at various points of the model) were corrected, the model achieved agreement within 5% of typical plant experience, and specifically with reference to the key performance metric of "elapsed vehicle time between match point in body & assembly to entry into the AS/RS." Hence, the model achieved credibility among client management.

5. RESULTS

The major usage first made of the model was relative to achievement of the AS/RS performance goals established by plant management. These goals specified that the AS/RS must be of sufficient size (but not unnecessarily large) to achieve the performance metrics summarized in Table 1.

Table 1. AS/RS Performance Metric Goals

% Vehicles in Sequence	No less than	98%
Vehicle set-asides	No more than	10
Dig depth	No more than	5
Digs/100	No more than	2

The model was repeatedly run with the current complexity level (220) and the hypothesized AS/RS capacity increased by one unit at a time, beginning at 350. Runs were made on a steady-state basis with warm-up time 2880 minutes (48 hours, equivalent to one calendar week at the plant) and simulation time 20,000 minutes (about seven weeks calendar production time). Graphical results of particular importance are shown in the Appendix (Figures 2 and 3). These runs demonstrated that the minimum acceptable capacity for the AS/RS, at current complexity levels, was 365 units. Since the client specified most production parameters (e.g., cycle time, BIW complexity), sensitivity analyses were not performed.

Table 2 below, shows detailed results of 15 distinct replications, with a different random number stream generator used for each replication.

Table 2. Detailed Results of Fifteen Replications

Min. Fill Level	% in Seq. (ASRS Out)	Max. Set Aside	Max. Dig Depth	Digs/ 100
386	98.01%	8	2	1.98
393	98.00%	7	2	1.99
391	98.03%	7	2	1.96
391	98.04%	7	2	1.95
390	98.00%	8	2	1.98
389	98.00%	8	2	1.98
392	98.03%	8	2	1.96
393	98.04%	9	2	1.94
393	98.04%	8	3	1.95
391	98.01%	8	3	1.98
391	98.04%	8	2	1.95
392	98.02%	8	2	1.97
392	98.01%	9	2	1.98
393	98.00%	9	3	1.98
391	98.03%	9	2	1.96

6. CONCLUSIONS AND FUTURE WORK

In the future, the complexity level will surely change periodically. Since this level depends heavily on marketing plans, production managers will have reasonable (several weeks or months) notice, during which operational parameters may be adjusted. Using this model, these managers will be able to insert a new complexity level and determine an updated AS/RS capacity requirement. With this comforting capability in reserve, managers in the client company have come to embrace the "simulate earlier" exhortation as enunciated within (Ball and Love 2009).

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SRINIVAS RAJANNA, CPIM, is a Senior Manager with over fourteen years of experience in simulation, lean, production, process improvement, six-sigma, theory of constraints, supply chain, and managing projects. He was graduated from Bangalore University with a Bachelor of Engineering in Mechanical Engineering. He holds a Master's Degree in Industrial Engineering from West Virginia University and an MBA from The Eli Broad Graduate School of Management, Michigan State University.

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APPENDIX

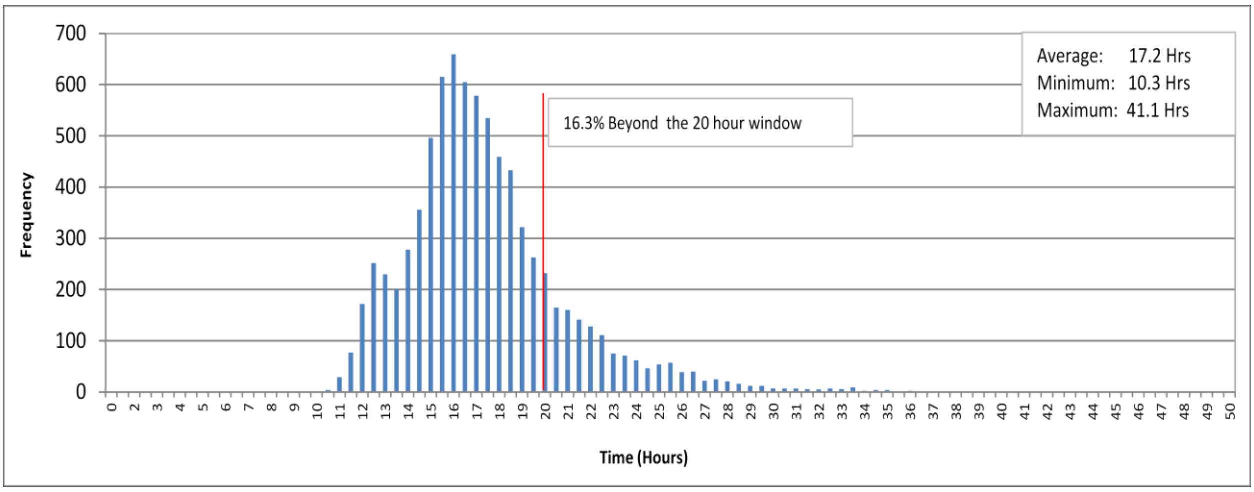

Figure 1. Distribution of In-Process Times Between Match Point (in Body-&-Assembly) and AS/RS Entry

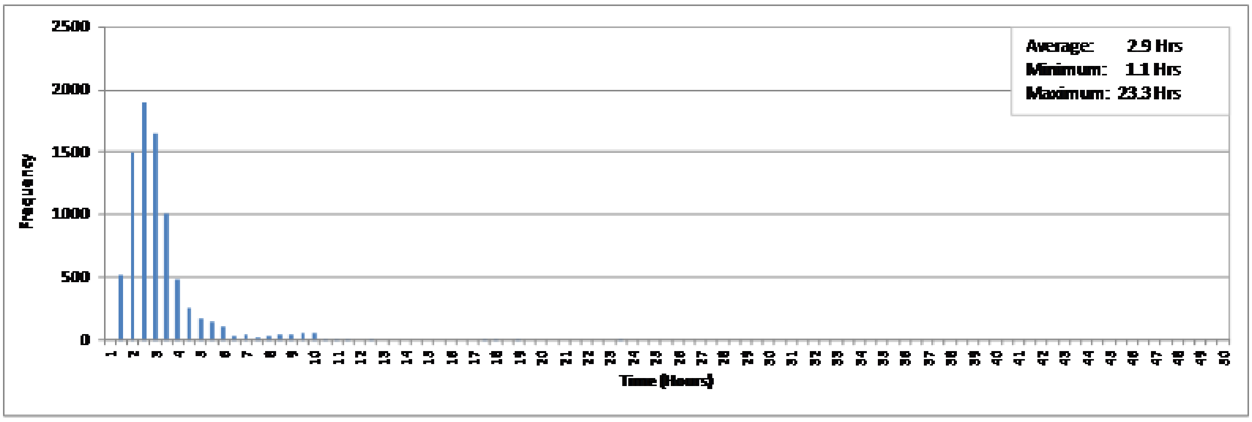

Figure 2. Distribution of Time-in-System from Match Point to Hang-To-Paint

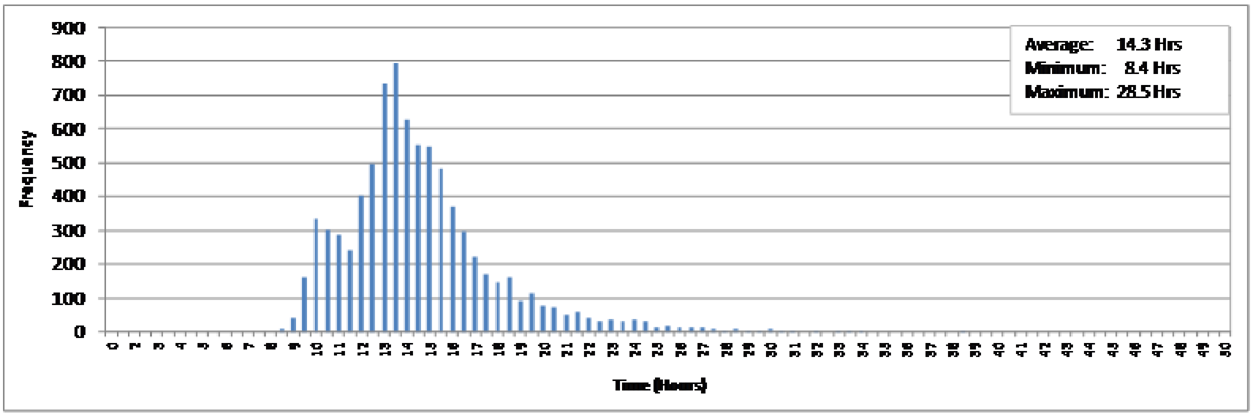

Figure 3. Distribution of Time-in-System from Hang-To-Paint to Entry into AS/RS

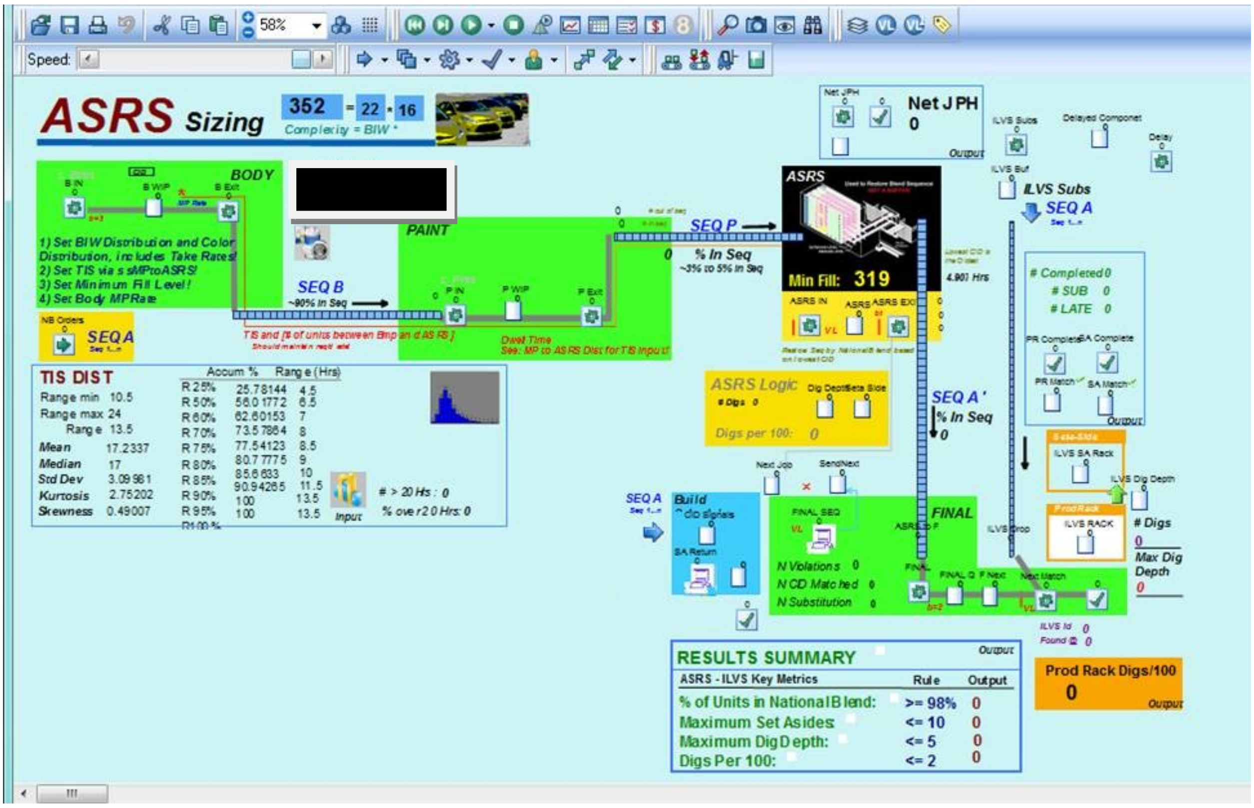

Figure 4. Screen Shot of SIMUL8® Model