Proceedings of the 1991 Winter Simulation Conference
Barry L. Nelson, W. David Kelton, Gordon M. Clark (eds.)

EFFECTIVE APPLICATION OF SIMULATION IN THE LIFE CYCLE OF A MANUFACTURING CELL PROJECT

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ABSTRACT

Boeing has been using manufacturing simulation techniques for the past several years. In our simulation of an automated floor panel fabrication cell, we have shown how simulation can be used successfully throughout the system development life cycle. This paper presents the role simulation played throughout the system life cycle with special emphasis on fine tuning the cell operations and cell controller scheduling algorithms.

1 INTRODUCTION

Worldwide economic pressures are demanding that American industry be more responsive and produce better quality products more cost effectively. Outstanding companies have adopted a philosophy of "Continuous Improvement" of the products they make and the processes that produce them. Key elements to the deployment of this strategy are redesign of manufacturing facilities along cellular lines and use of a systematic Development and Implementation Life Cycle. The premise of System Life Cycle Planning is that an existing system must be well understood before it is changed or before a replacement system is designed. This systematic approach to development and implementation of technology recognizes that development projects should follow the same steps. The system development life cycle follows from initial concept development to factory implementation and maintenance.

Simulation has proven an effective tool throughout the System Development Life Cycle for Boeing's Automated Floor Panel Workcell, currently in the Factory Implementation phase. Key benefits during each phase are outlined below:

Concept:	Capacity Planning
Requirements:	Evaluation of Vendor Designs
Design:	Design evaluation & enhancement
Construction:	Evaluation of system refinements
Verification & Integration:	Control system optimization
Factory Implementation:	System performance tuning

Simulation proved to be an accurate predictor of manufacturing cell behavior and was a powerful analysis tool to study the many design and operating alternatives.

2 THE SYSTEM DEVELOPMENT LIFE CYCLE

The steps of the Development Life Cycle, shown below, begin at concept definition and carry through needs analysis and requirements definition, preliminary and detailed design, construction, integration, implementation, and maintenance. Understanding and documenting system features, functions and performance are essential to enable successful design of the future system. This means that a significant amount of time and resources must be spent at the beginning of the project prior to any concrete design steps being taken. This is the major difference between Life Cycle Planning and traditional "seat of the pants" project planning, which often jumps into a system life cycle at the Design phase, avoiding significant but necessary front-end costs.

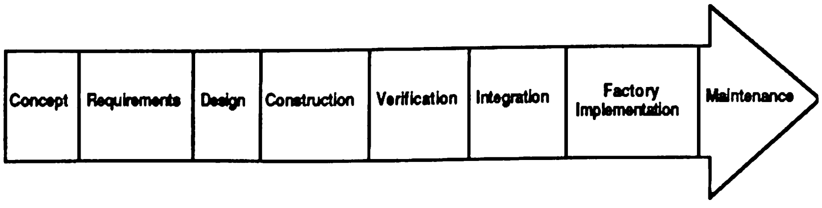


Figure 1. Project Development Life Cycle

3 SIMULATION AND THE SYSTEM DEVELOPMENT LIFE CYCLE AT BOEING

Though simulation has traditionally been a tool to help evaluate alternative design options, more recently it has effectively proven its worth throughout the Development Life Cycle. The development and implementation of a single automated manufacturing cell will illustrate how simulation has positively impacted all phases of the Life Cycle.

4 AUTOMATED FLOOR PANEL CELL SIMULATION

Floor panels are fabricated in the Boeing Fabrication Division and used by the assembly divisions at Renton and Everett. When fastened to floor beams, the panels form the floor of commercial aircraft such as the 737, 747, 757, and 767. The current fabrication process combined precision routing and drilling operations with extensive manual operations such as hand deburring, ditching and applying sealants (potting), attaching fasteners (inserts), masking, painting, and part marking. Because of the large number and variety of parts, order tracking was difficult, flow times were long, and inventory levels were high.

A new conceptual manufacturing design combining automation and centralized cell control promised significant reduction in handling, labor costs, work-in-process, floor space, and flow time. The Simulation Group was asked to simulate the new design to quantify the resources required, determine bottlenecks, and evaluate the new cell's ability to meet design and production objectives.

To give some perspective on the history of the Automated Floor Panel Workcell, the project was started in 1986 and was recently turned over to the shop in April 1991. It is currently producing production floor panels on a limited scale with full scale production slated for 1992. The initial cell design is shown in Figure 2. Upon entering the cell several floor panels are "nested" on a 4' by 12' sheet, periphery cuts made and holes are drilled, and the sheets are moved through automated machines performing functions now done manually. A cell controller performs sequencing and tracking operations and sends each NC machine instructions to perform its operations.

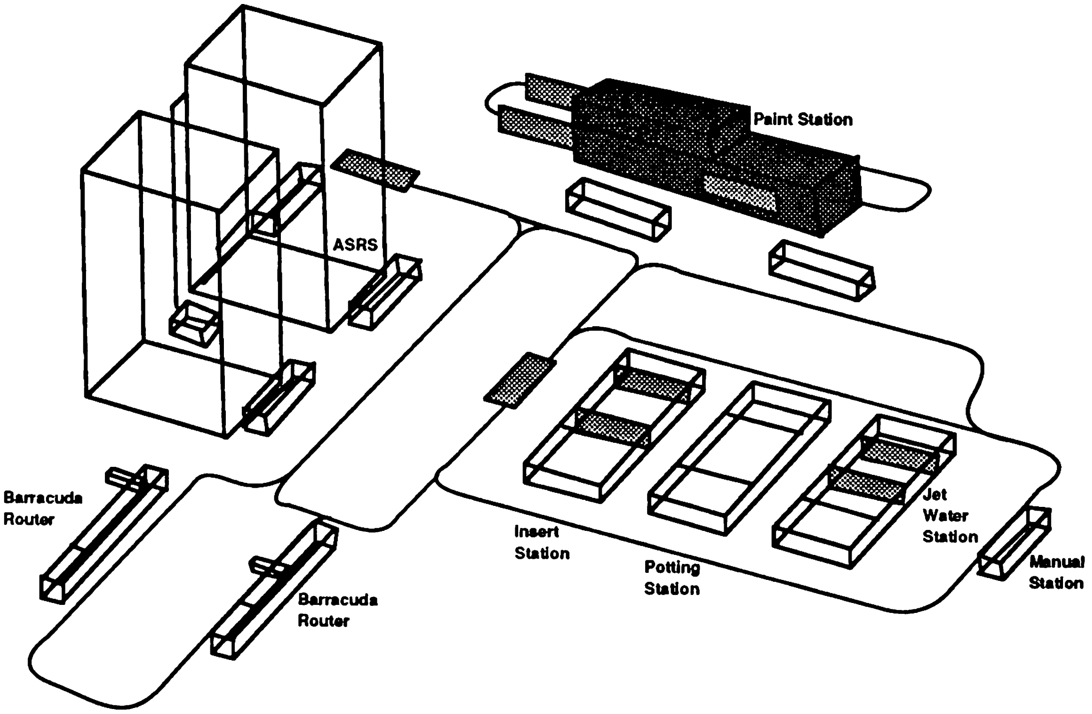


Figure 2. Initial Automated Floor Panel Workcell Design

5 APPLICATION OF SIMULATION THROUGHOUT THE LIFE CYCLE

The Automated Floor Panel Workcell project demonstrates the effectiveness of simulation throughout the life cycle. Traditionally simulation has been successfully used to evaluate and improve designs and as a capacity planning tool. With the Floor Panel project simulation personnel were an integral part of the development and implementation team from the beginning. This arrangement allowed them to provide more than simulation support; they also assisted with writing requirements and specifications, evaluating equipment and system designs, and optimizing control systems. Credibility gained as team members allowed them to more successfully apply simulation. During each phase of the Development Life Cycle significant impacts were made to guarantee project success.

5.1 Concept Definition

During the Concept Definition simulation showed its usefulness by providing quality 3D graphics animations that vividly showed the layout and the cell's dynamic performance. The simulation analyst, because of his experience, made material handling recommendations during initial data collection, making the static physical model obsolete before the first simulation model was developed, see Figure 2. Simulation showed a bottleneck and need for additional capacity for one of the machines. Within a week alternate designs were produced, evaluated, and decisions made. Even at that early date, analysis helped determine the impact of relocating ASRS, using bi-directional AGV's, and determining operating time sensitivity. These models were instrumental in communicating initial designs to prospective vendors and introducing manufacturing shop personnel to the manufacturing methods being proposed.

5.2 Requirements Phase

When the cell Requirements Document and Functional Specifications were released to vendors, video tapes showing the design concept were also provided. AutoSimulations Inc. software was used to simulate and animate the cell operations. During vendor selection, vendor proposals were modeled to ascertain their ability to meet performance specifications. In situations where vendor designs could not meet requirements, alternatives were modeled and design changes were recommended. The turn around time was usually less than a week.

5.3 Design

After vendor selection, the Simulation Group worked with the vendor and project team in the continuous evaluation and improvement of the design. Some fifteen simulation model versions have tracked design changes precipitated by changes resulting from better understanding of system components and control systems or from changes in production requirements. The latest design is shown in Figure 3.

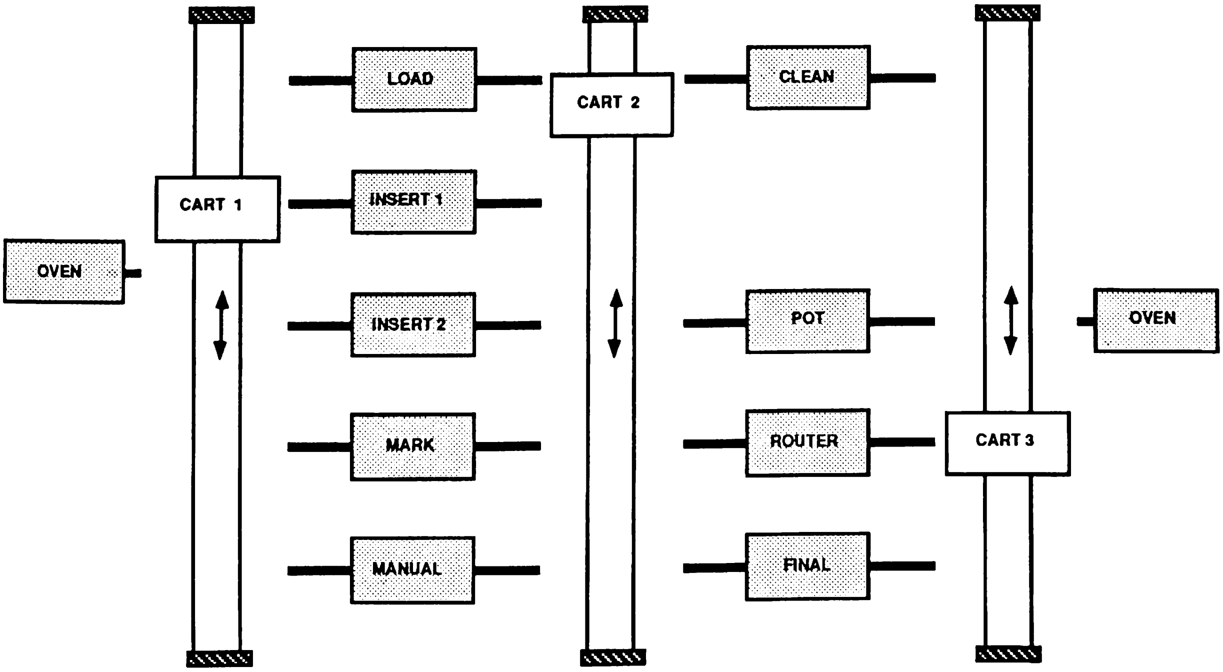


Figure 3. Final Automated Floor Panel Workcell Design

Practical design of mechanical systems resulted in a three-fold increase in panel transfer times from initial estimates; prototype equipment suggested that insert hole-to-hole cycle times could be 6 instead of 10 seconds; other operating times were refined based on the vendor's detailed design; alternate manufacturing flows were also evaluated. Simulation effectively evaluated these impacts and helped ensure that the system would meet the performance goals while balancing load between the three transfer carts. Although initially the curing ovens were integral to the handling system, simulation efforts showed the viability of an operationally simpler alternative with stationary ovens. The number of storage locations in the ovens and carts was also reduced by one third based on simulation results.

5.4 Construction

During the construction phase all operational parameters for the simulation were refined to reflect actual equipment performance. Simulation continuously verified the impact of the changes and evaluated subtle changes and improvements. At this point in the project the demand for Boeing aircraft was reaching record levels. Several expansions of the cell were analyzed due to the projected increase in airplane production rates.

5.5 Verification & Integration

During the verification phase each piece of equipment, the handling system, and the control system were tested to determine if they met requirements in a stand alone mode. During the integration phase overall system performance was evaluated--how well would the cell operate in a production environment? This further refined the simulation operation parameters with most of the emphasis focused on the operation of the cell controller.

Our "first" chance to validate the simulation model came during the Factory Acceptance Test where the operation of the integrated system was tested. The simulation model proved to be an accurate predictor of cell performance. Performance measures such as panels/day, flow time through the cell, capacity of system components, and uniformity of load were used to evaluate a number of control system alternatives.

5.5.1 Cell Controller Optimization

The Cell controller controls all stations and part movement in the automated cell. Its logic determines factors such as cell and individual station queue size, work selection rules and priorities, and raw material loading rules. After initial cell logic was modeled and verified, various improvement strategies were tested to alleviate control system software shortcomings.

5.5.2 Load Strategy/Queue Management

A common argument by production personnel for higher levels of Work-in-process inventory (WIP) is its need to protect capacity in case of equipment failure. To test that hypothesis simulations were run in which for a given level of equipment reliability the WIP levels were varied to determine overall cell production. These were repeated for various levels and durations of downtime. The results, shown in Figure 4, indicate that increasing WIP is only marginally effective in protecting capacity. All cases had similarly shaped curves. At low levels of inventory, downtimes affected cell output, but after a certain level was reached, no amount of WIP could improve output. Interestingly, the frequency and duration of downtimes are more significant than the level. Downtime of 15% was much more disruptive if taken once/week than once/day.

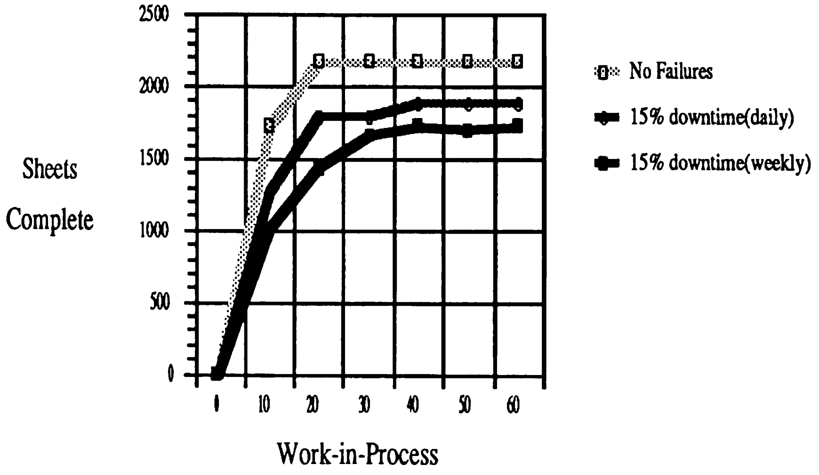


Figure 4. Floor Panel Cell Downtime Analysis

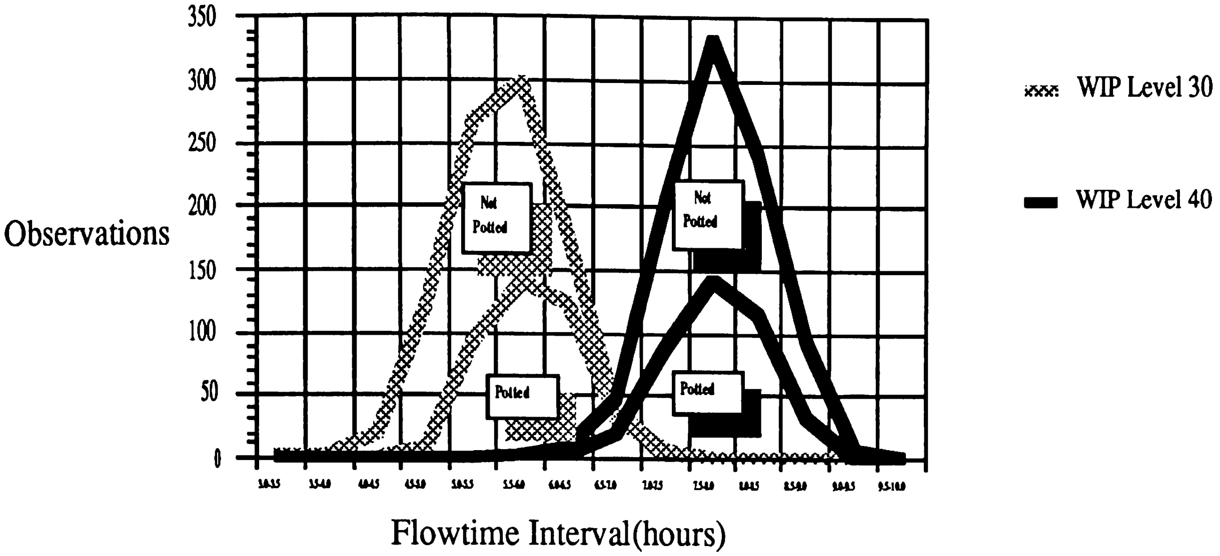


Figure 5. Sheet Flowtime

Higher levels of WIP have a significant effect on flow time through the cell, see Figure 5. When the cell controller limits the total cell WIP to 30 instead of 40 panels, flow time is dramatically reduced.

Simulation was also instrumental in determining how to load sheets into the cell. Allowing the system to empty itself of raw material then loading 10 sheets gave optimal use of the cell operator's time and had no impact on cell throughput. Since the first few operations have reserve capacity, the system easily catches up and fills the downstream queue at the bottleneck station.

Several queue management options were also tested to avoid gridlock should the center transfer cart (see Figure 3) fill. The center cart serves as a queue position for raw material, Insert station (constraint), and Final Router(last operation). The material handling logic dynamically allocated space and limited the queue size for individual stations based system requirements. Additional queue requirements for the Insert station are diverted to other carts.

5.5.3 Scheduling Strategy

System integration tests showed a radical variability in the flow time of panels through the cell. Expected times might range from six hours to two days. This large variability in expected completion times was disruptive and made planning delivery times to downstream assembly operations extremely difficult. An initial scheduling strategy calling for the sheets with the Longest Processing Time waiting at each station to be processed first led to a situation where the first shift's operator had almost no work to do while the second shift worked at twice the pace.

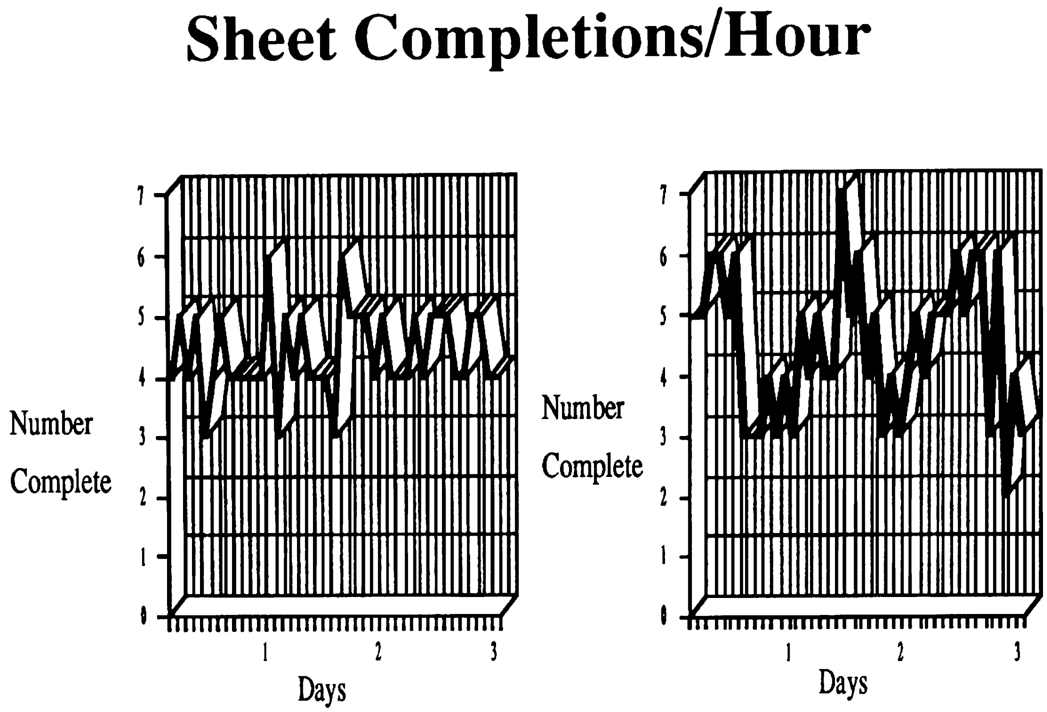
Four alternatives were compared to analyze scheduling strategy:

<u>Strategy</u>	<u>Logic</u>
FIFO Cell	First sheet into cell has priority
FIFO Station	First sheet into station has priority in that station
Longest Process Time First(LPTF)	Longest Process Time sheet at station has priority
Most Complex Part First(MCPF)	Most Complex Part First

The FIFO Cell strategy favored sheets with the greater number of processes. More complex sheets jumped ahead of the less complex sheets at the insert station (constraint) queue because they'd undergone four extra steps prior to entering the insert station queue.

LPTF strategy called for releasing orders and processing the sheet with longest processing time first at each station queue. The effect was that a complex part with potting would be processed first in the early stages of production, but would get continuously bumped at the insert station queue where the potted sheets required fewer inserts. Depending on the order mix, there were wild fluctuations in flow time through the cell.

The MCPF loaded the Potted sheets first (30% of total volume) causing the potting station to become a bottlenect and starving the true bottleneck station(insert stations). To compensate for the starving downstream operations the WIP had to be increased for this scenario to meet production goals.



FIFO Cell Strategy **LPTF Strategy**

Figure 6.

The FIFO Station strategy processed sheets based on a first-came-first-served basis at each station queue and produced good flowtimes with a minimal amount of variance.

Analysis results showed that

- Station queue sizes varied slightly
- Resource utilizations & capacities weren't significantly different
- Peak throughput was the same
- Flow times for various parts varied greatly between options
- Completions/hour variability differed greatly between options

The FIFO Cell alternative dramatically reduced the variability in completions/hour and evenly distributed the load between shifts. The results, see Figure 6, is a much smoother, more predictable manufacturing cell.

Simulation showed the criticality of evenly distributing the load, especially more complex potted panels, through the two-shift operation. Scheduling logic calling for the most complex parts(potted) to all be loaded at the beginning of a shift created a temporary constraint at the potting station, starving the true constraint (Insert station). Distributing that load quickly solved that problem.

Scheduling a third shift on the constraint resource(Insert station) proved a viable way to get additional capacity without additional capital expenditure. Simulation analysis helped avoid gridlock by determining where material should be stored while other stations are not operational.

5.6 Factory Implementation

During Factory implementation simulation has continued its effectiveness in tuning the cell controller. In the Continuous Improvement environment at Boeing overall system performance will fine tuned continuously. Simulation will continue as a low risk evaluator of improvement options.

6 SUMMARY

Simulation was effectively applied throughout the development and implementation of the Automated Floor Panel Workcell. Figure 7 below outlines how simulation benefited the project team throughout the project.

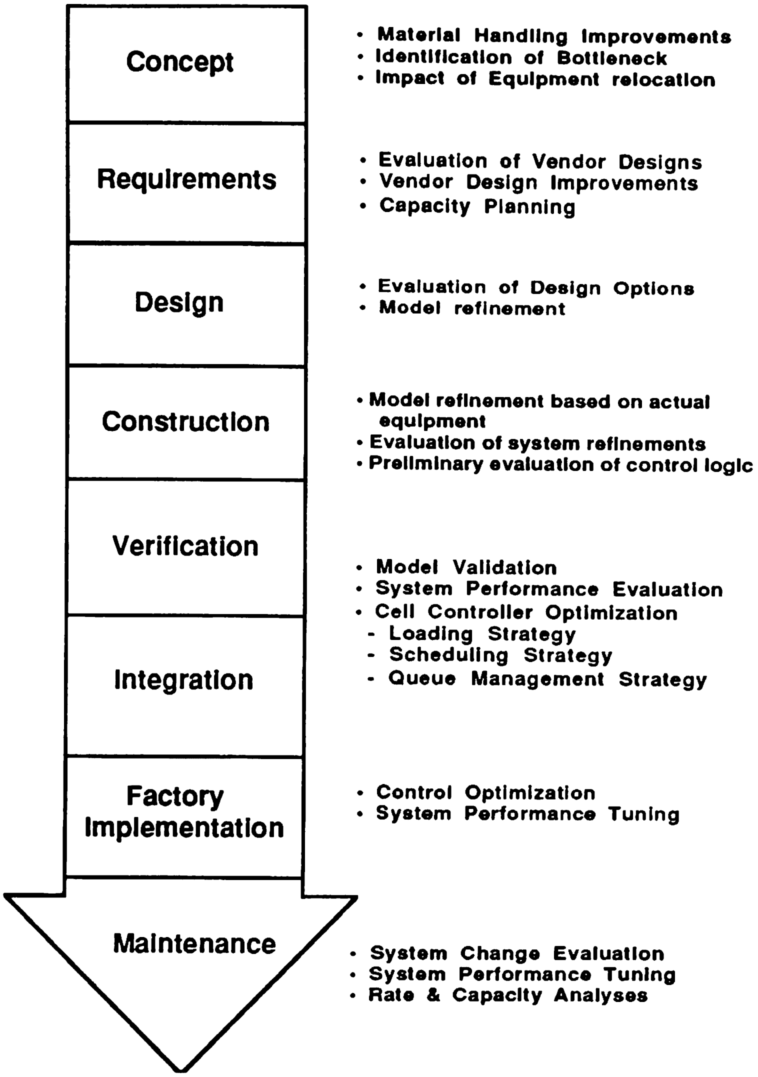


Figure 7. Simulation Benefits Through the Development Life Cycle

7 CONCLUSIONS

With Simulation numerous options were tested without incurring large capital costs or disrupting operations. Simulation provided an excellent vehicle for reducing risks associated with implementation of a very complex costly system because it provided excellent overall system visibility, was effective in communicating concepts and designs, reduced design and development time, and significantly improved the quality of designs. This simulation effort is credited with saving hundreds of thousands of dollars by reducing development time, optimizing layouts and operating procedures, and identifying and correcting problems long before the production facility was built.

AUTHOR BIOGRAPHIES

JERRY G. FOX is manager of simulation & integration for Boeing Commercial Airplane Group's Manufacturing Research and Development. He received his BS in general engineering from the U.S. Military Academy in 1966 and his MBA at the University of Tennessee in 1971. He has over 15 years experience implementing real-time process management and control systems in the U.S. and Japan. The central thrust of his group is advancement of simulator technologies so complex manufacturing applications can be evaluated faster with less trained analysts.

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