Proceedings of the 1987 Winter Simulation Conference
A. Thesen, H. Grant, W. David Kelton (eds.)

STAR*CELL: A FLEXIBLE MANUFACTURING CELL SIMULATOR

Harold J. Steudel
Taeho Park
Department of Industrial Engineering
University of Wisconsin
Madison, WI 53706, U.S.A.

ABSTRACT

This paper discusses STAR*CELL, a PC-based simulator for the design and evaluation of flexible manufacturing cell (FMC) flow line systems. As a design tool, STAR*CELL aids in determining the ideal number of machines, number and assignment of operators, and the size of inter-workstation buffers. The menu-driven simulator also assists in evaluating the impact on cell performance of Just-in-Time (JIT) factors, changes in product mix and demands, and different user-specified job input sequences. The paper provides numerical results for a gear workcell example to illustrate the effects of various design variables on cell performance. A brief discussion of the development, applications, advantages, and limitations of STAR*CELL is also presented.

1. INTRODUCTION

The need for improved quality, reduced inventories, and shortened lead times is driving many manufacturing companies to reorganize their facilities from a functional "job-shop" to a cellular layout. These cellular systems are typically composed of Group Technology (GT) based Flexible Manufacturing Cell (FMC) flow lines. The overall objective is to gain the efficiencies and control advantages of high volume repetitive flow processing in a small to medium volume batch environment.

Once a GT-workcell has been identified, there are numerous design decisions which need to be made before the cell is installed on the shop floor. Some major decisions include determining:

1. the number of identical machines in each work station,
2. the capacity of the inter-workstation buffers,
3. the number of operators and operator assignments to the workstations,
4. the number of working hours per day per workstation, and
5. the size of the transfers batches.

The design of FMC systems also requires an assessment of the effects of other practical considerations such as machine breakdowns, scrap, production efficiencies, product growth, and changes in product mix. Furthermore, the effects of Just-in-Time (JIT) factors such as reductions in setup time and batch sizes should be considered in the design of workcells. Since the effects of all these factors on system performance are highly inter-dependent, the use of simulation (with properly designed experiments) is most appropriate for workcell analysis.

The requirements of time, effort, and technical expertise demanded in using general-purpose simulation languages is prompting many companies to use special-purpose simulators. The need for a comprehensive yet easy to use simulator for GT-workcell analysis has motivated the development of STAR*CELL over the last two and one half years.

This paper describes STAR*CELL, a pc-based, menu driven manufacturing simulator which facilitates the design and evaluation of FMC flow line systems. It allows for simulation-based evaluations of the production capacity and performance characteristics of a proposed manufacturing cell before incurring the expense and risk of implementing the cell on the shop floor. In addition, STAR*CELL is also capable of sequencing jobs through a workcell in a specified order. This feature is useful not only for modeling but also for controlling a workcell after it has been installed on the factory floor. The paper describes the capabilities of STAR*CELL, and presents some generalized results which show the effects of the number of operators, operator assignments to workstations, and inter-workstation buffers on cell performance. Subsequently, it is shown that STAR*CELL not only reduces model development time and efforts, but also provides analysis capabilities concerning the relevant factors in modeling FMC systems.

2. STRUCTURE

STAR*CELL provides a powerful tool with dynamic animation for the evaluation of flow line manufacturing systems, yet it requires no programming. The software is entirely "menu-driven," with information entry and editing through spread sheet type operations. The simulation model is defined by entering actual operating data such as part routings. In addition, the simulator is equipped with on-line screen menus for defining variables which describe the characteristics of workstations, buffers between workstations: operator allocations, part family setup times, job run sequence, simulation run conditions, and so forth. STAR*CELL also provides performance reports which describe the "goodness" of a particular cell configuration in terms of commonly used measures of productivity.

STAR*CELL is written in Turbo-Pascal and is designed to run on an IBM PC, PC/XT, and/or PC/AT, or any true compatibles. It is recommended that STAR*CELL be run on computers having more than 256K of memory due to the dynamic memory requirements for the queues between workstations.

STAR*CELL is organized around a main menu consisting of nine special functions or tasks initiated through the F1 through F10 function keys on a PC style keyboard. In turn, each main menu task has one or more sub-menu(s) to perform a special function. A brief explanation of each of the main menu functions is given below:

F1 & F2: enter and edit part processing and workstation information. The data on part processing includes operation sequence, setup and processing times, annual usage, batch size, and transfer batch size. Information on efficiency, scrap rates, machine reliability, and part handling times describe the workcenters.

F3: define the run conditions for each simulation experiment. This information includes random number generator seeds, input and output file names, run length and data sampling frequency, and the optional specification of job run sequence.

F4: define and modify workstation configurations. This menu specifies operator assignments, the number of machines per workstation and operating times, and the capacity of buffers between workstations.

F5: define part-family setup factors. These factors describe the effect of job sequence on setup times.

F6: run the simulator. Dynamic animation of the histogram of queues (in buffers) or the work flow of parts throught the cell are user-specified options.

F7: generate performance reports of specified simulation runs through on-line screen or hard copy.

F8: manage files addressed by STAR*CELL. This menu allows the user to list, copy, delete, or rename a file without exiting the STAR*CELL system.

F10: exit STAR*CELL and return to DOS.

3. TYPES OF MANUFACTURING CELL SYSTEMS

An FMC system (namely, a workcell) consists of several workstations dedicated to processing similar types (families) of parts. Finite buffer storage exists between the workstations to compensate for processing inbalances, and thereby lessen machine idle time or under-utilization. Ideally the cell is configured (and part families assigned) in such a manner that each part can be totally processed within the cell, and there is no routing back to upstream machines. Furthermore, in order to achieve minimum flow time, work is usually processed and moved through the cell on a continuously piece by piece basis or in small transfer batches.

STAR*CELL is capable of modelling FMC-type flow line manufacturing systems in which no "back tracking" occurs. (Back tracking is defined as a situation where a part's processing requirements dictate the routing of the part back to an upstream workstation.) Figure 1 shows a number of different manufacturing flow line configurations which can be modeled by STAR*CELL. Figure 1-i depicts the general

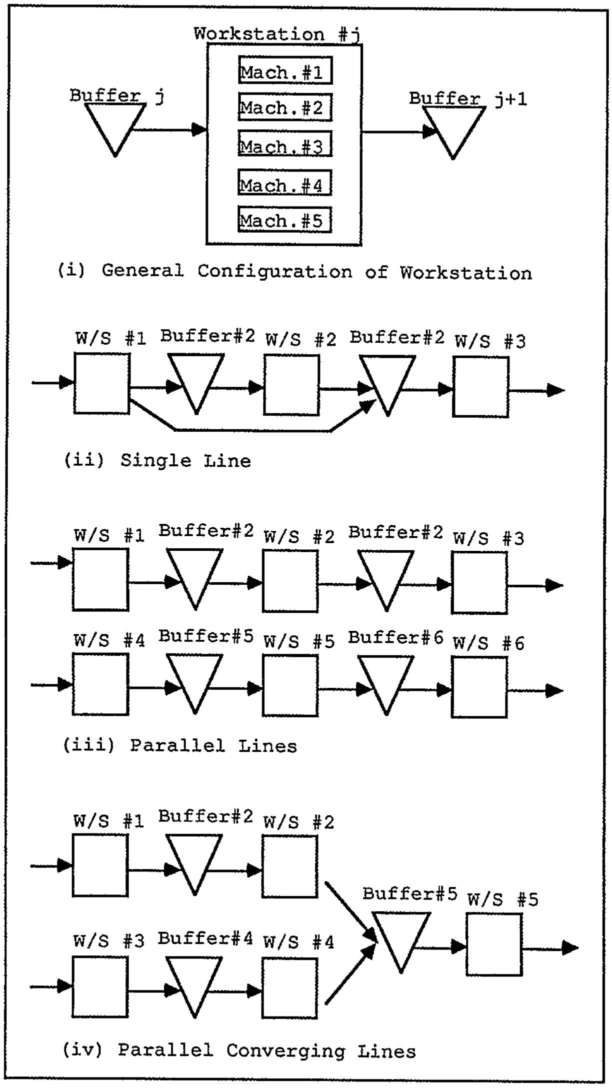

Figure 1. Alternative "Flow Line" Cell Configurations to be Modeled Using STAR*CELL

configuration of a workstation. The workstation is made up of one or more machines with similar processing capabilities. Work enters the workstation from a upstream buffer, and is placed in the downstream buffer after being processed in the workstation. Figure 1-ii shows the standard single line flow cell. The flow of materials is always from upstream to downstream workstations, but "leap frogging" is allowed. Figure 1-iii and iv show a parallel line cell configuration with or without converging common workstation(s). Likewise, other variations of these configurations are possible. For example, one could have parallel lines converging to a common workstation and then diverging again to parallel lines.

4. CAPABILITIES AND FEATURES

This section describes the capabilities of STAR*CELL in terms of special modelling features. Numerical results are also presented to show the importance of the special features.

STAR*CELL has a number of features which are essential for modeling a manufacturing workcell. To illustrate the effect of these features on system performance, a set of industrial data was used. The data describes the FMC flow line shown in Figure 2 for producing 98 different types of gears. Since all machines in the workcell are automatic, operators only are responsible for machine setup, and part loading and unloading.

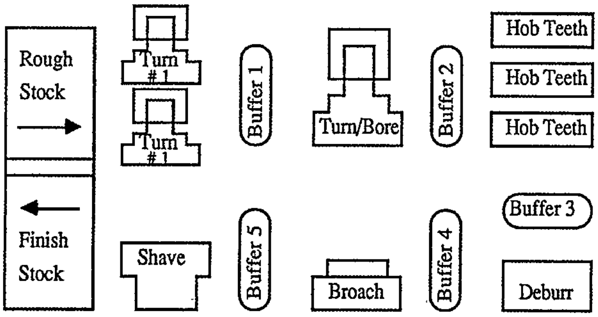

Figure 2: Configuration of an FMC Flow Line Producing 98 Types of Gears

The special features included in STAR*CELL are:

A. Operator Assignments. STAR*CELL allows for modeling and evaluation of operator assignments to the various workstations comprising a workcell. In reality, if an operator is not present at a machine, then the machine is not capable of producing parts in most cases. (The exception would be the fully automated machines for which setup of machines, part loading, processing, and unloading were accomplished without human intervention.)

Figure 3 shows the effect of the number of operators on throughput rate, assuming that any operator can work on any machine in the workcell. Throughput rate improvement is defined as 100 * (TH(i) - TH(1)) / TH(1), where TH(i) is the throughput rate of the system with i number of operators. It is clear that the number of operators in the cell have a major impact on cell performance. In this case, less than four operators greatly inhibits cell throughput, yet beyond four operators has little positive effect.

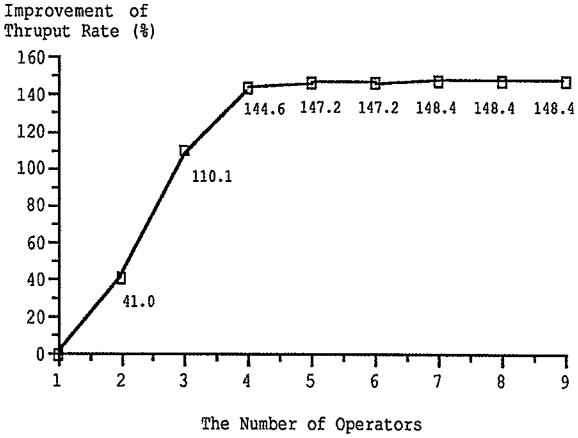

Figure 3: The Effect of the Number of Operators on Throughput Rate.

Since it may be physically impossible or somewhat inefficient to allow all operators to work on any machine in a workcell, operators may have to be assigned to specific workstations. The effects on production rate and operator utilization for four different assignments of four operators are given in Table 1. As expected, when all four operators are trained and assigned to work on any machine (Assignment strategy 1), the cell performance is best. If the ideal assignment is impossible (for example, a conveyor for material handling runs through the center of the gear workcell), assignment strategies 3 and 4 can be alternatives for the best assignment of four operators. Since workstations 1 and 3 involve the greatest number of machines, assignment strategy 3 results in higher productivity. Assignment strategy 2 is another alternative, in the case where the travel time of operators between consecutive workstations is considerable, yet operators can move easily across the center of the workcell.

B. Direct use of Actual Operating Data. A STAR*CELL model is defined and driven entirely on actual operating data and routing information for the parts to be processed through the cell.

Table 1: The Effects of Operator Assignment on System Performance

Assignment Strategy	Operator Number	Operator Assignment Workstation Number						Operator Utili-zation (%)	Thruput Rate (pcs/hr
		1	2	3	4	5	6		
1	1	x	x	x	x	x	x	80.3	6.19
	2	x	x	x	x	x	x	73.3	
	3	x	x	x	x	x	x	63.3	
	4	x	x	x	x	x	x	54.2	
2	1	x					x	95.3	5.41
	2		x			x		53.0	
	3			x	x			61.6	
	4			x	x			45.5	
3	1	x	x	x				73.9	5.12
	2	x	x	x				59.8	
	3	x	x	x				46.2	
	4				x	x	x	68.2	
4	1	x	x	x				64.7	4.93
	2				x	x	x	50.8	
	3	x	x	x				32.7	
	4				x	x	x	18.2	

(x indicates the assignment of an operator to a workstation.)

This approach often shows systems dynamics and interactions not seen by using theoretical service time distributions for parts processing. Furthermore, the direct use of actual routing data eliminates the necessity for pre-simulation modeling of service time data to determine appropriate probability distributions. Model building is largely reduced to the task of data entry. Simulation modelling is accordingly brought down from a level requiring a simulation expert to that of the typical manufacturing/industrial engineering analyst involved with cell design and implementation.

C. **Buffer Capacity.** STAR*CELL models the effects of the capacity of buffers between workstations in terms of blocking and starving phenomena. Not only can one model the effects of different buffer sizes on throughput performance, but STAR*CELL provides a means of determining the effects of resuming processing on blocked machines for different levels of the downstream buffer.

The effects of buffer capacity on throuput rate is shown in Figure 4 for the second buffer storage while maintaining the capacity of the other buffers at size 100. As the buffer size increases, the throughput rate becomes greater due to decoupling of blocking and starving phenomena between the second and third workstations. There is, however, no performance improvement beyond about buffer size 50. Furthermore, while a buffer size of 20 increases the throughput rate by 34.47%, an additional buffer size of 20 would improve system performance by less than 1%. Therefore, the buffer design problem implies trade-offs between increasing system performance and reducing buffer storage.

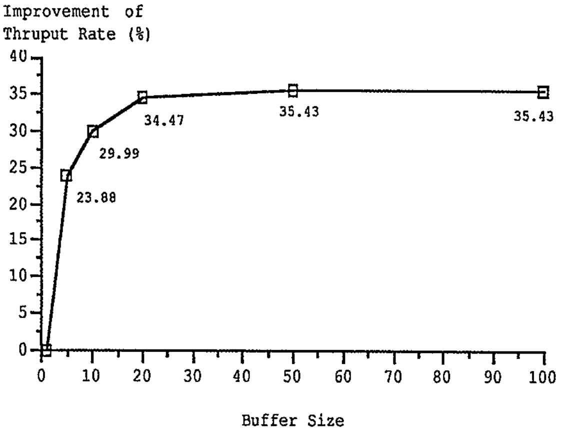

Figure 4: Percentage of Improvement in Throughput Rate by Increasing the Size of the Second Buffer Storage.

D. **Modelling of Transfer Batches.** STAR*CELL is capable of evaluating material handling in terms of the size of the transfer batch movement between workstations. The transfer batch size specifies the number of workpieces to be transferred between workstations for each movement of a material handling system. Determination of the transfer batch size (that is, unit load size) is an interesting factor to be considered in designing a material handling system for a manufacturing cell.

E. **Specification of Cyclic Job Sequence.** STAR*CELL simulates the loading of jobs into a workcell either in a specified fixed job sequence order, or in a job sequence determined by random job selection. Manufacturing systems having only a few part types to be processed in large batch sizes may often run jobs in a cyclic order. STAR*CELL can model these systems by using a cyclic job sequence. STAR*CELL reports the makespan for processing the set of jobs and the job starting and finishing times. This feature is useful for initial cell evaluation and as a tool for job order management, job scheduling, and material requirements management after a workcell is designed and installed on a shop floor.

To illustrate the effects of job sequence on throuput rate in a certain period, three different job sequences of six jobs were selected as shown in Table 2. Table 2 also shows the makespan for processing the jobs in the given job sequence, and the percentage of improvement in makespan by changing job sequence. Especially in manufacturing systems with job sequence-dependent setup times, job processing order plays a substantial role for improving cell productivity.

Table 2. Makespan for the Three Job Sequences

No.	Job Sequence	Makespan (Hrs)	Improvement in makespan
1	7 - 24 - 12 - 3 - 8 - 20	33.56	—
2	24 - 7 - 3 - 12 - 20 - 8	29.95	10.8 %
3	20 - 24 - 7 - 12 - 3 - 8	29.72	11.4 %

F. Evaluation of Just-in-Time Effects.
STAR*CELL allows for easy evaluation of Just-in-Time (JIT) effects. For example, one can easily determine the effect on throughput performance of a reduction in setup time for any one of the workstations in the cell. One can also evaluate the effects of part-families, in terms of reduced setup time requirements, when parts of similar family types are processed in succession. STAR*CELL also allows one to easily model the effects of increases or decreases in sales volume which may result from improved cell productivity and part quality. Furthermore, STAR*CELL has a provision for evaluating the effects of reducing order quantities from current levels. The relationships among reduced order quantities, increased order frequencies, and reduced setup times are a complex yet important factor in designing flexible manufacturing work cells for JIT environments.

In addition to the aforementioned special features, STAR*CELL also provides one with the modeling features found in most simulation software. These features include modeling machine breakdowns, repair times, workstation efficiency, separate part loading and unloading times, and the ability to operate workstations a variable number of working hours per day.

5. CONCLUDING REMARKS

STAR*CELL was developed by the CIMS: Design and Simulation Laboratory at the University of Wisconsin-Madison through university-industry research coorperation. The simulator has been used for research work in developing scheduling algorithms for FMC systems, and for designing and evaluating cells for gears, chain-link sidebars, computer card panels, and a nobake foundry molding line. In addition, STAR*CELL has been used numerously as a classroom tool to provide students with an understanding of the behavior of cell systems in response to changes in common design variables.

The philosophy of STAR*CELL is quite simple. It is not a general purpose simulator which encompasses all types of manufacturing systems. Rather, it focuses on flexible manufacturing cell flow line systems and provides an easy to use, yet powerful modelling tool. On the other hand, STAR*CELL, like any other simulation program, is only a tool to estimate the effects of changes in the system environment. Thus, the quality of the final solution is primarily dependent upon the creativity of the human analyst to generate ideas for evaluation.

AUTHORS' BIOGRAPHIES

Dr. Harold J. Steudel, Professor of Industrial Engineering at the University of Wisconsin-Madison, obtained a B.S. in Mechanical Engineering at the University of Wisconsin-Madison; a MSME from the University of Wisconsin-Milwaukee; and a Ph.D. in Mechanical Engineering (Production) from the University of Wisconsin-Madison. He maintains an active research program in the area of manufacturing simulation applied to facilities planning and the design of cellular manufacturing systems. His research has appeared in Management Science, International Journal of Production Research, IIE Transactions, Journal of Manufacturing Systems and numerous other publications. Dr. Steudel also serves as a consultant to many companies in the area of Just-in-Time manufacturing with special emphasis on workcell design and Statistical Quality Control. He is a registered professional engineer, a senior member of the Institute of Industrial Engineers (IIE), and a senior member of the Society of Manufacturing Engineers (SME).

Harold J. Steudel
Department of Industrial Engineering
University of Wisconsin-Madison
457 Mechanical Engineering Bldg.
Madison, Wisconsin 53706

TAEHO PARK is a Ph.D. candidate in the Industrial Engineering department at University of Wisconsin-Madison. He received B.S. and M.S. degrees in Industrial Engineerin from Seoul National University (Korea) in 1981 and 1983, respectively. His research interests are in the facility planning and control of flexible manufacturing cell systems via statistical design, analytical methods, and simulation models. He is a student member of CASA-SME, IIE, and ORSA.

Taeho Park
Department of Industrial Engineering
University of Wisconsin-Madison
446 Mechanical Engineering Bldg.
Madison, Wisconsin 53706