

## SIMULATION OF A NEW CELLULAR MANUFACTURING FACILITY FOR THE SSC PARTICLE ACCELERATOR

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### ABSTRACT

The purpose of this paper is to illustrate several facets of a simulation study. Practitioners need to be sensitive to multiple objectives from a variety of interested parties who can influence and be influenced by a simulation study. Many objectives are intrinsic to simulation, such as capacity estimates, cycle-time, and queue performance. Other objectives, such as communications and technology transfer, are not as obvious but exist in every simulation effort. All objectives, both intrinsic and extrinsic, need to be considered and satisfied relative to a user base of varying backgrounds.

An application of PC-based discrete event simulation that contains multiple objectives is presented. Each objective is listed and a modeling technique for satisfying each objective is discussed and illustrated. The case presented is the design of a new cellular manufacturing facility for the SSC particle accelerator. Satisfying all the objectives of this study required a robust problem definition, software selection, progressive modeling with phased validation, and multiple perspectives with animation.

### 1. BACKGROUND

The Department of Energy has embarked on an ambitious project to build the world's largest particle accelerator. The particle accelerator or atom smasher, as it is also known, will be assembled from large cylindrical super-conducting dipole magnets into a ring measuring 50 miles in circumference. This ring is roughly the size of the Washington, DC beltway! In late 1989 a site in Texas was selected for the Super-conducting Super-Collider, better known as the SSC.

The need and desire for such an engineering feat originated in the early 1980's, the vision focused through the mid 1980's, and the plan was established as the 1980's came to a close. To formulate the plan around existing scientific knowledge and emerging technologies has already required countless man-years! Westinghouse has been involved in the SSC project throughout the development process. Several key technologies, processes, tests, and equipment have already been developed by Westinghouse for the SSC project.

How many engineers does it take to build the world's largest particle accelerator? While we ponder how many engineers the project will require, the question of how to integrate and communicate detailed manufacturing plans to the diverse mass of engineers, scientists, managers, and officials has been answered...through SIMULATION!

The following effort describes an initial Westinghouse simulation of the final assembly of the dipole magnets. While the magnets are definitely a custom engineered unique item, the quantity of magnets required, roughly 5000 during the construction of the SSC, and the coordination of cutting-edge processes makes simulation an appropriate analysis tool. Visual communication of the proposed final assembly through animation was an important requirement of the simulation as well as generation of quantifiable planning statistics for facilities planning.

### 2. SIMULATION OBJECTIVES AND MODELING PERSPECTIVES

Detailed processes and procedures were developed by Westinghouse to provide the technology, skills, material, and planning to make the SSC a reality. Much effort has been expended in the National Labs, DOE, universities, and corporate entities to define and plan the concept. Westinghouse, as a leader in the process development of the dipole magnets, used discrete-event PC-based simulation to provide a coordinated plan for production and associated facilities planning.

The simulation had multiple objectives: (1) Concisely show sequential manufacturing operations in the final assembly of the dipole magnets. (2) Determine the balance of two key shared resources, a seam-track welder, and a transporter for vacuum vessel handling. (3) Estimate production capacity and size facilities for desired production. (4) Remain flexible to accommodate data on rapidly maturing processes and additional detail as it becomes available. (5) Provide a communications tool to illustrate Westinghouse expertise and process leadership to audiences involved in every aspect of the project.

#### 2.1 Single Assembly Line

The level of detail in the model and the multi-perspective communications aspects of the project led Westinghouse engineers to use the SIMAN simulation language with CINEMA animation. Figure 1 shows three of the process steps for a single final assembly line of the SSC dipole magnets. During execution of the simulation, the animation shows the sequential operations, where they are performed, and the time build-up as the magnets go through an estimated 24-hour cycle.

The descriptive text highlights the value adding process steps as the animation executes. Note the change in the entity (magnet) and the relative location on the assembly line as the corresponding text is highlighted. This animation layout provides detail to accomplish the first objective of describing the manufacturing operations on the final assembly line. Simulation with animation at this level of detail has been beneficial for demonstrating the integration of several processes which were developed by various groups at remote locations.

#### 2.2 Cell Design

The simulation progressed from the single assembly line to exploring the grouping of lines into cells. Most of the processes discussed in the single assembly line and illustrated in Figure 1 are manual assembly requiring simple tooling/fixtures and/or simple fixed automation. The most complex processes are the welding of the 20K and 80K shields and the movement, alignment, and insertion of the magnet into the vacuum vessel. Both of these processes require precision designed automation cells.

The welding of the 20K and 80K shields is to be performed by an automated bidirectional welder. The insertion requires moving the massive magnet delicately and accurately into the vacuum vessel. Because of the sizable capital investment required for these processes, the simulation was utilized to assess the sharing of a seam-track welder and vacuum-vessel transporter, both of which would be shared resources within a cellular layout.

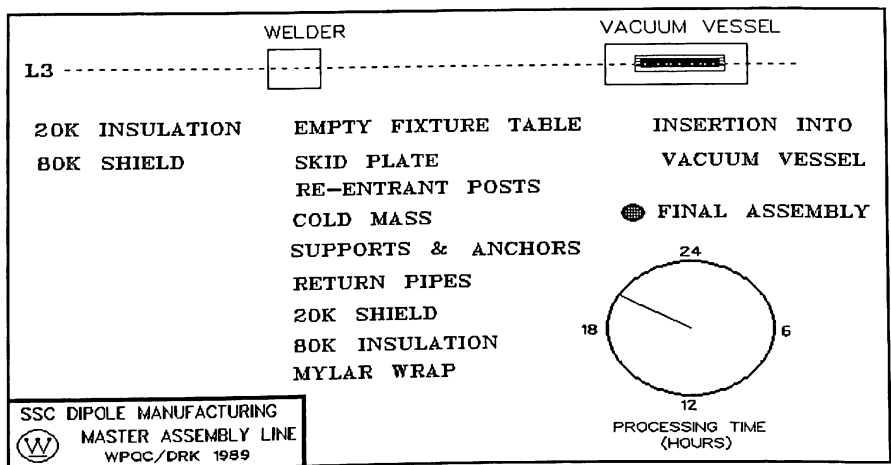
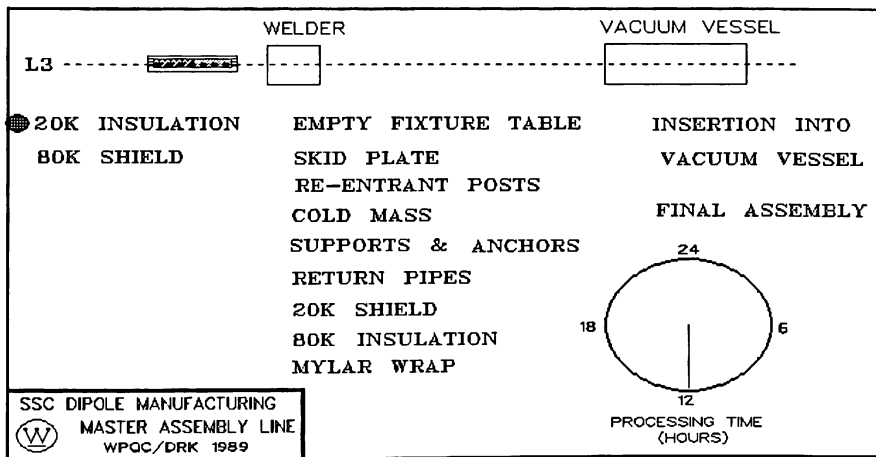
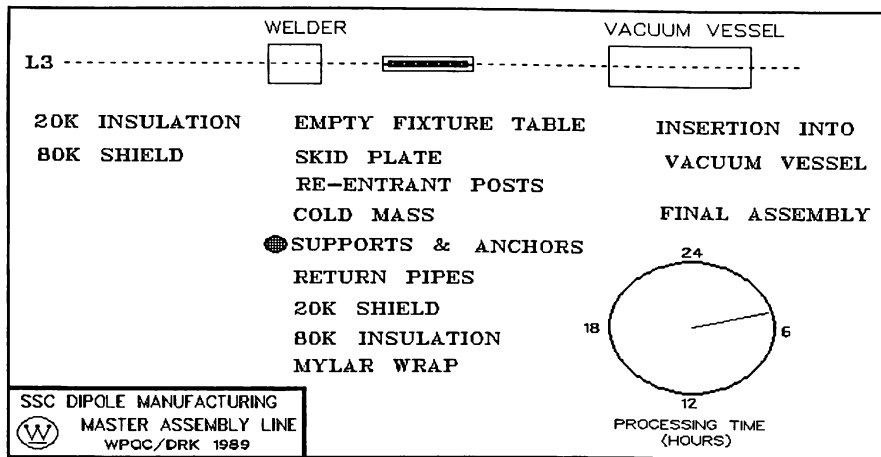


Figure 1. Snapshots from the SSC Single Assembly Line Animation

Early in the planning process, the key indicator for optimum cell size and resource balance was the utilization of the welder and transporter. It was decided early on, during the initial stage of the process and model development, that the simulated utilizations should not exceed fifty percent (50%). This would provide capacity to overcome variations in process times and machine downtime, neither of which was fully defined at the start. SIMAN's macro sub-modeling capability facilitated embellishing the single line model to configure parallel assembly lines into cells.

Nominally, the welder had a projected utilization of ten percent (10%) while the transporter was busy only eight percent (8%) of the time within the single assembly line. Based on these estimates, the simulation evaluated combining two to six assembly lines into cells. Figure 2 is a plot of the utilizations for the two key shared resources. Initial opinion was that four or five assembly lines could be adequately serviced by a shared welder and transporter. However, the queuing and transportation distances caused the utilizations to increase non-linearly.

The recommendation which was accepted was to limit cell size to three assembly lines. This satisfied the constraint of maintaining utilization below fifty percent (50%) for a planned safety factor. Figure 3 shows three final assembly lines in parallel, clustered into one cell for sharing of resources. It was crucial that these "high ticket" key machines be sized and integrated into the overall operations plan. The simulation assured engineers that a cell size of three lines in parallel was the optimum balance of quality service at minimum cost. The second objective of line balance and cell design had been satisfied.

### 2.3 Plant Configuration

With a consensus design of the cell size employing three assembly lines, the question for the simulation became the overall capacity and facility size. Based on the project construction schedule, the simulation was expanded to include combinations of cells into one facility. Each cell would operate independently but should have identical operating characteristics. Therefore, determining the number of cells required was achieved by factoring a single cell output into the production demand schedule resulting in the recommended number of cells.

Figure 4 is a view of the SSC Simulation layout depicting five cells in a given facility. This layout describes an aggregate of all production within the proposed facility. At this level, the issues of matching production to the project construction schedule and cost control are evaluated. With this, the third objective of specifying resource requirements to meet production schedules has been satisfied.

Since the model was first developed, process information continues to be updated. Time estimates have been updated in the SIMAN experimental frame. To date, the updated information has not radically changed the proposed system and the plans have been robust under several simulated scenarios. The ability to rapidly incorporate developing process data and predict performance has impressed our customers and helps satisfy the fourth objective of model flexibility.

Three animated views of this efficient model were required to meet the multiple objectives of the SSC final assembly simulation. Feedback from all users and observers has indicated that their different needs have been satisfied. No one particular need is more important than any other, as long as all customers are satisfied. The simulation has been reviewed and utilized by design engineers and scientists, program managers, government agencies, and a host of interested groups at SSC technical symposiums. The five objectives have now been completed.

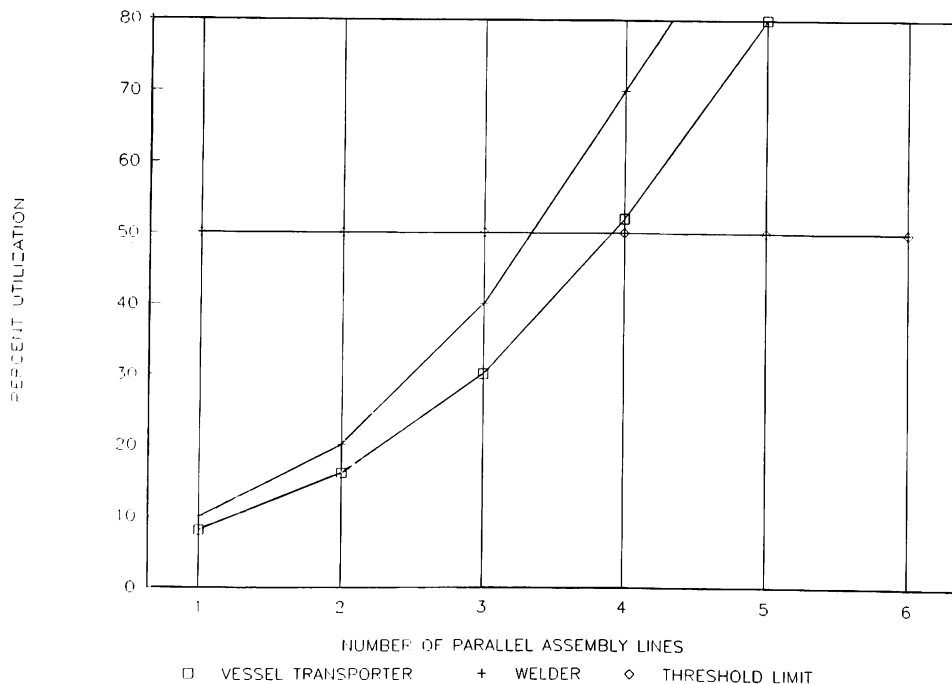


Figure 2. Average Utilization for the Welder and Transporter as a Function of the Number of Parallel Assembly Lines

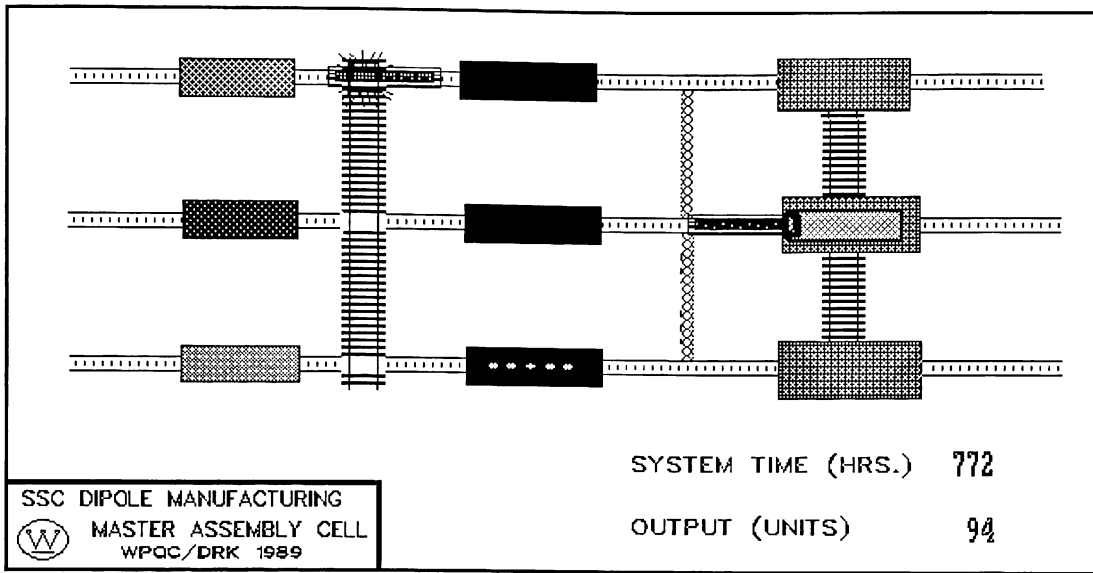


Figure 3. Snapshot of the SSC Cell Animation

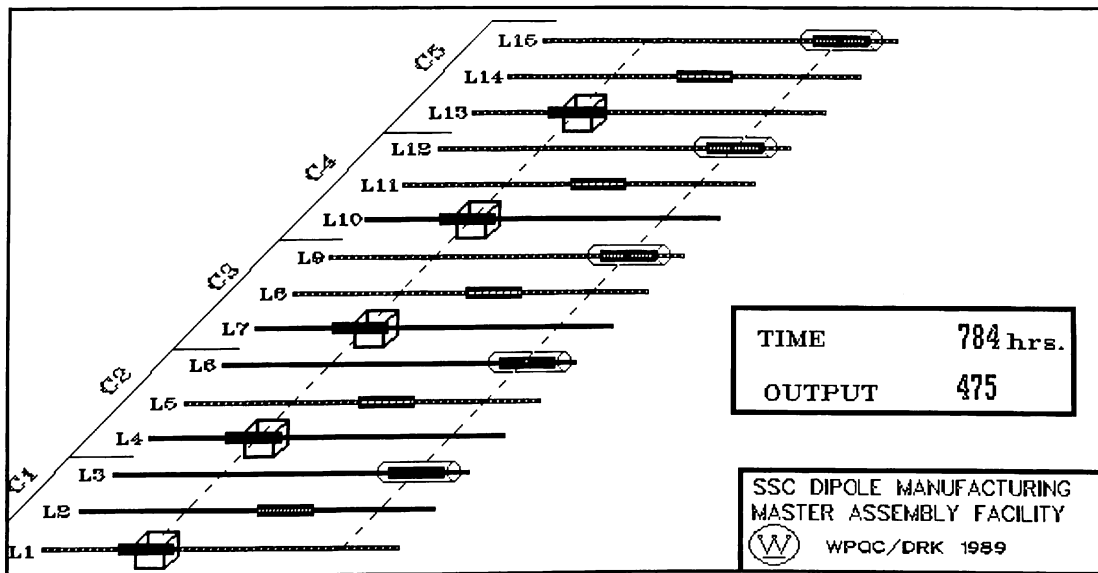


Figure 4. Snapshot of the SSC Facility Animation

### 3. MULTI-LEVEL PHASED VALIDATION

Within the single line simulation and animation, it was easy to verify the basic model flow and describe the sequence and location of each process. This also proved to be a credible building block to continue into cell design. While the projections from the cell simulation contradicted preliminary intuitive opinions, the validity gained by simulating the single line was useful in securing buy-in to the results of the cell simulation. It was a natural progression which started simple, gained credibility and user acceptance, and then was used to give unbiased estimates for a highly controversial decision. Taking the cell estimates then to the overall production plan was quite effortless.

As in most mathematical or scientific proofs, it is much easier to find cause to reject or disprove a theory than it is to prove and accept. Our experience has shown that a simulation model must answer several "rounds" of questioning. The first "round" of questions usually begins: "Did you include...?", or "What about...?" The analysts on the SSC Simulation were able to respond: "It's in there!", much like the spaghetti sauce!

The simulation began with a minimum amount of modeling in a flexible language structure to provide a good Value-to-Price ratio for our customers. This SSC project, as most of our efforts, eventually required language level detail to insure credibility. This is a key reason we employed a language such as SIMAN. Many applications require detail that only a language can provide and user-written sub-routines are also quite common.

The second "round" of questioning does not occur unless you have answered "It's in there!" in the first round. Questions like "What happens when...?", or "How does the system...?" are best described through animation and quantified through analysis of output statistics. The SSC cell animation (Figure 3) has been a valuable sounding board to answer those types of questions. Typically, isolated combinations of events are simulated and viewed through animation while steady-state output statistics quantify system performance.

The questions in the last "round" are higher level, overview type inquiries such as: "What is the monthly...?", or "If the volume...?" These inquiries are best answered from steady-state simulation output representing a valid run length. However, the first two "rounds" of questioning must have been successfully completed to have any credibility in the acceptance of planning estimates. The visual build-up through the three animation views has proven to be a good communicator, paving the way to model validation and acceptance.

### 4. SUMMARY AND CONCLUSIONS

We have applied simulation to keep Westinghouse a world-class performer. The SSC simulation is just one more example of "doing the right things right, the first time." Given the overall scope of the SSC project, the simulation focuses on only a small portion, namely the final assembly of dipole magnets. However, the small investment has provided significant value in meeting the integration, planning, and communication objectives in the early stages of manufacturing planning for the SSC.

The application presented illustrates several facets of a simulation study and methods for interaction where multiple objectives exist. Due to the nature and applicability of simulation, several other concerns and techniques that have been encountered were not discussed in this paper. However, this particular application was well suited to provide some modeling insight to effectively manage a simulation project.

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