Proceedings of the 1988 Winter Simulation Conference
M. Abrams, P. Haigh, and J. Comfort (eds.)

Simulation of a finished goods allocation system

Edward F. Stafford, Jr.
College of Administrative Science
Department of Management Information Systems
and Management Science
University of Alabama
Huntsville, AL 35899

Bernard J. Schroer
Johnson Research Center
University of Alabama
Huntsville, AL 35899

ABSTRACT

This paper describes an extensive project conducted to provide an independent assessment of the proposed major change in the way an electronics assembly firm would manage the production of their major product--modems. Whereas the current system handled, manufactured, and tested units in batches that corresponded to shipping orders, the proposed system would process individual product units singly, as in a hybrid flow shop. Microcomputer-based simulation models were developed, tested, and used to model proposed system changes. It was concluded that the proposed system would have no adverse effects on finished goods inventory, and that it could be implemented and used with other modifications planned for the production system.

1. INTRODUCTION

Corporate management is becoming more aware of, and receptive to discrete event simulation, both as a tool for improving a firm's competitive edge and as a tool for increasing productivity, improving quality, and reducing costs. With regard to competitive edge, simulation allows for the evaluation of alternative manufacturing system designs, new equipment options, product mix changes, and control strategies before incurring the upfront costs of system changes and facilities construction. At a more micro level, simulation allows similar analyses to select cost-effective alternatives and to prevent making decisions that would not deliver the productivity promised by proponents of proposed equipment and system changes.

Since simulation analyses and techniques have been readily available for nearly 40 years, one might wonder why management has only recently become very receptive to using simulation as a regular tool to support decision making. At least three reasons come to mind.

First, members of the newer generation of managers are more likely to have seen simulation used in the classroom to solve problems. This is especially true for those managers who have studied business or engineering, particularly at the graduate level.

Second, with the advent of the microcomputer, managers can put compact, easy-to-use simulation packages directly into the hands of their analysts. No more do analysts have to wait hours or days for turnaround on a mainframe batch processing system, particularly when accounting, payroll, and MRP transactions always get CPU priority.

Third, many of the popular mainframe simulation packages have been ported to the microcomputer. These include GPSS (Minuteman 1986), SIMSCRIPT (CACI 1987), and SIMAN (Pegden 1985). In addition, several new simulation packages, including SIMFACTORY (CACI 1988), XCELL (Conway and Maxwell 1986), and MAP/1 (Miner and Rolston 1986) have been developed specifically for management analysts working at either microcomputers or stand-alone workstations. Thus a modern, educated manager can approve the use of desktop simulation as an aid to decision making with full confidence that his analyst will have the software and hardware tools available to do the job.

1.1 Research Objectives

The objectives of this research study may be stated as follows.

1.1.1 Assessment of Change. The firm involved desired to acquire an independent assessment of a proposed major change in the way they manage the production of their major product: modems. The existing procedure is to process units in batches or lots throughout the plant, with a typical batch keyed to a specific order release or partial order release. The proposed alternative strategy involves the change to a predominantly single-unit flow system, with like units being collected in finished goods for allocation to specific orders and partial orders.

1.1.2 Industry-University Cooperation. Both the firm and the analysts desired to conduct a pilot joint effort in order to establish the feasibility of such studies in the areas of applied engineering, systems analysis, production management, robotics, computer-aided manufacturing systems (CIMS), and other related fields. Future efforts would be sponsored jointly by similar firms and the local university (the analysts' employer) to strengthen the competitiveness of the local high technology community.

1.1.3 Field Test Microcomputer-Based Simulation Analysis. This study gave the analysts the opportunity to examine one of the early microcomputer-based simulation packages, GPSS/PC, and to test this package for possible use both in the classroom and in other industrial and government research projects. The firm used this opportunity to examine simulation as a tool of analysis, with the idea of developing in-house simulation skills for future automation-related studies.

1.2 Outline of This Paper

This paper describes a four-month effort to fulfill the above objectives. First, the current and proposed finished goods allocation systems of the firm are described. A summary of the gathering, reduction, and analyses of production data is then provided. The description of the experimental design for this study is followed by a discussion of the various simulation model segments used to execute the design. Included is a brief description of some of the validation and verification techniques used. Lastly, the results of the experiment are presented, followed by the conclusions drawn by the analysts.

2 PROBLEM DOMAIN

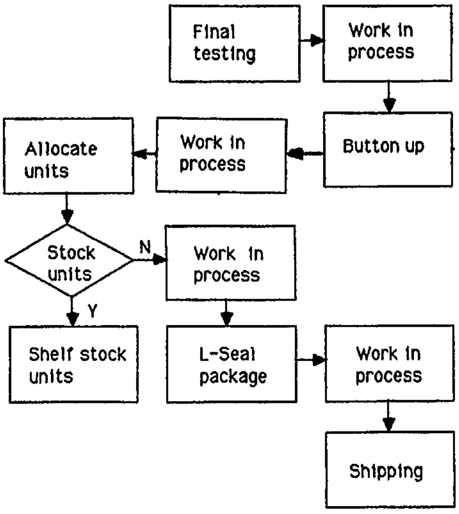
The setting for this study is an ultramodern electronics assembly plant in Huntsville, Alabama. This plant, which belongs to a large multinational firm, assembles complex telecommunications devices such as modems. This company had experienced rapid growth in sales, with resultant growth in production orders. As a result of this growth, various symptoms had emerged to indicate potential problems with the current methods of managing the movement of units throughout the plant. To address the problems underlying these symptoms, the company sought solutions from a number of functional areas including Manufacturing Engineering, Materials Management, Quality Control, Purchasing, Configuration Management, and Marketing.

The focus of this study is on a single proposal made with regard to the way the plant managed the flow of units as they moved through the various stages of production. At the beginning of this study, units were processed throughout the plant, from component insertion to final packaging, in batches. When one unit of a batch was delayed for re-work, the whole batch was delayed. A proposalcalling for the conversion of the entire plant to a hybrid flowshop, wherein an individual unit would be sent on to its next operation as soon as it was completed at the current operation, had been made. Plant management had serious reservations regarding the impact of this proposed change on the number of units of product stored in finished goods inventory. The authors were asked to provide an independent assessment of this impact before the company committed funds, time, and effort to changing the way they handled production units.

2.1 Current System for Allocating and Shipping Units

The flow of units through the finished goods allocation and shipping system, at the beginning of this study, is shown in Figure 1. A typical batch of units moved to Buttom Up,waited, and then was processed. Next the batch was moved into the finished goods storage cage, where it awaited processing by the allocation personnel. The batch then was moved back out to the same storage area where it again waited to be processed on the L-Seal (shrink wrap) equipment. Finally, the batch of packaged units was moved to shipping. Two phenomena were observed: (1) at times, there was extreme congestion in this storage area, which was limited in size by the wire cage for finished goods storage, by a major structural wall, and by two major thoroughfare walkways that had to be kept open; and (2) there appeared to be no queue discipline or priority system for assigning batches of units to either the Buttom Up operation or to the L-Seal operation.

Figure 1. Finished Goods Allocation and Shipping System at the Beginning of the Study.



Although this system of processing units in batches kept most units for a specific order together throughout the assembly/test/inspection process (an advantage), it tended to cause unnecessarily large work-in-process (WIP) inventories prior to the beginning of the finished goods stage of the production cycle. Production thus flowed in lumps through that part of the production process where the units acquired considerable added value in terms of labor, major components, and value added due to assembly itself. This variance caused by lumpy production flows created additional queue congestion at downstream work stations, especially at the finished goods allocation operations.

2.2 Foundations for Changing the Production System

Company management had made at least three different strategic decisions that provided a foundation upon which a successful change from batch processing to single-unit processing could be based. These decisions are summarized as follows.

2.1.1 <u>New Generation of Products</u>. To meet strong and growing competition, the company developed a new generation of models which offers more features, reduced size, and higher levels of performance. More important, the new product line is quite homogeneous (common components, similar housings, and the like), thus allowing a variety of models to be manufactured and handled by the same equipment.

2.2.2 <u>MRP II System Installation</u>. The company had installed and implemented a state-of-the-art material requirements planning and control system. Analysts can use this system realistic shipping dates for possible new orders, in real time; and they can determine the impact of premature release of orders, et cetera, on shop floor capacity bottleneck operations.

2.2.3 <u>Barcode System for Units</u>. A barcoded universal label system, that included the part number, serial number, engineering configuration number, and other pertinent data, was designed, and the hardware and software were assembled and tested in order to activate the proposed system. The final assembly, PCBs, and major PROMs would each have a separate barcoded label, which would be scan-readable by a variety of devices located throughout the production process. The success of the proposed allocation depends heavily on the successful implementation of this barcode system.

2.3 Proposed Finished Goods Allocation System

The lumpy demand described above, along with the evolution of the company's product line and the conceptualization of a barcode-based production planning and control system, led company management to seek alternative system designs for allocating and shipping finished product.

2.3.1 Differences from the Existing System. The proposed system differs from the current system in at least 7 critical ways:

1. Production units (modems, PCBs, and the like) would be allocated to shipping order releases on a one-at-a-time basis.

2. Units would be L-sealed and individually boxed prior to allocation. Currently, these two steps are carried out after allocation, in most cases.

3. Allocation would be completely controlled by computer software, with an operator to respond to computer instructions by placing the allocated unit in a computer-assigned position on an allocation table or rack. Currently, there is considerable human intervention in the allocation process.

4. Since units would be flowing into the allocation area in "random" order, one operator could be filling many orders simultaneously. Currently, an operator works on allocation, one order at a time.

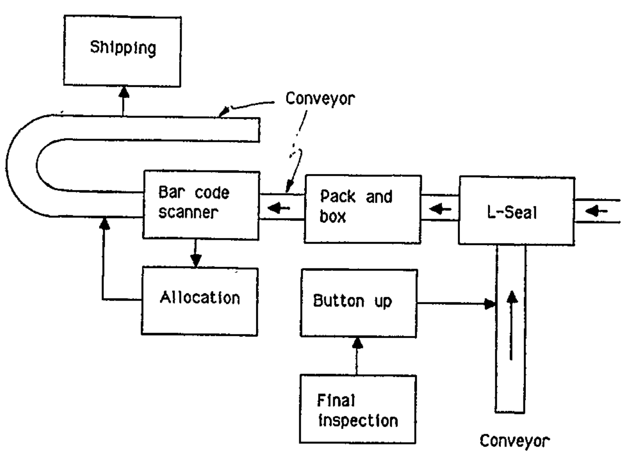
5. Allocated units would be forwarded to shipping in lots equal to one or two overpacked boxes, depending on the size of the unit. Currently, units are forwarded in a complete lot, sized to fill the order release to the extent possible.

6. All partially filled orders will be shipped at the end of each day, unless partial shipments are prohibited by the customer. Presently, many partially filled orders are held by allocation until sufficient units arrive to completely fill the order.

7. All units designated for hold status in finished goods, and those units stored for specific customers would be stored in individual packages, the units being ready for release to shipment immediately upon receipt of a request from the customer. Currently, many of these units are stored unprotected on the finished goods shelving units.

A model of the proposed allocation system is shown in Figure 2. Individual units pass serially through Button-Up, L-Seal, and Packing before entering the allocation system on a long roller conveyor in the finished goods storage area. A unit approaching the Laser Barcode Scanner is guided into proper position to have its universal label read. If the scanner/CRT operator is busy with a previous unit, the approaching unit is delayed in queue awaiting its turn with the scanner/CRT.

Figure 2. Flow of Single Units in the Proposed System for Allocating and Shipping Finished Goods.



After a clean read of the universal label, the data is transmitted to the controlling computer as a real-time transaction. The computer, following the algorithm developed in conjunction with Order Entry, Marketing, and Production personnel, selects the order release to which this unit is to be assigned. A message is returned to the CRT, and the operator, following computer instructions, places the unit in the proper tray. The computer keeps track of how many units have been allocated to each tray on the table, and gives the operator instructions on when to "push" the trays on to shipping. In addition, the computer maintains a file on the location and numbers of all unassigned units in stock.

2.3.2 Other Features. Several other features for the proposed allocation system are:

1. The order entry system would be linked to the allocation system via a mainframe file.

2. The list of orders to be filled would appear in the allocation file according to the planned shipping schedule.

3. Order Entry personnel would monitor order status daily, and update the ranking of the various opened orders awaiting filling.

4. Order Entry personnel will establish daily shipping priorities, as required.

5. All opened order releases are available in the files, and on the screen.

6. Units of a particular part number are allocated to a single open order for that part number, until the order is filled.

7. Partial orders are shipped at day's end unless prohibited by contract with the customer.

8. For a particular part number, the first order filled in a day is the one remaining from the orders not completely filled the previous day.

9. When new orders are added to the active list for Allocation, the computer immediately scans the shelf stock file for units to allocate to these new orders.

10. Shelf stock units chosen by the computer to fill or partially fill a newly opened shipping release must be entered into the scanner/CRT system to properly debit and credit the inventory, shipping, and allocation files.

11. Units processed by the scanner/CRT are done so based on the pattern of random arrivals. This system will not look upstream to previous operations to "plan" for unit arrivals, and thus do activities such as releasing partially filled orders early in the day if there is evidence that no more such units would be arriving that work day.

12. Processing time at the scanner/CRT is based on the response time of the scanner, local PC controller, and the host mainframe.

13. Allocation trays, used on the allocation table to collect units assigned to different open-

ed orders, must be sized to successfully negotiate the existing conveyor system, and must accommodate overpack quantities of most part number models.

3. DATA GATHERING AND ANALYSIS

In order to effectively conduct this project, it was necessary to gather and analyze a considerable volume of data. The most recent eight months of shipments records were gathered to estimate the complex distribution of orders that existed in this production system. These data were used to: (1) study the complexity of a typical order release; (2) estimate the distribution of order sizes; and (3) identify the role of each model or part number family in the overall distribution of orders shipped. Additionally, the physical properties of the part number families were studied to identify limiting values of parameters for any model developed to analyze the proposed system modifications.

3.1 Complexity of Orders

Shipments data for the nine months preceeding the beginning of this study were examined to determine the complexity and size of typical shipments. To determine the typical complexity of a shipment, these data were first tabulated by number of different part numbers in a shipment. The initial classification of data--one, two, and three or more part numbers per order--proved sufficient for purposes of this study. A summary of this data is provided in Table 1. Just over ninety percent of the orders and partial orders shipped during this six-month period (9391 releases shipped) involved but a single part number. Hence, for modeling it was assumed that all orders involved just a single part number.

Table 1. Complexity of an Order Release (Number of Models per Release).

Models/ Release	Percent
1	90.4
2	6.5
3	3.1

3.2 Order Size

The distribution of order sizes shipped was also determined to be a significant factor in planning for the analysis of the proposed shipping system modifications. The same nine months of shipping data were tabulated according to number of units shipped in a release. Table 2 shows a summary of these tabulations as a percentage of total releases and as a percentage of numbers of units shipped. Order size ranges of 8, 16, and 24 were used since modems would be overpacked 8 or 16 to a box, where possible, based on the reduced size of revised modem models, and the newly designed materials to be used for shipping these units.

3.3 Consistency of Order Mix

The consistency of the mix of orders shipped, with regard to part number families, was also analyzed. No attempt was made to separate part numbers that basically differed only by the intended customer. Thus, for example, all model 102s were aggregated together, as were all model 202LPs. These data were further classified both by numbers of releases and by numbers of units shipped within each part number family. The summaries of these nine months of data are are too extensive for this report. Although dollar values were also gathered for these months, specific amounts are not presented in this report because of the proprietary nature of the data.

Table 2. Size of Order Release

Size of Order	% Releases	% Units
1 - 8	64.3	16.3
9 - 16	15.8	15.9
17 - 24	6.7	11.6
25 - 74	11.3	38.1
75 - up	1.9	18.1

Additional data analyses are described later in this report. These analyses were used to "parameterize" the model developed to analyze the feasibility of the proposed finished goods allocation system.

4. EXPERIMENTAL DESIGN

In a study such as this, analysts would normally sit down with concerned management and jointly develop a formal experimental design to insure that the questions answered in the subsequent analyses are the questions management really wants answered. This sharing in the development of the experimental design did not happen for this project. Instead, the assigned company contact person kept himself between the analysts and manufacturing management; it was his instructions that led to the experiments described below.

4.1 Experiment I: Supply Independent of Demand.

Once this contact person was convinced that the programs described below actually represented the proposed system, he specified that the first experiment to execute was one that would provide the "worst case" possible. It took considerable discussion to discover what it was that he meant by "worst case."

The first experiment examined the effects of having total independence between the order releases arriving to be filled and the units arriving to be allocated to orders. Both orders and units were randomly generated from the same distribution, but two different random number sources were used such that there was absolutely no planned correlation between what units were needed to fill the incoming orders, and what units were being "produced" by production. In terms of microeconomics, there was no correlation between supply and demand. This, of course, was not the case in the real production system at the firm, but this case was chosen to represent the very worst that could happen if the proposed allocation system were implemented.

In all experiments for this study, a day's worth of new orders is generated at the beginning of a production day. Those orders that can be filled or partially filled from shelf stock are opened immediately, and filled to the extent possible. All other new orders are filed, FIFO, in the orders-to-be-filled file. For this first experiment, units arrived at the system according to a uniformly distributed interarrival time ranging from 14 to 26 seconds. As described below, this unit arrival process had to be radically modified for the second experiment.

4.2 Experiment II. Supply and Demand Highly Correlated: Random Pattern of Unit Arrivals.

The second experiment was designed to study the effects of having supply (units produced) correlated strongly with demand (orders to be shipped to customers). This high correlation exists in a well controlled production environment such as that at of this firm where the order entry and production planning and control systems are linked by a network of computerized production control modules. The order generation process for this second experiment was the same as that for Experiment I. On the other hand, to achieve the high supply-demand correlation desired, an entirely new approach had to be taken to generate unit arrivals to the scanner/CRT mechanism.

As the title of this experiment indicates, supply and demand were to be highly correlated. In effect, sufficient units, in the right mixture of part numbers (family members), had to arrive at the allocation system on a given day to fill, or almost fill, the orders that were to be shipped that day. (This is approximately what was happening at the firm during this study, except that the orders being filled were selected based on the units arriving at the finished goods processing system.) If units were created to arrive at the scanner in the same pattern, and in the same numbers as required by the orders generated for a given day, then in effect Experiment II would be processing units in batches (the current system). Thus a method for mixing up a day's quota of units, so that the units arrived in a totally random pattern, had to be developed. This method is described below.

4.3 Performance Measures for the Experiemnts

The performance measures observed for both experiments are listed in Table 3. Thirty days of operation were simulated, using identical order sets for Experiments 1 and 2. In this way, positive correlation was induced between the experiments so that any differences observed could be attributed solely to the different ways in which units were generated for allocation. The results of these experiments are presented and discussed below.

5. SIMULATION MODELS FOR THE TWO EXPERIMENTS

Four separate program segments were written and tested to develop the simulation models used to execute the two experiemnts described above. Each of these segments was written in GPSS/PC using an IBM PC/AT. The program segments, described below, are: (1) shipping orders generator; (2) laser scanner/CRT allocation system; (3) unit generator for Experiment 1; and (4) unit generator for Experiment 2. First, the data reduction necessary to make these segments operational is discussed.

5.1 Data Reduction to Determine Simulation Parameters

Three criteria had to be met in building an order generation process to emulate the actual pattern of orders being filled by the firm's finished goods allocation system. These were:

1. The <u>number</u> of orders per day should reflect the average number of orders expected, given the production/shipping levels that were to be simulated.

Table 3. Performance Measures Observed for Experiments 1 and 2 Involving the Finished Goods Allocation System

Area of Concern	Performance Measures
Simulation Day	*Number of Day in the Simulation
List of Orders Being Filled	*Average Contents of the List *Maximum Contents of the List *Average Time an Order Spends on the List
List of Orders Waiting to be Filled	*Average Contents of the List *Maximum Contents of the List *Average Time an Order Spends on the List
Set of Trays into which Allocated Units Are Placed	*Avg. Number of Trays Being Used *Max. Number of Trays Being Used *Avg. Time Tray Spends on Table before It Is Sent to Shipping
Daily Order Data	*Number of New Orders Arriving at System Each Day *Number of New Units Required to Fill These New Orders *Number of Orders Shipped Each Day (including partially filled orders shipped at end of day) *Number of Orders (and partially filled orders) Left, Day's End
Total Order Data	*Number of New Orders that Have Arrived, Cumulative, to Date *Number of Orders that Have Been Shipped, Cumulative, to Date *No. Orders Shipped As Partial Orders, Cumulative to Date *No. Units Required to Fill All Orders Received, Cumulative, to Date
Daily Unit Data	*Units Arriving at Scanner/CRT Each Day *Number of Units Shipped from Stock Each Day *Total Units Shipped Each Day *Ending Inventory, Each Day
Total Unit Data	*Units Arriving at Scanner/CRT, Cumulative, to Date *Units Shipped, Cumulative, to Date

2. The <u>pattern of part numbers</u> (model families and family members) within this group of daily order arrivals should reflect the pattern of part numbers experienced in the real product mix.

3. Order sizes generated should be similar to the sizes of orders typically found in the firm's order releases.

Additional data analyses were required to develop an order generation process that met these criteria.

Eight months of shipping history for the firm were used to develop a target for mean number of units per order, and mean number of order releases per day, given the increased production/shipping target of 1200 units per day selected for testing the proposed allocation system. Table 4 summarizes the extensive data

Table 4. Order Size Classification Probability Density Functions Created from Analysis of Historic Shipping Data

Order Size	1 - 8	9 -16	17 -24	25 -74	75+
Prob[Size]	.643	.158	.067	.113	.019
Actual Mean (from historic data)	2.932	11.698	20.119	39.080	114.34
Simulation Mean (from E[X] of created PDF)	2.90	11.75	20.16	39.10	113.85
Probability Density Function	X P(X)	X P(X)	X P(X)	X P(X)	X P(X)
	1 .40	9 .10	17 .06	25 .40	100 .75
	2 .20	10 .40	18 .07	30 .04	120 .08
	3 .04	11 .10	19 .10	40 .10	125 .13
	4 .04	12 .05	20 .50	50 .40	250 .03
	5 .20	13 .05	21 .10	60 .03	500 .005
	6 .04	14 .05	22 .07	70 .03	600 .005
	7 .04	15 .20	23 .06		
	8 .04	16 .05	24 .04		
	1.00	1.00	1.00	1.00	1.00

analysis required to develop different probability density functions for each order size classification such that:

1. The expected value for the density function created to represent orders for a given size classification would approximately equal the expected value of the historical order group in that size classification.

2. Individual order sizes within each created density function would be similar to those sizes typically found in the historic data, for the same size classification.

From Table 4 it is seen that condition 1 is fully met. Condition 2 was met by reviewing the raw data printouts for the eight months of shipping history and then choosing the most often occurring order size values to be included in each created density function. The overall expected value of the density functions found in Table 4 is 11.67 units per order, which is approximately the overall order size average for the historical data. This value results in a required average of 103 orders per day to reach the target of 1200 units shipped per day, for the simulation study.

The data reduction represented by Table 4 provided a set of simulation parameters that met Criteria 1 and 3 without requiring such large numbers of parameter inputs so as to be intractable. Table 5 summarizes the reduction of model families to meet Criterion 2 for simulation purposes. The variety of modems was reduced from 200 to 25, while nine varieties of PCBs were chosen to representtypical active production varieties. Tables 4 and 5 were represented in the simulation programs by a complex network of GPSS Functions.

5.2 Shipping Orders Generator

The program segment for generating shipping orders was written in two parts: (1) a segment to generate orders according to the appropriate distribution; and (2) a segment to process these orders as units arrive at the allocation system.

Table 5. Reduction of Model Families for Simulations

Model Family	No. Members Simulate	Real	Percent of Total Releases	Units	Simulation Target Average Units/Release
1 LP's	4	28	9.28	18.46	20.30
2 High Speed	4	33	15.57	11.38	7.43
3 DAA	1	8	6.49	5.07	7.98
4 Racks	3	24	10.49	2.85	2.78
5 Boards	9	?	16.12	23.74	15.00
6 Medium Speed	13	107	42.05	38.48	9.32

5.2.1 Order Generator. The GPSS code written to generate orders similar to the pattern shown in Table 4 is included in the program presented in Figure A-1 in the Appendix. The order size distribution generated by this program was validated in the following two ways:

1. By Units. The percent of units falling into each family in the simulation data was compared to the percent of units falling into each family group historically (see Table 5). This comparison is summarized in Table 6. Even without a formal nonparametric test of the goodness of fit, one can see that the simulation data follows the historical data quite well.

2. By Orders. The percent of orders falling into each family in the simulation data was compared to the percent of orders falling into these same for the historic data (see Table 5). This comparison is summarized in Table 6. Again, it is clear that the simulation outputs fit well with historic data.

5.2.2 Order Processor. The next program segment developed took an incoming order and either started to fill it or, if no units were available, placed it on a file of orders awaiting units. The GPSS code for this segment is included in Figure A-1 in the Appendix. Extensive run analyses were made to insure that this program code faithfully followed the appropriate logic. These analyses took approximately 40 hours of pencil-and-paper calculations to examine the outputs of three different days of simulation runs. It was necessary to combine the code for this task with the code of the previous task in order to fully test and validate the generation, arrival, and processing of orders.

5.3 Modeling the Barcode Laser Scanner Operation

Since the laser scanner/CRT system did not exist, estimates had to be made regarding the operating parameters, especially the processing times of

Table 6. Validation Test of the Order Generator, by Orders and by Units per Family Group

	By Units/Family		By Orders/Family	
Family	Data (7 months)	Simulation (N= 31,699)	Data (7 months)	Simulation (N= 10,000)
1 LP	18.46%	18.59%	9.28%	9.36%
2 H Speed	11.38	11.43	15.57	15.47
3 DAA	5.09	5.15	6.49	6.17
4 Racks	2.85	2.61	10.49	10.01
5 Boards	23.74	23.53	16.12	16.97
6 M Speed	38.48	38.69	42.05	42.02

the scanner, the host computer, and the operator. Units were assumed to arrive at the scanner following a Uniform distribution, with a range of 14 to 26 seconds between consecutive arrivals. This corresponds to an arrival rate of one unit every 20 seconds. It was assumed that the system would be in operation 400 minutes out of every 8-hour day, so that the average number of arrivals per day would then be 1200 units. This corresponds to a shipping rate of 24,000 units per month (20 working days), which was the desired maximum production level for the firm based on current sales orders projections.

It was assumed that, once a unit was allowed to enter the scanner, five seconds were required to move the unit to the read area of the laser scanner. An additional three seconds were allowed for the scanner to attempt to obtain a good read. (At a rate of 200 scans a second, this gave the equipment 600 chances to pick up the two or three matching reads necessary to trigger a transaction message to the host computer.) If a good read was obtained, the system waited for the host computer to process the inquiry transaction. This processing time was assumed to be uniformly distributed between 1 and 5 seconds. (In observations of transaction processing times on terminals in the Data Processing Department, no transaction from the IBM 4361 host computer took more than three seconds, with less than one second being the norm.) After receiving allocation instructions on the CRT from a good read, the operator put the scanned unit in the proper location. This time was assumed to be uniformly distributed between five and 25 seconds. Meanwhile, another unit was allowed to enter the scanner, if it was available.

If the laser scanner could not obtain a good label read, the operator would attempt a hand-held scanner read. This time was assumed to be uniformly distributed between two and eight seconds. A successful hand read sent an inquiry transaction to the host computer as did the laser scanner read. If the operator could not get a good hand-scanner read, he would key in the necessary information on the CRT keyboard. This time was assumed to be distributed uniformly from 10 to 20 seconds.

The Uniform distribution was assumed for all equipment and operator processing times in the scanner/CRT operation. This distribution generally has more variance than the other distributions with similar ranges of values. Hence any results from these assumptions would be overstated on the conservative side. Therefore, if the results of this study were satisfactory, production management could assume that the system would behave under real operating conditions where system variation (in processing times) could be minimized.

The GPSS program written to model the scanner/CRT system is presented in Figure A-2 in the Appendix. Preliminary runs with this program indicated that the system required so little average processing time, relative to the interarrival times of the units, that there was almost no delay at all, let alone the build-up of a queue of units awaiting processing. For these preliminary runs, probability of getting a good read with the laser scanner (and with the hand scanner) was set at 0.99. Based on his experience with laser bar-code reading systems, a company engineer suggested that such a reader would achieve approximately 995 good reads in every 1000, so that the probability of 0.99 seemed reasonable.

To be safe, additional runs were conducted with the probability of an unsuccessful read (a bad label) varying from 0.01to 0.20. Even with 20 percent of the label reads failing, causing the operator to intervene, no more than five units ever accumulated at the scanner at a time. Each of these runs processed 5000 units through the scanner/CRT system. Based on these results, it was concluded that the scanner equipment, operator, and computer hardware/software interface would not be a problem if implemented. Therefore the modeling study commenced to examine the effects of processing units individually on the level of finished goods inventory.

5.4 Program for Experiment 1

The programs written for Sections 5.2 and 5.3 were merged to form the complete GPSS program used to execute Experiment 1, described above. The results of this experiment are discussed below.

5.5 Program for Experiment 2

The order generation and laser scanner unit processing segments of the complete program developed to simulate Experiment 1 were directly transferrable to Experiment 2. At the same time, unlike Experiment 1, where the units and orders generated each day were independent, supply (units) and demand (shipping orders) in Experiment 2 were to be highly correlated. In effect, sufficient units, in the right mixture of part numbers (family members), hadto arrive at the allocation system on a given day to fill, or almost fill, the orders that were to be shipped that day. If units were created to arrive at the scanner in the exact pattern, and in exactly the same numbers as required by the orders generated for a given day, then in effect Experiment 2 would be processing units in batches and not one at a time. Thus a method for mixing up a day's quota of units, so that the units arrived in a totally random pattern, had to be developed.

In this method, when the GPSS transaction representing a new order arrived at the order processing section of the program, a copy of it was made using the SPLIT Block, and this copy was sent to the unit generating section of the program. This copy contained information regarding the part numberof the order and the required number of units needed to fill the order. The copy immediately entered a program loop that did the following: (1) created a transaction to represent the first unit coming down the production line to fill the corresponding order; (2) sent the unit transaction to a FIFO queue of units that were waiting to approach the scanner/CRT operation; and (3) placed the order transaction in a queue of unit generating transactions that were waiting to generate the remainder of the units required to fill the corresponding orders. These transactions were filed randomly within this queue. Since the first transaction was always removed to create the next unit approaching the scanner, units thus came to the scanner in a random pattern.

When a unit left the queue described in Step 2 above, it triggered the release of another unit-generating transaction from the queue described in Step 3. The unit transaction continued to the scanner. The unit-generating transaction re-entered the loop, and all three steps were repeated. In this way, each unit bootstrapped another unit into the system as long as there were units waiting to be created; and the order of units approaching the scanner was completely random.

6. ANALYSIS OF SIMULATION RESULTS

Experiments 1 and 2 were executed, using the GPSS/PC programs described above, on an IBM PC/AT computer. Run time for each experiment was approximately 35 minutes, for 30 days of simulated operations, thus demonstrating the wisdom in selecting a micro computer on which to conduct this study. In addition to the security provided by keeping all work in-house, the actual program development, verification and execution times required were probably halved by using the PC. An analysis of the simulation results from each experiment follows.

6.1 Experiment 1

The 30 days of simulation results from executing Experiment 1 were recorded in a GPSS MATRIX SAVEVALUE, and later transferred to a report for the company. Since the supply and demand generation functions were totally independent for this experiment, one should not assume any meaning in any of this data. Rather, it represents what would happen if production management and marketing management totally refused to co-ordinate sales orders and production planning, but instead worked independently to create the supply (production) and demand (marketing) agreed to by higher management, for the company's master plan. This experiment, then, gives the "worst" case, and the firm's production management could expect to achieve much better results if they retained control of the relationship of supply to demand. The values of the various performance measures for the 30th simulated day are presented in Table 7.

The following items are noteworthy from the results of Experiment 1:

1. The average number of orders waiting to be filled continually increases throughout the simulation. This occurs because so many orders are shipped, partially filled, at the end of a production day; and yet the order remains on this list into the next day, waiting for more units to continue the filling of this order. With units being generated randomly and independently of orders, orders of a particular part number would tend to build up if (1) a particularly large order was currently being filled, or (2) the unit generator just happened not to send enough units of that part number at a particular segment of time.

2. The average number of orders being filled at any point in time levels out at about 15, rather quickly in the simulation run.

3. The average number of trays required to handle the simultaneous allocation of orders reaches steady-state by the end of the first day of simulation. This number was in the 44-46 range. The maximum number of trays required was 85, on day 12.

4. By the end of day 30, production had built 170 more units than were needed, in total, to fill all orders that had arrived, to date. Yet there were 1980 units in shelf stock at the end of that day; and there were 180 orders (full and partial) yet to be filled. Thus the real danger of not correlating supply and demand is to have both unfilled orders and units on hand, and to be unable to use any of these units to fill any of these orders.

Table 7 Results, Day 30, Experiments 1 and 2

Experiment		1	2
ORDER	Avg. Content	148	66
LIST	Max. Content	247	195
AVG. TIME ON LIST (sec.)		43,544	12,424
ORDERS BEING	Avg. Content	15	20
FILLED LIST	Max. Content	28	30
AVG. TIME ON LIST (sec.)		4,790	3,883
ALLOCATION	Avg. #	46	52
TRAYS	Max. #	85	93
AVG. TIME ON TABLE (sec.)		8,234	6,193
DAILY	New Orders	120	120
ORDER	New Units	1,323	1,323
DATA	Shipped	118	117
	Partial Shipments	14	14
ORDERS REMAINING		180	53
TOTAL	New Orders	3,526	3,526
ORDER	Shipped	3,764	3,781
DATA	Partial Shipments	418	308
NEW UNITS		36,189	36,189
DAILY	New Units	1,199	1,197
UNIT	Shipped from Stock	632	0
DATA	Total Shipped	1,263	1,197
	Ending Inventory	1,980	0
TOTAL UNIT	New Units	36,019	35,670
DATA	Shipped	34,038	35,669

6.2 Experiment 2

The 30 days of simulation results from executing Experiment 2 were also recorded in a MATRIX SAVEVALUE, and later transferred to the technical report. The various performance measures recorded for the 30th simulated day are also presented in Table 7. These results should be viewed in two ways: (1) in and of themselves; and (2) compared to the results of Experiment I.

6.2.1 Analysis of Experiment 2 Results. The following items are noteworthy from the results of simulating the Experiment 2 system for 30 days:

1. No units are ever shipped from stock. This is because every unit generated in this experiment is created only in response to demand, as espoused in a particular order release. Additionally, one of the ground rules for the study was to assume that all partially filled orders would go to shipping at the end of each production day.

2. There is never any ending inventory of units at the end of the day. See the ground rule cited in item 1, just above.

3. The accumulated number of units shipped, at the end of day 30, is about 520 units less than the total needed to satisfy all orders that had been received, up to that point in time. The problem here is that in day 10, the system received new shipping releases for 1583 units (an unusually large number compared to the average), yet production delivered just 1183 units, slightly below the average target of 1200 units per day. So even though production provided more units than were needed for newly arrived order releases on more days than they did less units, day 10

caused production to get behind demand, and they have not yet caught up. (This suggests a follow-on study that would investigate appropriate decision rules for when to invoke overtime to catch up.)

6.2.2 Comparing Results of the Two Experiments. When compared to the results of Experiment 1 (see Table 7), several noteworthy observations may be made about the results of Experiment 2:

1. The system depicted in Experiment 2 will, on average, be filling more orders than that from Experiment I. And the average number of orders waiting to be filled is less than half, for Experiment 2.

2. Because more orders are being filled, on average, more trays will be needed to handle the additional orders being actively filled at the scanner/CRT operation.

3. The order arrival process is identical for each experiment.

4. The number of orders left to fill or partially fill in the system of Experiment 2 is significantly less (53 compared to 180) than those left in Experiment 1 on day 30. This is because all units that entered the allocation system have been shipped.

7. CONCLUSIONS AND RECOMMENDATIONS

This section presents conclusions drawn after analyzing carefully the outputs from Experiments 1 and 2. In addition, some of the recommendations made to the firm's management are presented.

7.1 Conclusions

The following conclusions are drawn concerning the results of this study. It should be noted that these are solely the opinions of the analysts.

1. The concept of allocating production units to orders on a one-at-a-time basis, as these units arrive at the finished goods system on a seemingly (to that system) random basis, is feasible and viable. An interdiciplinary team of several people would need to be assembled to design all of the parameters of the system.

2. At this point in time, the rest of the production system, upstream from allocation all the way to mechanical assembly, is not structured to operate smoothly with the proposed allocation system. Most of these upstream departments and operations still process units in batches, with material handling equipment designed to handle units in batches. Thus implementation of the proposed system would not yet realize the smoother production flows envisioned until upstream operations also processed units one at a time.

3. Although implementation of the proposed system is perhaps premature, assuming it is to be implemented, this system could also handle allocation in batches, one or a few at a time, if it were implemented. Thus the system operators could be developing experience with the equipment, and Data Processing could have sufficient time to insure that all program routines, data files, and data file links were correct before this system had to carry the load for which it was designed.

4. The alternate layout of the finished goods area, implemented during this study, appears to have eliminated a good deal of the congestion that occurred near the Button-Up area. In theory, this layout is now a straight line, with side paths in and out of planned storage, so that, with proper capacity planning and proper controls on the loading of the system, this redsigned configuration could handle all allocation for some time to come. Attention should be given to reducing the existing finished goods inventory on the shelves in order that this space can be opened up, allowing a freer flow of new units through the finished goods and shipping departments.

5. Although the results of Experiment 2 seem to indicate that the proposed one-at-a-time allocation system is feasible and viable, caution should be exercised until such time as this experiment can be replicated using different random numbers. The cost of this caution is certainly worth it when considering the risk costs of implementing such a system without additional verification of the apparent results of Experiment 2.

7.2 Recommendations.

These recommendations deal with directions to consider taking in extending the pilot study described in this report.

1. The first recommendation is to replicate Experiment 2 at least four more times. These five runs should be compared, and if they indicate similar results, then a much stronger confidence can be assumed for the conclusions drawn for this project.

2. Although Experiment 2 assumed a strong correlation between supply and demand, the extremely random pattern of unit arrivals does not approach the pattern that would be experienced in reality. Experiment 3 should be designed and executed (with proper replications). This experiment would have a "quasi-random" pattern of unit arrivals. Currently, units come to Button-Up in batches, from upstream parallel servers who specialize, at a point in time, on a narrow range of models. This would be captured in Experiment 3 by having the copy of the new order enter a loop dedicated only to members of its part number family. In this way, six (or more) loops would act as parallel feeders into the scanner/CRT system. Each of these parallel loops would randomly generate the next unit from among its current active part number orders.

3. In this study, the system boundries were set at a point downstream of the L-Seal equipment. In future analyses, this boundry should be moved upstream, one step at a time, until all production facilities from mechanical assembly through shipping are included in a macro model of the entire system.

4. The ultimate goal should be to develop a simulation model of the entire production facility, from parts receiving to orders shipping. In some regards, the MRP system in place is such a model. Unfortunately, it is difficult to properly simulate with MRP without a systems regeneration; and frequent regenerations are impossible because of the time and cost per regeneration, and because a regeneration requires so much mainframe time and resources that are best used for handling regular production transactions in real time. This total systems model would not have the fine details found in Experiments 1 and 2. But it would be able to quickly assess the overall impact of realized or proposed changes in the production or marketing aspects of the firm.

5. Certain of the data analyses and reports generated for this project would be useful to senior members of the production management team, and ought to be considered as regular outputs from the firm's database.

8. EPILOG

In the middle of the study reported in this paper, the firm's management elected to rearrange the finished goods allocation area to eliminate the congestion due to criss-crossing of flow paths near the Button-Up area. Significant reduction in congestion was immediate and pronounced.

In subsequent months, the firm has installed a number of material handling devices that will handle nearly every product in the company's product line. This equipment, along with the barcode labeling system now in place, makes it possible to implement the one-at-a-time processing studied in this project.

ACKNOWLEDGMENTS

The authors acknowledge the many inputs of members of the Manufacturing Engineering Department of the firm studied for this paper. In addition, financial support for this project was provided by the firm and by the Johnson Research Center, University of Alabama in Huntsville. The opinions in this paper are strictly those of the authors.

Several trademarks have been referenced in this paper. IBM, PC, and AT are trademarks of the International Business Machines Corporation. SIMSCRIPT II.5 and SIMFACTORY are trademarks of CACI, Incorporated. SIMAN is a trademark of Systems Modeling Corporation. GPSS/PC is a trademark of Minuteman Corporation.

APPENDIX

The GPSS programs located in the appendix have been deleted for space considerations. Genuinely interested readers may obtain a copy of the listing by sending a blank diskette (DS/DD, 360K) in a mailable pouch to the first author. Return postage is the responsibility of the requestor.

REFERENCES

CACI (1987a). PC SIMSCRIPT II.5 Introuction and User's Manual, Third Edition. CACI, Inc.-Federal, Los Angeles.

CACI (1987b). SIMFACTORY with Animation. CACI, Inc.-Federal, Los Angeles.

Conway, R. and Maxwell, W. (1986). XCELL: A Cellular, Graphical Factory Modeling System. In Proceedings of the 1986 Winter Simulation Conference, Institute of Electrical and Electronic Engineers, Washington, D.C., 160-163.

MINUTEMAN (1986). GPSS/PC Reference Manual. MINUTEMAN Software, Stow, Massachusetts.

Pegden, C. D. (1985). Introduction to SIMAN. Systems Modeling Corp., Sewickley, Pennsylvania.

AUTHOR'S BIOGRAPHIES

EDWARD F. STAFFORD, JR. is Associate Professor of Management Science, University of Alabama in Huntsville. He received the BS and MS degrees in Industrial Engineering, and the Ph.D in Management Science, all from The Pennsylvania State University. His research interests include simulation and modeling of manufacturing systems, scheduling, and sequencing problems. His papers have appeared in such publications as Journal of the Operational Research Society, Journal of Consumer Research, Decision Sciences, Production and Inventory Management, and Robotics.

Dept. of MIS/MSC, University of Alabama in Huntsville, Room 342 Morton Hall, Huntsville, AL 35899 (205) 895-6510.

BERNARD J. SCHROER is Research Professor of Management Science and Director, Johnson Research Center, University of Alabama in Huntsville. He received the Ph.D degree in Industrial Engineering from The Oklahoma State University. His papers have appeared in such publications as Simulation, Robotics, and Computers and Industrial Engineering.

Johnson Research Center, University of Alabama in Huntsville, Huntsville, AL 35899. (205) 895-6361.