PRODUCTIVITY SIMULATION IN THE AUTOMOTIVE INDUSTRY

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ABSTRACT

The paper discusses the role of process and robotics simulation in the automotive industry. Real-world applications of simulation in the body shop, paint shop and general assembly areas of a vehicle assembly plant are given in addition to Business Process Reengineering (BPR) and supply chain logistics applications. Uses of simulation during the different phases of an engineering project are addressed. The phases of an engineering project are identified as the conceptual design, detailed design, launching and fully-operational phases. The specific application issues discussed include material handling, ergonomics, engineering design, scheduling, vehicle launching, supply chain logistics-engineering, and management.

INTRODUCTION

In this paper we discuss the use of discrete-event and kinematics computer simulation in automotive industry. Most of the automotive manufacturers world-wide and, in particular, the big three U.S. based companies (General Motors Corporation, Ford Motor Company, and Chrysler Corporation) currently require all new and modified manufacturing system designs to be verified by simulation analysis before they are 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. (Ülgen et at. 1996) 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. One may classify simulation applications in automotive industry into four major applications areas, namely; (1) applications in vehicle assembly plants, (2) applications in major component plants (e.g., stamping, engine, and transmission plants), (3) applications in small components plants (e.g., electronics, small metal parts, and small parts assembly -alternators, starters plants), and (4) supply chain and logistics applications. Examples pertaining to each of these application areas can be found in (Ülgen and Gunal 1994), and (Ülgen and Upendram 1995). In the following sections of the paper, we first discuss the role that simulation plays in automotive industry by classifying simulation applications in terms of the time-frame in which it is applied during the life cycle of a vehicle program as well as the type of problems it is used to problems it is used to solve. In the following section, we describe the manufacturing simulation applications in automotive industry and case studies that fall into the classifications described previously. Next, we discuss non-manufacturing applications of simulation in automotive industry with a case study on the use of simulation for supply chain logistics. In the final section of the paper, we discuss the importance of model classifications, life-cycle approach to model building, and model archiving as it applies to simulation applications in automotive industry.

ROLE OF SIMULATION IN PRODUCTIVITY IMPROVEMENT

Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and or/evaluating various strategies for the operation of the system. Simulation can be classified into discrete-event, continuous or hybrid type based on the manner in which the model represents changes of state within the system modeled. Simulation has proven to be a cost-effective analysis tool which assists engineers and managers make decisions quicker and reliably. There are a lot of benefits of applying simulation technology for productivity, improvement initiatives, some of these benefits include:

Avoiding Costly Mistakes - Simulation empowers the engineers and managers with a powerful technology to verify and improve the design and operational rules of material handling systems even before their installation. This clearly reduces the inherent risks and enormous costs involved in any automotive project.

Choosing The Right Material Handling System Specific To System - Each automated system problem may have many solutions. The goal is to find the best solution for a given problem. "Best" may be defined in many ways, but it is usually a combination of the cost of the automation and the benefits of applying automation. The phrase "bang for the buck" summarizes this goal. Sometimes a particular material handling technology does not fit your application. Technology designed for another industry may not meet your needs. The old adage "square peg in a round hole" comes to mind. But how do you determine which automation technology, if any, fits your system the best'? Intuition and experience can help, but the more complex the system is, the harder it becomes to explore all the possibilities without a decision support tool. A computer model gives you a "virtual factory" to determine which of the proposed automation technologies best fits your system (Norman, 1995).

Test-bed To Improving Design And Operational Rules And Implement New Systems - Simulation can serve as an "experimental test-bed" to try out new policies and decision rules for operating a system, before running the risk of experimenting on the real system. When new machines or product lines are introduced into a system, a computer model can be used to point out bottlenecks and other problems that may arise during system operation. Similarly, with new systems about which we may have little or no information, simulation can be used to answer “what if” questions in concept and design phases of the project.

Effective Integration With Other Systems - New automation is being added to existing equipment or manual operations. No matter what the integration issues are, all automation components must work well together in order for a project to be successful. A detailed computer model helps determine how well the system components integrate. A model also shows which of the components fall short of performance goals. Getting this information early in the design stage eliminates problems once your system is installed (Norman, 1995).

Providing Valuable Insight - The experience of designing a computer simulation model may be more valuable than the actual simulation itself. The knowledge obtained in designing a simulation study frequently suggests changes in the system being simulated. Simulation of complex systems can yield valuable insights into which components are more important than others in the system and how these components interact. This knowledge may result in a possible new approach or simplified redesign of the system.

Estimating Crucial Parameters - Simulation modeling of an automated system helps estimate crucial parameters such as throughput of the proposed system, number of pallets, carriers or AGVs required, specification of the material handling equipment needed, etc. These parameters help engineers make the right decisions regarding the need for and type of material handling systems required from both an economic and operational point of view.

Experimenting On Model Rather Than Actual System - Through simulation, one can study the effects of certain informational, organizational, and environmental changes on the operations of a manufacturing system by making alterations in the simulation model rather than experimenting directly on the system itself. This enables the analyst to observe the effects of these alterations on the systems behavior before making costly changes on the real system.

Visualization And Communication - The animation provided by 2D and 3D simulation packages make an excellent case for the motto "a picture is worth a thousand words." Visual aids go far in helping to comprehend solutions. Animation helps the engineer visualize and explain the working of a proposed or existing material handling system. The clients, in turn, find it an excellent tool to present their solutions to decision makers and upper management. Animation also helps the simulation model builders verify and validate a complex model visually. Simulation packages such as Quest (Hugan 1995) and AutoMod (Rohrer 1996) have excellent 3D animation capabilities for many material handling systems, and users, aside from designing accurate systems, can also develop quality presentations and involve managers in design decisions.

APPLICATIONS OF SIMULATION IN AUTOMOTIVE INDUSTRY

Manufacturing Applications

Automotive assembly plants typically have three major sections with respect to the stages of the assembly process: Body Shop, Paint Shop, Trim and Final Assembly. Each of these areas has different types of processes with unique features. There are many issues throughout the plant that are effectively addressed through simulation models. The following is a discussion of the typical issues.

The applications of simulation in the design and operation of vehicle manufacturing systems can be categorized in two different ways (Ülgen et at. 1994). 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 packages with 3D animation capabilities are the popular simulation tools at this phase e.g., AutoMod, Quest. 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 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 take 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 at 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 typically 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 as models tend to be at a macro level than a micro level. **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 be 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.** The **equipment and layout design issues** include typical problems such as location of departments and equipment, cycle time verification, identification of surge bank locations, buffer size (strip conveyors and sequencing banks) analysis, and conveyor length and speed determination. It should be noted that, in addition to simulation the use of layout analysis tools such as LayOPT (Grajo 1996) and FactoryFLOW (Sly 1996) have proven to be very effective in solving the facility layout design problems. The typical problems in the **variation management** area are repair and scrap policy analysis, order size variation, and paint gun spray surge scheduling. The **product-mix sequencing issues** typically include trim line and body shop sequencing, shift scheduling, and trim and final assembly line balancing. In the other operational issues area, typical applications involve priority assignment at traffic intersections, assembly line sequencing, and shift and break scheduling. Table 1 summarizes different uses of simulation in vehicle assembly plants in a matrix format where the crosses indicate the typical phases(s) that the use of simulation can play an essential role for the particular application area. The crosses in the table indicate only where certain types of problems are more likely to be attacked by the designers or managers. For example, cycle time verification problems are more likely to happen at earlier stages of the design and operation cycle.

TABLE 1: APPLICATION OF SIMULATION IN THE FOUR PHASES OF AN UTOMOTIVE PROJECT

APPLICATION CATEGORY	EXAMPLE APPLICATION	PHASE			
		Conceptual Design	Detailed Design	Launch	Full Operation
EQUIPMENT AND LAYOUT	Buffer size analysis	X	X	X	
	Surge bank locations	X	X	X	
	Cycle time verification	X	X	X	X
	Conveyor length and speed	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
DEATILED OPERATIONAL ISSUES	Traffic priority management		X	X	X
	Assembly sequencing		X	X	X
	Shift and break scheduling		X	X	

However, shift scheduling problems are likely to be solved once all equipment and layout design issues are finalized. It should be noted, however, that the table constitutes only a broad framework since. in reality, each type of problem area can be attacked in any phase of the design cycle.

Case 1. Simulation In The Design Of A Body Shop

SUMMARY: This simulation study involved modeling and analysis of skid movement on roller flight, production, power and free, and cross transfer conveyors in a new body shop. The model was used to verify if the body shop would meet the required production rate. Additional studies determined the shift timing necessary to coordinate production with the paint shop, and determined the minimum stock required in individual surge areas to maintain continuous production.

SYSTEM DESCRIPTION: The simulated facility consisted of 2 power and free conveyors, 14 roller flight conveyors. 5 production conveyors, 20 cross transfer conveyors, and 50 power roll conveyors.

PROBLEM: The automotive plant is expanding to increase capacity of light trucks. A new light truck body shop will be built. Will the proposed design meet the capacity requirements? Additionally, the existing medium/heavy paint shop will also paint the light trucks in the first and second shifts until a new light truck plant shop is built. Can the light truck body shop build up a large enough reserve of trucks in one shift to allow the paint shop uninterrupted production in both shifts?

OBJECTIVE: The objective of this study was to determine if the new body shop could meet the required production rate in phase 1, when the existing paint shop would paint the trucks, and in phase 2, when a new light truck paint shop would paint the trucks and a higher production rate would be necessary.

SOLUTION: The study determined that the proposed design did meet the required production rate in both phases of production. In phase 1, coordination of the shift schedule between the body shop and the paint shop was necessary for the body shop to build up a large enough reserve of trucks for the paint shop to paint in the second shift.

SAVINGS: The proposed design can be built with much greater assurance that it will work correctly. Correct coordination of shifts between the body shop and

Kinematics or Robotics Simulation Applications

Robot applications are becoming more and more widely used in industries from manufacturing to health care. The most common utilization of robots are in the manufacturing. Main areas of robotics applications in the automotive industry include: arc and spot welding, painting, material handling, assembly, testing and inspection, numerically controlled machines, and telerobotics. Space and environmental programs also make use of robotics applications. There also seems to be a strong trend in increased use of robotics in all of those industries. Consequently, there is going to be a stronger need for effective analysis and design tools for successfully applying the technology. With its flexibility to address a wide range of design and operational problems in robotics applications, the simulation technology proves to be an invaluable tool. Some of the commonly used software include IGRIP from Deneb Robotics, ROBCAD from Technomatix Technologies, CimStation from SILMA and Workspace from RWT. All of these can display a workcell in BLVD graphics. They also provide inverse kinematics calculations to facilitate a wide range of analyses on robotics systems such as robot selection, robot placement, reaching capability assessment, and interference checks.

Robotics simulation applications can be categorized into four areas:
(i) **conceptual design and presentation** applications, where a proposed or existing system is modeled for demonstrating a concept, marketing, training, or documentation of different designs. A typical simulation in this category consists of machines, robots, robot tools, jigs and fixtures, material handling devices, and human operators.
(ii) robotics workcell design applications involve mostly engineering applications. Designing and evaluating the layout of a workcell, designing tools and fixtures, eliminating colliding motion paths, optimizing robot movements, and cycle time assessment and task allocation are among the typical uses of robotics simulation models.
(iii) off-tine programming, Once an accurate model of a workcell is created, it is possible to develop programs for the robots. Those programs

can then be downloaded to the robot controllers on the floor eliminating the need for teaching by using a pendant.

(iv) integrated simulation with ergonomics and discrete-event simulation. An assembly line simulation can determine a time window for the cycle time which can then be fed to a robotics simulation model for determining the feasibility. On the other hand, a robotics simulation model can help determine the best and worst estimates of the cycle time in a robotics workcell. Those estimates can then constitute a basis for what-if scenarios by using a discrete-event simulation of the entire production line.

Case Study 2. Robotics Simulation Of A Core Assembly System

SUMMARY: The simulation study involved developing a computer simulation/animation model of a proposed process for an automated core assembly operation. The workcell concept, developed in RobCad, was studied for the specified process and material handling equipment for robot placement, reach, gripper design and cycle time. A three dimensional simulation model of the cell was constructed and its operation was demonstrated to upper level management in the form of a short video film. This study was also coupled with a discrete-event simulation analysis of the entire production line.

OBJECTIVE: The robotics simulation model was used to establish the feasibility at workcell level whereas the discrete-event model was used to evaluate the capacity of the overall production process.

SYSTEM DESCRIPTION: The workcell studied consisted of: Two ABB IRB6000 robots, one core making machine, a walking beam to move core packages in and out of the workcell, and two end-effectors to perform the robotics operations. The following parameters and variables (evaluated in the "what if" scenarios) were used in the simulation model: Robot movement parameters such as speed, acceleration, approach speed, movement type (linear, joint, slew), conveyor speed, and various methods of presenting work pieces to both robots

SOLUTION: The workcell layout was evaluated for robot placement by considering work points and cycle time constraints. Robot program's required to complete the operation in the workcell were developed and tested using the RobCad robotics simulation software. A feasible placement for the robot was determined. The results from the cycle time study indicated that with the assumed parameters and the present robot model, the cycle time requirements could be met.

Non-Manufacturing Applications

The non-manufacturing applications of simulation in automotive industry have been concentrated in several support areas including (1) **warehousing and distribution center models, (2) supply chain logistics models,** and (3) **vehicle program development models**. The *warehousing and distribution center models* look at the design and operations of a distribution center or warehouse. A typical automotive parts distribution center may carry more than 250,000 parts which may involve from very small parts (e.g., spark plugs) handling systems to very large parts (e.g.. engines, hoods) handling systems. The design and operational issues looked at include the selection of the proper storage systems, the location of the different storage systems and the receiving and shipping areas in the facility, the selection of the material handling systems, the design and operation of the marshaling systems, sortation systems, picking stations and packaging stations.

The *supply chain logistics models* generally involve flow of parts among multiple plants and warehouse/distribution systems. Generally one or more of these plants are sink plants, warehouses (e.g., final assembly plants), while others are source (e.g., part or component subassembly plants) or both a sink and a source plant (e.g., component subassembly plants). The major criteria in modeling such systems include the minimization of transportation, raw material, parts, subassembly, and finished goods inventories in the chain, flexibility and transportation equipment availability to support JIT scheduling at the sink plants, the minimization of storage containers (e.g., racks) in the system, the distribution of storage containers in the system, and the selection of the least cost transportation/shipping system. The modeling of such systems generally consider each plant/warehouse as a black box with the raw material/part inventory levels consumed as inputs and/or finished goods inventory levels generated as outputs of the plants.

The *vehicle program models* are excellent examples of high-level Business Process Reengineering (BPR) models that one can develop in the automotive industry. In these models one looks at the phases of a vehicle development program (i.e., package/target development, appearance concept release component, fabricate tooling, and build vehicle) and considers concurrent engineering techniques to overlap the phases in order the minimize the total project time and cost. The effects of disturbances (e.g., design changes) on project cost and completion date are evaluated and more robust vehicle development procedures are identified. These models are also used for effective management of resources (e.g., designers, test equipment) when multiple vehicle programs are considered at the same time.

Case Study 3: Design of a Shipping System (Williams and Khoubyari 1996) This case study involved the design of a shipping and distribution system supporting a component-fabrication plant and two automotive assembly plants interconnected by truck lines and railroads. The objectives of the study included the optimization of the inventory levels and distribution of racks (containers) circulating throughout the shipping system, the determination of the sizes of the turnaround areas for truck and rail cargo at each plant, the location of loading docks required at each plant, and the forecast of the annual truck and rail shipping volumes and costs.

One of the assembly plants and the component fabrication plant was located in US while the second assembly plant was located in Mexico. The shipping system comprised of two truck routes and two railroad-yards. The input data required for the model was collected in three categories, namely: general system input data, plant-specific input data, and railroad-yard specific input data. The general system input data included the number of available truck trailers, truck cabs, and racks, the number of components carried by each rack, time required to attach/detach a trailer to/from a cab, time required to load/unload a trailer, truck/train transit times allowing for holidays in US/Mexico, times spent at customs and crossing through time zones, and rates of damage and required repair times for racks and trailers. The plant-specific input included the hours of operation, production rates and schedules, material rejection rate, rack storage capacity for inbound and outbound racks, capacity of staging areas for truck trailers, the number of truck docks and their schedule of availability, and truck travel time from plant to local railroad-yard. The railroad-yard specific input data included the hours of operation of each railyard, inbound and outbound storage capacities at each railyard, loading and unloading times of trains, and train schedules and cutoff times for train departures from each railyard

The study investigated four different types of shipping deployments (a base case and three competing deployment methods) where the parameters included two sizes of truck trailers-14 and 18 rack trailers, fixed capacity racks, and "unit trains" (complete dedication of one train to move the goods of one shipper from one loading point to one unloading point). Table 2 below gives the main results of the study.

Table 2: Starvation Results of Four Scenarios

Scenario in System	No of Racks Plant #1	No of Docks at	No of Instances of Starvations/Year
Base	1699	1	21
1	1299	2	0
2	1055	2	0
3	1030	2	10

These results highlighted the effects of an additional dock at Plant #1 which reduced the number of racks required in the system down to 1055 from 1699. This is a saving of almost one-third of the capital invested in racks in the system. This will further reduce costs of storage and maintenance of racks. The model further predicted the optimal number of truck trailers with full and empty racks at each plant location as well as the average and maximum number of trailers per train. Management implemented Scenario 2 and after eighteen months of actual operation under Scenario 2, all predictions of the simulation model held to within 4% of the actuals.

CONCLUSION

Simulation has become an indispensable tool in designing and operating automotive plants as their cost and competition for productivity increases in such systems. The problems that can be attacked by using simulation arise in all phases of the design and operation cycle of a vehicle development program. 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. It has been observed that in the life cycle of a vehicle program, a simulationist may be involved in building at least four different models of a manufacturing system, namely a conceptual design model, a detailed design model, a launch model, and models for changes during the fully operational phase. The proper archiving of these models can increase the efficiency of simulation model building for a single program as well as the future vehicle programs. The life-cycle approach to simulation model building in automotive industry has a number of prerequisites to be satisfied in order to be successful (Ulgen et. al. 1994a, 1994b). A comprehensive project plan with detailed steps and standardization of models across the vehicle program development phases is the most important factor for successful development of reusable simulation models in automotive industry.

BIOGRAPHIES

Onur M. Ülgen is the President and Founder of Production Modeling Corporation and also 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 the applications of discrete-event and robotics (kinematics) simulation to manufacturing problems, object-oriented simulation program generators, scheduling, and project management.

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