THE ROLE OF SIMULATION IN DESIGN AND OPERATION OF BODY AND PAINT SHOPS IN VEHICLE ASSEMBLY PLANTS

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ABSTRACT

The paper discusses the use of discrete-event simulation in design and operation of body and paint shops in North American Vehicle Assembly Plants. Two broad classifications are given on the use of simulation in body and paint shops. First classification is based on the stage of development of the system. Four categories are observed in this classification. Namely: conceptual design phase, detailed design phase, launching phase, and fully operational phase. Second classification of the use of simulation in body and paint shops is based on the nature of the problem investigated. Four categories are also observed in this classification which are equipment and layout design issues, issues related to variation management. product-mix sequencing issues, and other operational issues. In this paper. The classification is described in detail and three case studies are provided to demonstrate the use of simulation in selected problem areas.

INTRODUCTION

In this paper we discuss the use of discrete-event computer simulation in design and operation of the body and paint shops in North American car and truck assembly plants. The big three North American automotive Companies (General Motors Corporation. Ford Motor Company, and Chrysler Corporation) currently require all new and modified body and paint shop designs to be verified by simulation modeling before they ire approved for final equipment purchases. In fact, there is a general push in the big three automotive companies that any new equipment purchase or manufacturing line modification costing more than several million dollars should be verified by simulation modeling_before approval. Studies performed in the past are indicators of how useful simulation could be in the design and operation of production systems of all kinds including vehicle manufacturing. Examples can be found in Fox (1991), Graehl (1992), Gupta and Arasakesari (1991), and Jeyebalan and Otto (1992).

One can classify the use of simulation in body and paint shops in two different ways. The first classification is based on the stage of the development of the design of the system. Four categories are observed in this classification, namely; **conceptual design phase, detailed design phase, launching phase, and fully operational phase.** The conceptual phase refers to the initial stage where new methods of manufacturing and material handling concepts are tested by the engineers. Discrete-event simulation QUEST) are the popular simulation tools at this phase. The **detailed design phase** refers to the stage where detailed layout designs and equipment operations are verified for the system. The principle factors considered here include equipment justifications (e.g.. the number of hold tables, power and free carriers, the size of buffers), cycle time verifications (e.g..conveyor speeds, line throughput), line operational and scheduling issues (e.g.. strip logic for ovens and paint booths, repairs. And product mix decisions). Discrete-event simulation packages with 2D or 3D animation capabilities are commonly used at this phase. Among the discrete-event simulation packages, the ones with the built-in detailed equipment features and 3D animation features appear to be the most popular ones used at this stage. The **launching phase** refers to the stage where the plant operates below the designed operational conditions. In some cases, it may cake up to six months for the plant to operate under maximum capacity conditions. Simulation studies done at this stage are generally used to test operational policies (e.g.. operate one of the two paint booths it a time, run each shop for half of the total available time, use different product mixes). Discrete-event simulation packages used at this stage do not require the detailed equipment features or the 3D animation features. The simulators with user-friendly features are the most popular packages used at this phase. Fully operational phase refers to the stage where the plant is operating under full capacity conditions. The simulation studies done at this phase consider factors such as product mix decisions, new product introductions, new operational policies, and line modifications. Simulation packages used at this Phase generally require the same capabilities of the packages used at the launching phase

The second classification of the use of the simulation in body and paint shops is based on the nature of the problem to he investigated. Four major categories can also be identified in this classification, namely; **equipment and layout design issues, issues related to variation management, product-mix sequencing issues,** and **other operational issues.** In what follows, we will discuss in detail how simulation can be used in resolving some of the problems faced by engineers at each of these areas. More specifically, in the **equipment and layout design issues** area, we will discuss the cycle time verification, surge bank locations, buffer size (strip conveyors and sequencing banks) analysis, and conveyor lengths and speeds. In the **variation management** area, we discuss the repair and scrap policies and paint gun spray surge scheduling. In the **product-mix sequencing issues,** we discuss trim line sequencing, body shop sequencing

TABLE 1. APPLICATION AREAS IN BODY AND PAINT SHOPS

		PHASE			
APPLICATION CATEGORY	APPLICATION	1	2	3	4
EQUIPMENT AND LAYOUT	Buffer size analysis	X	X	X	
	Surge bank locations	X	X	X	
	Cycle time verifications	X	X	X	X
	Conveyor lengths and speeds	X	X	X	
VARIATION MANAGEMENT	Test-repair loop analysis		X	X	X
	Scrap analysis		X	X	X
	Paint gun spray purge scheduling		X	X	X
PRODUCT MIX SEQUENCING	Trim line sequencing		X	X	X
	Body shop sequencing	X	X	X	X
	Shift overlap scheduling	X	X	X	X
DETAILED OPERATIONAL ISSUES	Traffic priority management		X	X	X
	Assembly sequencing		X	X	X
	Shift and break scheduling		X	X	X

PHASES: 1. Conceptual Design 2. Detailed Design 3. Launch 4. Fully Operational

shop sequencing, and shift overlap sequencing, trim and final assembly line balancing. In the **other operational issues** area. we discuss the priority assignment at traffic intersections, assembly sequencing, and shift and break scheduling. Table 1 summarizes the different uses of simulation in vehicle assembly plants in a four-by-four matrix format where the cross marks indicate the typical phases(s) where the use of simulation plays an essential role for the particular application area.

CASE 1: CONCEPTUAL DESIGN - BODY SHOP SEQUENCING

Years ago when designers were in the early stages of the manufacturing design phase, sample sketches of manufacturing processes were made based on common industry rules of thumb. These designs were often accepted and put into production. As time passed, these rules of thumb fell short of manufactures needs in terms of quality, reliability, complexity, and increased diversified customer demand. It was at this point that the manufacturing community began to took more closely at discrete event simulation as tool to help them design manufacturing systems for the future.

As manufacturers tried to adapt to the complex demands of both product and manufacturing, more and more of them started using simulation in the conceptual design phase. The conceptual design phase itself, is that phase in which no current manufacturing process currently exists. The entire process is "on the drawing board" and there are no physical systems out into place that will actually manufacture a product. Designers and engineers start with a rough idea of what they want to accomplish. In the process of developing a new manufacturing system, they incorporate into their design the past experience of systems that did not work well and their expectation of what the new system will have to accomplish. The new goal of the manufacturing system is often some process(es) that have never been used before in manufacturing that will allow the manufacturer to be more competitive in their particular market.

Using discrete event simulation in this matter allows designers and engineers to have a “crystal ball” to evaluate their proposed design before further phases of the design concept are attempted. The goal is to achieve a reasonable, if not optimal, system or equation to produce the product(s) they need in the manner they wish to have them built.

In the conceptual phase, many resources for the analysis do not exist. For example, layouts and data may nor exist. Since an actual facility may not exist anywhere it is often difficult to obtain data or layouts from the actual system. In this case, simulation analysts often draw upon their knowledge of similar systems to start the bail roiling. Application engineers often use data distribution rules of thumb or get data from a similar process operation. Even after this is done, analysis may be difficult for the engineers and designers. Often the location of the design is not known. Having no building constraints or floor space constraints, the layout may take on any form or shape. Trying to develop a material handling simulation could be a nightmare It is at this step when the application engineer can still use simulation to help-design the manufacturing system. The engineer will have to develop "equations" for the design layout. These equations will have variables which are currently the unknowns of the layout and design parameters.

Using equations to analyze a particular problem gives the utmost flexibility in the concept design phase. The engineer studies the problem and then tries to simplify the analysis in the initial stages. As the analysis progresses, the equation gets larger and incorporates more variables into it. For example, a situation may arise where the engineer needs to know the amount of buffer space needed in order to meet the demands of a particular system. Normally a study would be done to determine the overall capabilities of the subsystem feeding the jobs and the capabilities of the system being fed. The dynamics of how the two Systems interact becomes important in order to deter-mine buffer requirements. However, the design is still in the conceptual phase. There are no actual systems, space requirements, no material handling constraints, etc. Therefore, it is necessary to estimate the system in general terms and build an equation that would Lake ail those factors into account. Simulation would then be used to demonstrate the interaction between one or more factors in the equation. In this example, the simulation could show how altering a particular variable in an equation can change the model and also suggest a different buffer strategy. The designers could give the constraints to the equation and simulation would evaluate the equation. This allows the engineers and designers to look at the interaction of the variables in the system and make better choices in terms of their manufacturing design.

In order to remain competitive and meet fickle customer demand, a car manufacturer needed the ability to run their body shop so that it could handle three models for a total of 5 styles of cars. The manufacturer needed to design a body shop that could handle so many different products at one time.

The engineers needed to determine how fluctuations in model/style percentages and other model mix factors would effect the throughput capabilities of the process system.

The object of the study was to investigate the effects of the following factors on system throughput:

a) Model mix
b) Sequence of jobs in the system
c) Line balancing with respect to model mix on parallel lines
d) Size of buffers before process stations
e) Cycle time of process stations
f) Reliability of the process stations

It was also desired to develop a parameterized model that would help demonstrate the manufacturing processes sensitivity to these factors.

Using discrete-event simulation, process engineers developed a model that helped define the interaction between the above factors and the throughput of the system. Observing the interactions in this system, helped to build some design factors into the manufacturing system that would allow greater fluctuations in the model/style sequences of the cars.

CASE 2: DETAILED DESIGN PHASE - TRAFFIC PRIORITY MANAGEMENT

Typical body and paint shops in car and truck assembly plants consist of systems or conveyors, either on the floor, overhead, or somewhere in between, that provide transport means either between or within various departments. In several instances, most of these conveyor systems diverge at certain points only to merge again at some later location. Usually, these intersections merge, and diverge points are dictated either by line capacities, production schedules, required throughput rates, or recirculation requirements due to repair or specialized operations. To a large extent, traffic management at these 'meeting points' is very critical in determining whether the entire system makes the required throughput.

Traffic management at these points on one band relates to cycle Lime issues as products or carriers navigate these intersections, merge points, or diverge points. Also of concern relating to cycle times are clearance points, speed-up sections, release points, turntable speeds, conveyor speeds, etc.

On the other hand, traffic management at intersections merge and diverge points also requires studying the assignment of priorities to products or carriers arriving or departing from these points. The issue of priorities arises when several product types (e.g. light truck, medium-heavy truck, heavy-duty truck) or product states (e.g. second color pass or a tutone truck, a light truck requiring minor repair, a truck requiring extensive metal repair, etc.) exist at the same time during a production run of the paint or body shop. This could either be the result of any of the following factors: mixed-batch scheduling, in-line repair and surge facilities, cross-shift production overlaps, or simply intrinsic process requirements. Repair loops are a notorio Usually, a test/inspect station and a repair station are involved in the loop. A part or part carrier is inspected and based on the result of the test and/or the product type is routed to any of generic or specialized repair stations. Aside from their role in generating randomness in the system resulting from these inspections as described (earlier or later) in this paper, the following complication also arises. After repair, the same parts are usually sent back to the same test station for further inspection. Priorities are necessary to determine how these repaired parts are sent back to the test station both in relation to each other and to arriving parts being inspected for the first time. This can help determine maximum allowable failure rates or rest and repair cycle times to prevent the system from choking. Grajo (1992) presents a simplified way of analyzing and modeling these test-repair loops in a simulation model.

Another case requiring priority assignments at intersections and merge/diverge points involve various product types that share some shop lines (e.g. bake ovens) then branch out to their own specialized assembly lines or loops then merge back to another shared facility at a later location along the line. Refer to the following figure:

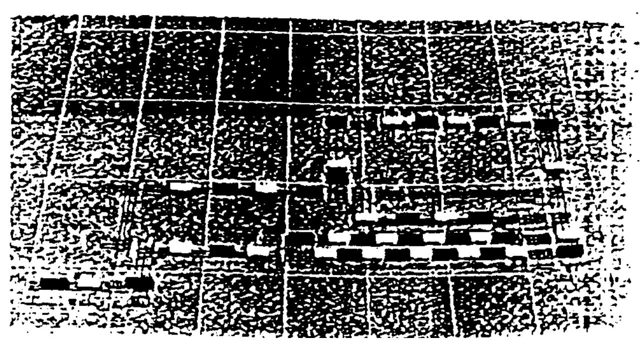

Figure 1: The Conveyor System

Two product types, A and B, share most of this line except for the top loop which is a specialized assembly loop for product B only. While product A bypasses this loop, every arriving product B must go through it. Hourly requirements for the two products vary greatly: 35 for A and 16 for B. While product B can arrive interspersed with product A. it can also arrive in consecutive groups of up to four. The issue at hand revolves around the way product B is allowed to re-enter the main line after going through the dedicated loop. In the initial case, an FCFS (First Come, First Served) rule was used. This means the first arriving part at the location departs first. This, however, increasingly kept units of product A at the short conveyor (immediately after a pair of bake ovens) prior to the re-entry point until the upstream line became consistently blocked. Simulation showed that assigning a higher priority to product A at this point and allowing product B to leave the loop only when another unit of product B enters it provides a better rule that prevented the system from getting blocked.

Simulation can be used to study different priority rules at these intersections and merge/diverge points to avoid costly problems arising from mismanaged traffic flow. General failure to consider critical affecting factors such as product rate mixes, conveyor speeds and lengths, random failure rates, etc. usually lead to such traffic flow problems. Simulation is an effective tool in sorting out these issues and providing simple solutions before

CASE 3: DETAILED DESIGN - BUFFER SIZE ANALYSIS

The paint facility of a typical vehicle manufacturing plant consists of various types of conveyors chat can move a limited number of units of product from one process to another. Such a system has also banks of conveyors that act as buffer areas between various paint operations. The design of such a facility is usually made by using estimates of various critical parameters such as major and minor repair percentages, repair times, scrap rates, and product and paint mixes. In most cases, these estimates represent the mean value of a distribution of values, e.g.. average time to repair and average scrap rate. These mean values are then translated into facility requirements by considering what the available equipment is capable of and what the average requirement is. Consequently, the equipment requirements calculated in this way are accurate only on average. In other words, sometimes such equipment requirement estimates are grossly under what a peak load might be depending on the shape of the load distribution. Since it is rather expensive to build and operate a facility based on worst case scenarios, it is very desirable to be able to evaluate various equipment configurations prior to Finalizing the design.

During the daily operation of a paint facility the production must be scheduled so that shift changes and lunch breaks can be made with a minimum amount of interruption in production. What makes the scheduling of these breaks difficult is that the conveyors running through bake ovens cannot be stopped while there are parts on them. Furthermore, subsequent paint stations should be buffered so that parts coming to a station could be stored during breaks and shift changes. Random fluctuations in the volume of incoming parts also impact the size and location of these buffers. A feasible shift schedule around this constraint can be achieved by a) having buffer areas at key locations and b) interrupting the job flow into the paint facility from body shop for predetermined periods of time. Also, at the end of the day, the facility should be emptied so that there is no jobs left on production conveyors and in bake ovens. Consequently, the following questions must be answered to determine a feasible work schedule:

-What should the size and location of buffer conveyors be?

-When and how long the flow of new jobs should be interrupted?

- When should the buffers be emptied back into regular production flow?

- How should the work schedule be at various stages of the production process? That is, When each process should begin and end during a shift?

- How the shifts can he scheduled to allow sufficient time for cleaning of paint booths?

An examination of these questions indicates that a simulation model could be very instrumental during any phase of the system launch. Selection of location and size of buffers are mostly detailed design phase issues that can be effectively addressed by using simulation. Evaluating changes in shift schedules can be an issue virtually during any of the detailed design, launching, and operational phases. Once the facility is operational, the model can be used to assess the impact of changing product and paint mixes on the daily schedule. In operational phase, simulation can also help to determine additional buffer requirements under conditions which were not considered at the conceptual design phase. A case study involving a simulation model that addressed those issues is given below.

The paint facility of an assembly plant was simulated to determine the size and location of buffer conveyors and a feasible shift schedule. The system studied consisted of the following subsystems: electrocoat/phosphate line, electrocoat oven, sealer lines and sealer gel oven, prime booth and prime oven, main enamel booth and enamel oven, inspection lines, spot repair area, tutone paint booth and tutone oven, and mask and repair lines. The material handling system mostly consisted of roller flight conveyors running through ovens and paint booths, cross-transfer lines, turntables, and power-roll tables. The facility was also interfaced with a high-capacity automated storage and retrieval system (AS/RS), that could be used as a buffer prior to the mask repair, tutone paint, and tutone oven conveyors. Another buffer area was located between the electrocoat oven and the sealer lines. The main components of the system are schematically shown in figure 2.

An initial shift schedule assumed that the enamel system (enamel paint booth and oven) could be emptied to the AS/RS. It was also assumed that the buffer prior to sealer lines would be utilized to flush out the electrocoat oven. The facility would be running two shifts of operation each at 9.5 hours. A simulation model of the system was built and used to evaluate the proposed shift schedule. The results from the -simulation runs indicated several problems with the schedule: First of all, there would not be sufficient time left after the second shift to clean the paint booths. It also showed that in order to make the required throughput, the tutone system (mask lines, tutone paint, and tutone oven) and inspection lines would have to be run without lunch breaks. The schedule also created a potential problem by filling the AS/RS to its capacity.

In general, the results of the first simulation model pointed a need for additional buffer areas within the system to allow breaks and faster flushing of the paint booths and ovens. Based on this conclusion and available space considerations, a second buffer area was proposed for installation at the mezzanine level above the enamel paint booth. This buffer would be used to divert the flow from the enamel paint booth during lunch breaks of both shifts and at the end of the day to flush out the prime oven. After lunch breaks, the flow would resume its normal course by first

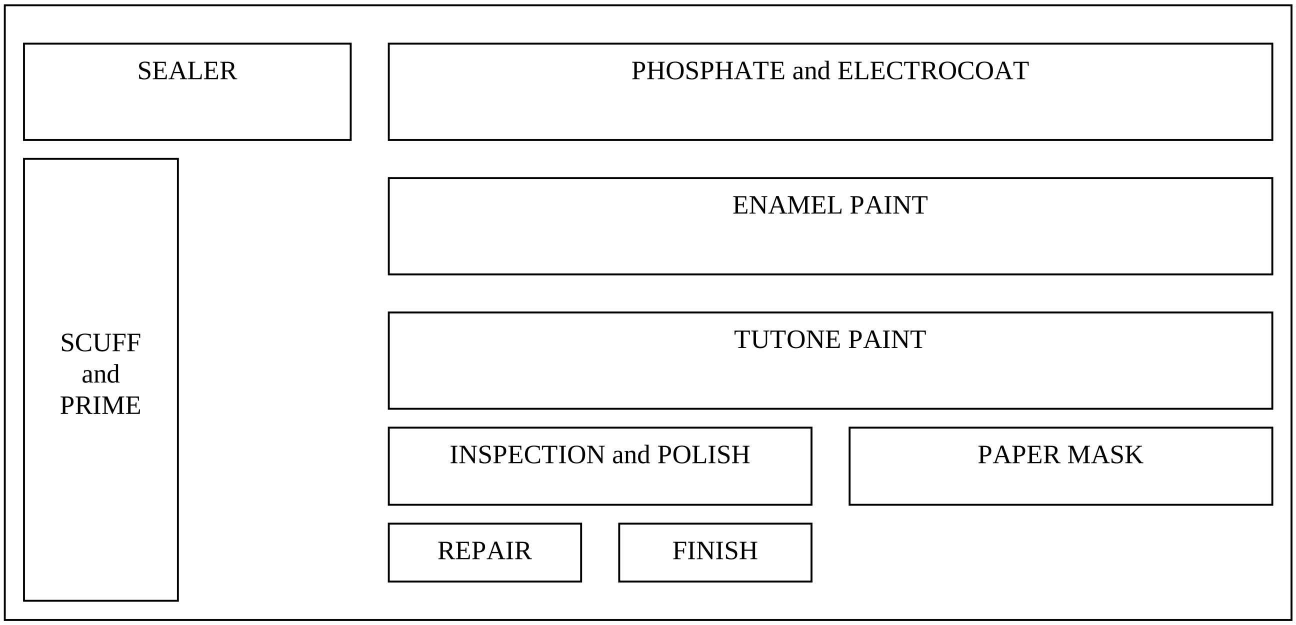

Figure 2: The Vehicle Paint System

emptying the buffer. At the beginning of first shift, the enamel paint booth and subsequent operations could also start earlier than it was possible with the first scenario. The simulation model modified for this new scenario was used to verify that the proposed shift schedule would be feasible with minor modifications.

CONCLUSIONS

Simulation has become an indispensable tool in designing and operating vehicle assembly plants as it has in many ocher production systems. The problems that can be attacked by using simulation arise in all phases of the design and operation cycle. Although these problems depict a great variety in nature, they also show similarities with respect to application areas and the phase of the development cycle. A classification scheme based on those features was developed and presented in the paper. It is expected that such a classification will lay the groundwork for the characterization of simulation models and tools that can be used in addressing those problems. The case studies provided in the paper exemplify the problems and their solutions through the use of simulation technology. An examination of the problem classification and case studies shows that simulation is a technology with many potential applications in vehicle manufacturing plants where return on investment can be highly rewarding.

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BIOGRAPHY

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