Automatic Programming of Simulation Models

Task 3

Final Report
D.O. 34 Task 3

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ABSTRACT

This report contains the research results from 1988 research grant NAG8-641 from NASA/MSFC and a follow on 1989 contract NAS8-36955. Therefore, some of the results in this report were documented in the final report, Automatic Programming of Simulation Models, UAH Report 725, September 1988.
1.0 INTRODUCTION

The concepts of software engineering offer an approach to minimizing software development problems and to improving the overall simulation modeling environment. Software engineering encompasses the entire life cycle process by which a program is conceptualized, structured, programmed, verified, validated, and maintained. The goal of software engineering is to develop quality code, on time, and within budget. To meet this goal requires a variety of programming tools such as a good language with a library of reusable modules, a flexible editor, and a potent debugger.

The focus of this research project is on using the concepts of software engineering to improve the simulation modeling environment. Of special interest is to apply an element of rapid prototyping, or automatic programming, to assist the modeler define the problem specification. Then, once the problem specification has been defined, an automatic code generator is used to write the simulation code.

The following two domains were selected for evaluating the concepts of software engineering for discrete event simulation: manufacturing domain and a spacecraft countdown network sequence.

The specific tasks for this follow-on contract were to:

1. Define the software requirements for a graphical user interface to the Automatic Manufacturing Programming System (AMPS) system.
2. Develop a graphical user interface for AMPS.
3. Compare the AMPS graphical interface with the AMPS interactive user interface.
2.0 MODELING LIFE CYCLE

There has been considerable interest in improving the process for developing simulation models. One area of interest is the development of simulation support environments. Henriksen (1983) suggests a simulation software development environment composed of a set of integrated software tools. Standridge (1983) proposes the integration of software tools and database management techniques on each stage of the simulation model development process. Pidd (1984) also outlines a simulation support environment concept for handling one simulation problem at a time.


More recently, the Semiconductor Manufacturing Technology Initiative (SEMATECH) is developing a coherent modeling environment called CHIPS (Coherent Intergrated Planning System). CHIPS consists of five major modules: process flow analysis module, queueing network analysis module, system simulation module language, and a cost analysis module (Phillips, et al 1989). SEMATECH is a cooperative project between industry and government with the goal to recover the world leadership in semiconductor manufacturing.
Figure 1 outlines the phases of the model life cycle (Balci 1986 and Nance 1988). Basically, the modeling process is iterative rather than sequential as indicated in Figure 1. That is, the modeler goes back and forth between the various phases during the modeling process.

Figure 1 can be considered as the traditional approach to simulation modeling (Balci 1986 and Nance et al 1988). The same process also applies to general modeling problems. The process consists of six stages described on the left side of the figure. On the right side, different types of models generated at different stages through the process are listed. For example, a conceptual model of a manufacturing system may be the understanding of the system by the modeler and in the mind of the modeler. A communicative model of the manufacturing system may be a graphic representation of the system in the form of a block diagram, flowchart, or network diagram. A GPSS simulation program of the manufacturing system is a programmed model. The model results are generated by executing the program.

3.0 SOFTWARE ENGINEERING IN THE MODELING LIFE CYCLE

Rapid prototyping is a technique used in software engineering for capturing system requirements early in the modeling life cycle so that these requirements can be evaluated, tested, verified and validated early in the process before starting the actual coding. The end result of rapid prototyping is the potential for large increases in productivity.

An element of rapid prototyping is the automatic conversion of the communicative model into executable code. Automatic Programming (AP) is defined as the automation of some aspects of the computer programming process (Barr 1982). This automation is accomplished by developing another
Figure 1. Phases in the modeling life cycle
program, an automation programming system, that raises the level of satisfying computer program instructions. In other words, an AP system helps programmers write programs. AP systems improve the overall environment for defining and writing programs (Brazier and Shannon 1987). Consequently, there should be a reduction in the amount of detail that the programmer needs to know.

To write simulation programs automatically, two phases in the simulation modeling process are usually automated. The first phase is the automation of the process of specifying the problem. The second phase, and the more difficult phase, is the automatic generation of executable code in the target simulation language.

3.1 Problem Specification

Figure 2 shows the overlaying of automatic programming onto the modeling life cycle in Figure 1. Phase II, model development, has been replaced by a user interface program that assists the modeler in defining the problem specification.

The automatic problem specification can be considered as an intelligent assistant to the user in defining the simulation model. Some authors call this approach the specification acquisition element of the simulation model construction (Murray and Sheppard 1988).

Three approaches for assisting the user in defining the simulation model or problem specification are:

° Natural language interface
° Interactive graphical interface
° Interactive dialogue interface
Figure 2. Software engineering imbedded in the modeling life cycle
There is a fourth approach for assisting in the definition of problem specification, which is the use of a high-level specification language. This approach is less domain specific. However, the use of a high-level specification language requires the user to learn another language in order to define a problem.

3.1.1 Natural language interface

The Natural Language Interface (NLI) allows the user to specify the problem in free text format to the computer via a keyboard. The NLI then attempts to parse the text and automatically generate the simulation code in the target language. Most NLI's communicate interactively with the user to identify missing information and possible inconsistencies. The Natural Language Programming for Queueing Simulations (NLPQ) (Heidorn 1974) and the Electronic Manufacturing Simulation System (EMSS) (Ford and Schroer 1987) are two examples of a NLI.

3.1.2 Interactive graphical interface

The second approach to assist the user in specifying the problem is an Interactive Graphical Interface (IGI), which is less difficult than the NLI. An IGI consists of a menu of icons that are mouse selectable by the user in constructing a graphical representation of the system being simulated. Once the system has been constructed, the user inputs the attributes corresponding to the icons through the keyboard.

An example of an IGI is by Khosnevis and Chen (1986) who developed an object-oriented approach for graphically modeling a system. This system is rule-based and written in common LISP on an IBM PC. Once the graphical
description of the model is completed, the system automatically generates the equivalent SLAM simulation code.

3.1.3 Interactive dialogue interface

The third approach to assist the user in defining the problem specification is the Interactive Dialogue Interface (IDI). An IDI consists of a series of questions that are asked the user. Among the three approaches for defining the problem specification, the interactive dialogue interface is the one most commonly used by developers.

Several systems have been developed using the interactive dialogue approach. Haddock and Davis (1985) have developed a Flexible Manufacturing System (FMS) simulation generator. Brazier and Shannon (1987) have developed an automatic programming system for modeling Automated Guided Vehicle System (AGVS). Murray and Sheppard (1988) have developed a Knowledge Based Model Construction (KBMC) system to automate model definition and code generation. These last three systems generate SIMAN code.

3.2 Automatic simulation code generation

In Figure 1, Phase III, write model, has been replaced in Figure 2 by an automatic code generation program. Basically, two approaches exist for taking the internal problem specification and then automatically generating executable code in the target simulation language. The first approach is to generate simulation code directly from the internal representation of the problem specification.

A second approach is to use a library of predefined macros to assist in the automatic generation of the simulation code. The advantage of such
an approach is the ability to solve more specialized problems than those previously discussed in the literature. The disadvantage is that most macros are domain specific. As a result, additional macros are needed to solve another problem domain.

4.0 AUTOMATIC MANUFACTURING PROGRAMMING SYSTEM (AMPS)

4.1 Introduction

The Automatic Manufacturing Programming System (AMPS) is a software engineering tool for rapidly prototyping selected phases of the simulation process for domain specific manufacturing systems. The AMPS system consists of the following elements:

° A set of generic manufacturing modules written in GPSS/PC (Minuteman 1986)

° An interface program for extracting the problem from the user and for creating a problem specification file

° An automatic code generator program for creating the code in the target simulation language GPSS/PC

The AMPS system domain is those manufacturing systems that can be described as having:

° Assembly and subassembly lines where parts are being added to an assembly.

° Manufacturing cells that are providing parts to the assembly and subassembly lines.

° Inventory of parts being moved between the manufacturing cells and subassembly lines.
4.2 AMPS System Overview

Figure 3 is an overview of the AMPS system operation. Once the user has scoped the problem domain, the user sits at a workstation and responds to the questions from the interface program. Based on the responses, the interface program creates an internal problem specification file. This file includes the manufacturing process network flow and the attributes for all stations, cells and stock points. The problem specification file is then used as input to the automatic code generator program which generates the simulation program in the target language GPSS/PC.

The user then adds the experimental frame, such as the run statements, and the GPSS/PC simulation program is executed. To change the GPSS/PC model, the user recalls the problem specification. The user interface then provides the simulationist with a number of options to change or modify the problem specification. The code generator will then rewrite the GPSS program.

4.3 Library of GPSS Macros

In analyzing most manufacturing systems at the macro level, the following function are generally similar in nature:

- Assembly - adding part X to part Y resulting in part Z
- Fabrication - making of part X from part Y
- Inspection - inspecting part X
- Inventory transfer - moving part X or a cart of part X from stock point A to stock point B
- Simple operation - performing an operation on part X resulting in a modified part X
Figure 3. AMPS system overview
These five functions represent the current domain of manufacturing functions within the AMPS system. Once the manufacturing functions have been defined, GPSS subroutines are written for the functions (see Appendix A). These routines constitute a library of predefined GPSS subroutines, or macros. This library of macros is then called, when needed, in the construction of the GPSS simulation model. Currently, the AMPS system has the following five GPSS subroutines:

- Assembly
- Manufacturing
- Inventory transfer
- Inspection
- Task

In a recent article on SEMATECH (Phillips, et al 1989), researchers have identified ten machine modules for the semiconductor manufacturing domain. Furthermore, the SEMATECH group has indicated that possibly no more than 16-20 generic machine modules may be required to completely represent the semiconductor manufacturing environment.

Figure 4 briefly describes each of these macros. For example, the assembly station macro has the capability of simulating the adding of a variety of different items to the incoming part resulting in a modified part that is then transferred to the next destination, a station or stock point. For example, in Figure 4, station STA1 may assemble two part C's and three part D's to the incoming part A resulting in Part B.

The manufacturing cell makes a cart of specified parts when an order is received. The cell can make multiple part types. For example, in Figure 4, cell MC1 may make one part A from two part C's and three part D's.
Figure 4. GPSS manufacturing macros
and one part B from one part D. The task station performs an operation on a part. For example, in Figure 4 an operation is performed at station STA4 on part E resulting in a modified part E. The inspection station inspects a defined percentage of parts. Of those inspected, a defined percentage is defective. Of those defective, a defined percentage is scrapped.

The inventory transfer macro grants part requests from an assembly station or a manufacturing cell and checks if the inventory system is a push or pull. For a pull system the macro orders a cart of parts by sending an empty cart back to the source and sends a full cart of parts to the demand stock point from the source stock point.

4.4 Sample Problem

Figure 5 is an example of a typical manufacturing system that can be modeled by the AMPS system. The manufacturing system consists of one assembly line, two subassembly lines, and two manufacturing cells. The assembly line consists of two assembly stations, one task station and one inspection station. Subassembly line 2 consists of one assembly station and one task station while line 3 consists of two assembly stations. Manufacturing cell MC1 provides part type C for assembly station ASSY1 and part type H for assembly station ASSY8. Manufacturing cell MC2 provides part type E for assembly station ASSY5 and part types F and G for assembly station ASSY7. There are a variety of stock points, labeled A through L, located throughout the manufacturing system.

The GPSS program for the manufacturing system in Figure 5 that was generated by AMPS consists of 344 blocks, of which 110 blocks are for the five macros, 25 blocks are for the main program and 209 blocks are matrix savevalues for defining the system attributes.
Figure 5. Manufacturing system
5.0 AUTOMATIC NETWORK PROGRAMMING SYSTEM (ANPS)

5.1 Introduction

Large simulation projects have been undertaken for the space program. One of the projects involves simulating the countdown sequence prior to spacecraft liftoff. A countdown has a number of constraints. For example, on a lunar mission, these constraints may include allowable launch azimuth, required earth orbit inclination, daylight at the lunar landing area, and daylight at the primary recovery area. As a result of these constraints, a launch window of only several hours could exist during three consecutive days in a month.

Another constraint is the cryogenic propellents. The handling of the cryogenic propellents prevent a launch hold from one day to the next. For example, a launch that is scrubbed after the cryogenics have been loaded is generally delayed at least until the third day within the launch opportunity. In addition, a typical prelaunch consists of thousands of events, both on the launch vehicle, as well as the ground support equipment, that must be successfully completed to launch within a given launch window.

The Automatic Network Programming System (ANPS) is a tool to assist the modeler of prelaunch countdown sequences define the problem, and to then automatically generate the program code in the target simulation language GPSS/PC. The domain of problems that can be solved by ANPS is the prelaunch activities of space vehicles and the operation of supporting ground support equipment. A broader domain is reliability network models of hardware systems and subsystems.
5.2 Previous Research

Snyder et al. (1967) have developed a simulation model of the Saturn V prelaunch activities beginning at T-24 hours and continuing through T-O hours, or lift-off. This model was used to predict the probability of launching the spacecraft within a given launch window. A second objective of the model was to identify locations in the countdown for placing holds and to determine the length of these holds. The model consisted of over 1100 vehicle subsystems and 400 ground support subsystems. A detailed time line was developed showing the interrelationships of these subsystems. In additions to the time line, the model input included operational data, reliability data, and maintenance data. The model was written in GPSS-II and ran on an IBM 360 computer.

The Snyder model was expanded to include multiple launch windows and the operational sequence when a launch window was missed and the spacecraft had to be recycled to the next launch window (Schroer 1969). The model was used to predict the probability of launching a spacecraft within a given set of back-to-back launch windows. A second objective was to predict the probability of launching in a subsequent window, given a window had been missed and a recycle sequence and a possible hold had to be executed before resuming the countdown.

5.3 ANPS System Overview

The three AP elements in ANPS are an Interactive Dialogue Interface (IDI), a library of software modules, and an automatic simulation code generator.
The actual operation of ANPS is similar to AMPS (see Figure 3). The ANPS system uses an interactive dialogue interface to assist the user define the problem specification. Using this interface, the user sits at a personal computer and enters into a dialogue with the ANPS system. Based on the user's responses, the interactive interface creates an internal problem specification file. This file includes the time line for the countdown sequence, the attributes for the activities, and the dependent relationships between the activities. The specification file is used by the code generator program to create the simulation program in the target simulation language GPSS/PC.

5.4 Library of GPSS Macros

Since the ANPS system is domain specific to prelaunch countdown sequences, the number of needed software modules is minimal. Consequently, ANPS consists of the following four GPSS modules (see Appendix B):

- Fixed activity operation function (VENT_A)
- Continuous activity operation function (VENT_B)
- Activity failure function (FAIL)
- Activity interrupt function (XACT_DELAY)

These modules were selected based on a detailed evaluation of the two previously discussed models by Synder (1967) and Schroer (1969). Interestingly, several of these previously developed modules were written as Fortran HELP routines using the old GPSS-II.

The fixed activity operation function (VENT_A) simulates the operation of each fixed time activity and its time to failure. If the activity fails during its operation, the transaction is forwarded to the activity failure function (FAIL).
The continuous activity operation function (VENT_B) simulates the operation of each continuous time activity and its time to failure. This activity is not completed until all other related activities are completed. For example, system power is a continuous time function that will be on until all activities requiring power are completed. If the activity fails, the transaction is forwarded to the activity failure function. (FAIL).

The activity failure function (FAIL) simulates the failure of an activity as indicated by functions VENT_A and VENT_B. When an activity fails, all the dependent activities enter a hold state. The function then simulates the time to repair the activity. If another activity fails during the delay of a dependent activity and the dependent activity is dependent on the first failed activity, the additional time to repair, if any, is added to the delay of the dependent activity. The failure function assumes that a dependent activity that has been delayed cannot fail during the delay. The activity interrupt function XACT_DELAY contains the logic to add any additional time to an activity on hold if another activity fails during the hold and the held activity is dependent on the failed activity.

The ANPS macros impose the following constraints:

- An activity failure will cause that activity to be delayed until the failure has been repaired.
- All dependent activities will also be delayed for the same time until the failure has been repaired.
- If another activity fails during the delay of a dependent activity and the dependent activity is also dependent on the just failed activity, the additional time to repair, if any, is added to the delay of the dependent activity.
A dependent activity that has been delayed cannot fail during the delay time and will not cause other dependent activities to be delayed.

No two continuous activities can end on the same node.

No two activities can start from the same node and terminate on the same node.

5.5 Sample Problem

Figure 6 is a time line for a simplified prelaunch countdown sequence consisting of 16 fixed activities and two continuous activities. Figure 7 is the time line redrawn in the form of a network diagram and structured for input to the ANPS system. The dotted lines in these figures indicate time line constraints. For example, activities ACT11 and ACT15 must be completed before starting activity ACT12. ACT21 is a dummy activity with zero time that is used to impose the activity ACT15 constraint.

Several other dummy activities were also required to construct the network diagram. For example, dummy activity ACT23 was added to simulate the termination of the second continuous activity ACT2, since no more than one continuous activity can end at a node. Also, dummy activity ACT19 was added at the completion of activity ACT5 since no two activities can start from the same node, node 2, and end at the same node, node 4.

Table I contains the time attributes for the activities in the prelaunch countdown. These attributes include activity duration, activity time to failures, and activity time to repairs. Note that activities ACT1 and
Figure 6. Prelaunch countdown for sample problem
Figure 7. Network representation of prelaunch sequence
Table I. Countdown sequence attributes

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<th>Failure time (hours)</th>
<th>Repair time (minutes)</th>
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<td>N(60,6)</td>
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<tr>
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Table II. Operational dependencies between activities

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<td>x</td>
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<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table I.
Table II.
ACT2 have continuous operation times. That is, these activities will operate during the entire prelaunch countdown. An example of a continuous activity is electrical power that may be needed to operate a number of activities.

Table II contains the operational dependencies between the activities. In other words, the table gives the effect of an activity failure on other activities in the prelaunch. For example, a failure of the continuous activity ACT1 will cause a stopping of activities ACT3, ACT4, ACT5, ACT12, ACT13, and ACT18. Likewise, a failure of activity ACT4 will cause a stopping of activity ACT5.

Figure 8 gives the distribution of time to complete the prelaunch sequence in Figure 6. This distribution is based on the simulation of 200 launches. The mean time to complete the countdown is 34.2 hours. Launch vehicle availability (LVA) is defined as the probability of launching within a given launch window. The LVA for up to six hour window is given in Figure 9. The LVA for a two hour window is 0.015 and increases to 0.596 for a six hour window.

6.0 DEVELOPMENTAL AP SYSTEMS

Table III contains a comparison of the six platforms that have been developed for the AMPS and ANPS systems. Two programmers were used to develop the systems. Programmer A was Mr. W.S. Dwan who was a graduate student in computer science at the University of Alabama in Huntsville (UAH). Mr. Dwan was experienced in LISP on a Symbolics workstation. Programmer B was Mr. S.X. Zhang who was a visiting scholar at UAH from Northwestern Polytechnical University in Xian, China.
Figure 8. Time to complete prelaunch countdown
Figure 9. Launch vehicle availability
<table>
<thead>
<tr>
<th>System</th>
<th>User interface</th>
<th>Order of development</th>
<th>Programmer</th>
<th>Platform</th>
<th>Language</th>
<th>Target language</th>
<th>Man-months</th>
<th>Lines of code</th>
<th>Lines of code per month</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMPS</td>
<td>IDI</td>
<td>1</td>
<td>A</td>
<td>Symbolics</td>
<td>Lisp</td>
<td>GPSS/PC</td>
<td>6</td>
<td>1,500</td>
<td>250</td>
</tr>
<tr>
<td>ANPS/PC</td>
<td>IDI</td>
<td>2</td>
<td>B</td>
<td>IBM/PC</td>
<td>Prolog</td>
<td>GPSS/PC</td>
<td>4</td>
<td>1,300</td>
<td>325</td>
</tr>
<tr>
<td>AMPS/PC</td>
<td>IDI</td>
<td>3</td>
<td>B</td>
<td>IBM/PC</td>
<td>Pascal</td>
<td>GPSS/PC</td>
<td>3</td>
<td>1,900</td>
<td>633</td>
</tr>
<tr>
<td>AMPS/PC</td>
<td>IDI</td>
<td>4</td>
<td>B</td>
<td>IBM/PC</td>
<td>C</td>
<td>GPSS/PC</td>
<td>4</td>
<td>1,300</td>
<td>325</td>
</tr>
<tr>
<td>AMPS/Graphics</td>
<td>IDI</td>
<td>5</td>
<td>A</td>
<td>Symbolics</td>
<td>Lisp</td>
<td>GPSS/PC</td>
<td>15</td>
<td>3,500</td>
<td>233</td>
</tr>
<tr>
<td>AMPS/PC</td>
<td>IDI</td>
<td>6</td>
<td>B</td>
<td>IBM/PC</td>
<td>C</td>
<td>SIMAN/PC</td>
<td>3</td>
<td>1,600</td>
<td>533</td>
</tr>
</tbody>
</table>

Notes:
1. IDI - Interactive Dialogue Interface
2. IGI - Interactive Graphical Interface
3. AMPS - Automatic Manufacturing Programming System
4. ANPS - Automatic Network Programming System
6.1 AMPS/Symbolics

The AMPS system was initially developed for the Symbolics 3620 workstation and used the Interactive Dialogue Interface (IDI). Figure 10 is a portion of a typical IDI dialogue. The AMPS system was written in LISP by programmer A in six man months. The system consisted of 1,500 lines of LISP code. The code production was 250 lines per month.

A detailed description and operation of the AMPS system is given in UAH Report 720, Automated Manufacturing Programming System User's Manual, September 1988. The system has been submitted to NASA COSMIC (reference #28367). The AMPS/Symbolics system was also ported to the TI Explorer workstation.

6.2 ANPS

ANPS was the second system developed and used with the IDI dialogue. Figure 11 is a portion of a typical IDI dialogue. This system was developed by programmer B using Turbo Prolog on an IBM/PC. The system consisted of 1,300 lines of code. The code production was 325 lines per month.


6.3 AMPS/PC

This version of AMP was developed in Turbo Pascal on an IBM/PC and uses an IDI dialogue. The system was developed by programmer B using Turbo Pascal (Borland 1987) on an IBM PC. The system consists of 1,900 lines of code. The code production was 633 lines per month.
How many types of final products to be made in the manufacturing system: 2
Name of the product 1: A
Name of the product 2: B

Do you want to modify the input above? (Y or N) No.

------------------------------------------
* Specification of product A
------------------------------------------

Type of the facility used to produce product A at the final stage: Assembly line

Name of the line to produce product A: MAIN
Number of stations in line MAIN: 2
Capacity and initial inventory at the stock points:
  Maximum number of parts at stock point: 2000
  Initial number of parts at stock point: 0

Do you want to modify the input above? (Y or N) No.

------------------------------------------
* Description of line MAIN
------------------------------------------

Input process (Interarrival time of orders):
  Time:
  Distribution: Exponential
  Mean: 100

Do you want to modify the input above? (Y or N) No.

station 1
(1) Station id: 1
(2) Type of station: Assembly station
(3) Station name: ONE
(4) Part required:
  Number of part types required: 2
  Name of part: C
  Number of part: 1
  Name of part: D
  Number of part: 2
(5) Time:
  Distribution: Normal
  Mean: 100
  Standard deviation: 2

Do you want to modify the input above? (Y or N) No.

Figure 10. Typical IDI dialogue for AMPS/Symbolics
Name of GFSS program file : EXAMPLE1
Name of GFSS problem specification file: SPEC1

1. Number of activities : 7

2. Activity attributes
   Activity name : $ACT1
   Activity type (fixed/variable) : FIXED
   Duration distribution type : CONSTANT
      mean time : 20
   Starting node number : 1
   Ending node number : 5
   MTTF distribution type : CONSTANT
      mean time : 10
   MTTF distribution type : CONSTANT
      mean time : 0

   Number of dependent activities : 0

Do you want to modify the above input (Y/N): N

Figure 11. Typical IDI dialogue for ANPS
A detail description and operation of the system is given in UAH Report 723, Automatic Manufacturing Programming System User's Manual, October 1988. The system has been accepted for publication by NASA COSMIC (reference #28398).

6.4 AMPS/PC

This version of AMP is identical to the AMPS/PC in Section 6.3. The only difference is this version is written in Turbo C (Borland 1988) for the IBM/PC. The system consists of 1,300 lines of code. The code production was 325 lines per month. This system has not been submitted to NASA COSMIC.

6.5 AMPS/Graphics

This version of AMPS was developed for the Symbolics 3620 workstation and uses the Interactive Graphical Interface (IGI). The system was written in LISP by programmer A in fifteen months. The system consists of 3,500 lines of code. The code production was 233 lines per month.

The AMP/Graphics system is documented in UAH Report 788, Automatic Manufacturing Programming/Graphics, August 1989. The system is being submitted to NASA COSMIC. Since the AMPS/Graphics has been developed under the followon contract, a more detailed discussion of the system follows.

6.5.1 AMPS/Graphics Overview

An overview of the AMPS/Graphics system is given in Figure 12. The user sits at a Symbolics 3620 workstation to create or modify the model. The output of the Interactive Graphical Interface (IGI) program is the
Figure 12. AMPS/Graphics system overview
The problem specification file. The automatic code generator program combines the specification file with the selected GPSS/PC macros and writes the simulation program. The program is then downloaded to the IBM PC and executed by the GPSS/PC system. To modify the program, the user recalls the problem specification file and the cycle repeated.

The tree structure of the AMPS commands is given in Figure 13. The system consists of five menus: Main, Model, Layout, Specification and GPSS. In summary, the Main Menu contains the master control commands. The Model Menu contains the commands for creating, editing, saving, and reading models. The Layout Menu contains the commands for constructing the model. The Specification Menu includes the commands for defining the model parameters. The GPSS Menu contains the commands for writing the simulation code.

Figure 14 is a list of the icons available in AMPS. These icons serve as the construction blocks in defining a manufacturing system. To define a manufacturing system the user selects these icons and develops a process flow showing the various stations and the flow between the stations. Figure 15 gives all the feasible connections between the icons. For example, it is not feasible to connect an inspection station to a manufacturing cell.

The function and connection rules for each of these icons are documented within the system. The user can click on an icon to learn the function and the rules of the icon. All the connection rules are implemented in the system as construction rules of the models. As the user creates a model, the AMPS checks the partially completed model immediately for possible local violations of the rules. For example, Figure 16 shows the rules for an assembly station.
Figure 13. AMPS/Graphics commands
<table>
<thead>
<tr>
<th>Icons</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Assembly station icon]</td>
<td>Assembly station</td>
</tr>
<tr>
<td>![Starting point of an assembly line icon]</td>
<td>Starting point of an assembly line</td>
</tr>
<tr>
<td>![Demand stock point of pull inventory system icon]</td>
<td>Demand stock point of pull inventory system</td>
</tr>
<tr>
<td>![Ending stock point for final product icon]</td>
<td>Ending stock point for final product</td>
</tr>
<tr>
<td>![Inspection station icon]</td>
<td>Inspection station</td>
</tr>
<tr>
<td>![Manufacturing cell icon]</td>
<td>Manufacturing cell</td>
</tr>
<tr>
<td>![Stock point for part ordered from outside icon]</td>
<td>Stock point for part ordered from outside</td>
</tr>
<tr>
<td>![stock point for Push inventory system icon]</td>
<td>stock point for Push inventory system</td>
</tr>
<tr>
<td>![Supply stock point of pull inventory system icon]</td>
<td>Supply stock point of pull inventory system</td>
</tr>
<tr>
<td>![Task station icon]</td>
<td>Task station</td>
</tr>
</tbody>
</table>

Figure 14. Library of AMPS/Graphics icons
Figure 15. Valid AMPS/Graphics icon connections
Figure 16. Assembly station rules
When the process flow has been completely drawn, the AMPS/Graphics will check the completeness of the structure. After the layout has passed the check for completeness, the user enters the parameters of the manufacturing system. The user then clicks on each icon to input the specifications. A parameter menu will pop up on the screen. Figure 17 shows the parameter menu of an inspection station. The user can move the cursor to each field to enter the data. The system then performs additional checking. For example, the AMPS will check whether the data are the right types for the fields. The AMPS will make certain that an initial inventory level is not larger than the capacity.

6.5.2 Sample Problem

Figure 18 is an example of a simple manufacturing system formulated using the AMPS/Graphics system. The manufacturing system consists of an assembly line, MAIN and two assembly stations, STA1 and STA2. The assembly line produces part A. Station STA1 assembles part C to the incoming part and passes it to station STA2. Station STA2 then assembles part B to the incoming part from station STA1 and produces part A. Part C is supplied through a pull inventory control system from manufacturing cell MC. A part C is made of parts D and E at the manufacturing cell MC. Parts B, D, and E are supplied from outside sources.

Parts arriving at the assembly line follow the exponential distribution with a mean of 100. The assemble time of each of the two stations is a constant 100. Station STA1 requires one part C and station STA2 requires one part B for an assembly. The stock point to hold the final product, part A, has a capacity of 1000 units.
Figure 17. Typical parameter input

Figure 18. Sample manufacturing system
Part C is used at station STA1 and is manufactured at manufacturing cell MC. A pull inventory system controls the production and shipment of part C, which is represented by a pair of supply and demand stock points. A vehicle WIG is used to move the carts between the stock points. The time to move the carts is 10. Each cart has a capacity of 4 parts C. Initially there is a cart of parts C at each of the supply and demand stock points. Parts B, D, and E are supplied from outside sources. Initially there are 1000 units for each part type. Manufacturing cell MC makes part C. One part D and two parts E are used to make one part C. The manufacturing time is 100 and there is no setup time.

The model is created by selecting the Model command from the Main Menu and the Create command from the Model Menu (See Figure 13). The actual layout of the model is created by using the commands Draw Icons and Connect Icons in the Layout Menu.

After the model has been completely drawn, the Layout Complete option is selected to start specifying the model parameters. Figure 19 shows a portion of the model parameters. To specify an icon the user simply clicks on the icon when the AMPS is in the Specification Menu.

Both the layout and the parameters can be saved for future use through the Save command in the Model Menu. At the completion of the problem specification, the user selects the Specification Complete command to end the model specification. The system then leads the user to the GPSS Menu command to create the corresponding simulation code in the target language GPSS/PC.

Appendix D contains another sample problem. Included in this appendix are layout of the manufacturing system, a listing of the input parameters, and a complete listing of the GPSS simulation model.
Starting Point of Line
Name of line: MAIN
Interarrival time distribution: Constant
Constant: 100

Final Product from Assembly Line
Part name: A
Capacity and initial inventory at the stock point:
Maximum number of parts at stock point: 1000
Initial number of parts at stock point: 0

Demand Stock Point
Part name: C
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 1
Initial number of carts at supply stock point: 1
Vehicle used to move carts between stock points: qq
Moving time distribution: Constant
Constant: 10

Supply Stock Point
Part name: C
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 1
Initial number of carts at supply stock point: 1
Vehicle used to move carts between stock points: qq
Moving time distribution: Constant
Constant: 10

Ordered from outside
Part name: D
Capacity and initial inventory at the stock point:
Maximum number of parts at stock point: 1000
Initial number of parts at stock point: 1000
Will Part D be replenished during the simulation? No

Figure 19. Partial parameter input
6.6 AMPS/PC/SIMAN

The basic AMPS/PC system in Section 6.4 was modified to create SIMAN (Pegden 1985) rather than GPSS/PC code. This system used the identical Interactive Dialogue Interface (IDI) as the AMPS/PC system. However, the automatic code generator program was rewritten to create code in the target simulation language SIMAN. A listing of the SIMAN macros is given in Appendix C.

The system was written by programmer B in Turbo C on an IBM/PC. The system consisted of 1,600 lines of code. The code production was 533 lines per month. This system has not been documented and has not been submitted to NASA COSMIC.

7.0 SYSTEM EVALUATION

The concepts developed in AMPS have been used to model three real world problems. The first system was a Flexible Manufacturing System (FMS) at Rexham Speedring Inc., in Cullman, Alabama. The FMS consisted of 18 stations and nine alien stations. The FMS makes four different parts with each requiring 47, 31, 22 and 22 operations respectively (Schroer 1988).

The second system was a 25 station assembly line at SCI Manufacturing Inc. in Huntsville, Alabama. The line assembles a health monitoring device (Schroer 1988). The third system was a twelve station Unit Production System (UPS) at Camptown Togs, Inc. in Clanton, Alabama (Schroer and Ziemke 1989).

The following observations are made based on the above implementations:

- The problem domains were sufficiently different that the AMPS user
interface could not be used in defining the problem specification.

° The library of GPSS modules were used extensively in writing the simulation models. For the FMS model, several additional simulation modules were developed.

° By using the library of GPSS modules, the UPS model was written and validated in less than four hours as compared to forty hours without the use of the modules.

° The use of the GPSS modules caused the resulting simulation code to be structured code and well documented.

8.0 PUBLICATIONS

The following is a list of publications resulting from the research supported by NASA Grant NAG8-641 and NASA contract NAS8-36995.


9.0 CONCLUSIONS

9.1 Comparison of the AMPS/GRaphics System with the AMPS System

Both AMPS and AMPS/Graphics were written in Lisp on the Symbolics 3620 machine. The AMPS/Graphics used the Symbolics system dependent features such as the flavors (frame) window, and the graphics function. Also, AMPS/Graphics use object oriented programming concepts. The adoption of the above features greatly simplified the programming effort for such a complicated system. However, these system dependent features also make the conversion of the AMPS/Graphics to other types of machines very difficult. On the other hand, the AMPS system used very few system dependent features. Most of the statements in AMPS are Common Lisp compatible. Therefore, it is much easier to convert AMPS to other platforms. For example, the AMPS system has been successfully ported converted to a TI Explorer with only minor modifications.

The AMPS system provides an Interactive Dialogue Interface (IDI) for the user to create the model. In AMPS, the user must follow the preset logic system and answer a series of questions prompted in constructing a model. That is, the user is in a passive role. The AMPS system controls the main logic. The AMPS system allows the user to make only very limited modifications throughout the development process. Also, the user must remember the stage of the development process. Consequently, it is difficult to visualize the development process of the model in AMPS.

The AMPS/Graphics has a an Interactive Graphic Interface (IGI) through which the user builds the model mainly by icons. The user can start building the model from any part of the model. Also, the user can
always see the partially completed model on the screen. The AMPS/Graphics system allows the user to modify any part of the model throughout the development process. Consequently, it is much easier to build a model and to trace the logic by the AMPS/Graphics. Furthermore, a graphical model is also a much better communicative model than a descriptive model.

The AMPS/Graphics system provides several help features. For example, on-line documentation of each icon can be obtained by clicking a button. The documentation shows the function of each icon and the connection rules with other icons. In the construction process, if a mistake is made, the system will immediately give the appropriate error message. The AMPS system does not have these help features.

The models created by the AMPS/Graphics can be saved and then modified through the IGI interface. The corresponding simulation program will then be modified automatically. The AMPS system does not have this capability.

It is much slower to design a user friendly system such as AMPS/Graphics at the beginning of the design process because of the many factors to be considered. However, once the basic framework of the system is completed, a system such as AMPS/Graphics is much easier to modify and expand. For example, it is rather easy to add a new facility icon or to change a model construction rule. A carefully designed system should be flexible enough to add or remove a construct from the system with only minor effort. On the other hand, a system like AMPS is easier to initially design, and therefore is ideal to serve as a prototype. However, any change after the initial design requires a major modification to the system.
The AMPS/Symbolics system makes use of some advantages of the Symbolics machine. For example, the system automatically checks for some types of errors, executes much faster, and has a large amount of memory available. However, currently none of the popular commercially available discrete simulation languages, such as GPSS, is available on the Symbolics. The simulation programs must be downloaded to an IBM-PC to run the simulation. On the other hand, the AMPS/PC system is much slower than the AMPS/Symbolics. The small memory of the PC's also limits any reasonably large models to be constructed on the AMPS/PC.

9.2 Summary

In summary, an Automatic Programming (AP) system, such as AMPS and ANPS, offers a number of advantages for improving the simulation modeling environment. These advantages include:

- Rapid prototyping - Once the necessary library of simulation modules has been written, the AP system permits the user to rapidly construct a model. As a result, the AP system produces executable simulation code that is syntax error free.

- Software correctness - Correct simulation software requires the definition of a complete and formal set of model requirements. An AP system forces the user to completely define these requirements.
Improved clarity of simulation code - The simulation code generated by the AP system is structured code that is easy to read, trace, and modify. An added benefit is embedded code documentation.

Increased productivity - By using an AP system, the modeler should have an increased productivity in the lines of simulation code written per hour.

Automatic documentation - Instead of changing program code, the user modifies the problem specification through the AP system's user interface. The AP system then rewrites a new simulation model. Therefore, the problem specification file always reflects the current configuration, or documentation, of the problem.

Software reusability - Software reusability refers to the ability of new simulation models to use elements of other models. Large collections, or libraries, of reusable program modules can be defined, making it possible to develop new models by writing only a small amount of new code. The library of GPSS modules provides the basic building blocks for the simulation model. This library is constantly being updated and expanded as the AP system is used in other domains.

Software compatibility - Software compatibility is the ability of program modules to be interfaced with other simulation code. An AP system designed with expansion in mind and as generic as
possible will be easier to modify as additional requirements are defined.

- **Extendability** - Since an AP system operates in a structural environment, the overall software maintenance is less difficult. Software designed and developed using an AP system will have each data element and related processes grouped into one location, making modifications simpler.

- **Reduced simulation knowledge** - An advantage of an AP system is a reduction in the modeler's knowledge of the simulation language.

There are also a number of disadvantages of an AP system such as AMPS and ANPS. These disadvantages include:

- **Domain specific** - Most AP systems are very domain specific. Therefore, the systems can only model a very limited class of problems. To model a slightly different problem in a similar domain may require additional modules and modifications to the user interface.

- **Library robustness** - A related disadvantage is the robustness of the library of predefined modules. Generally skilled GPSS programmers are needed to write a new modules.
Memory and execution time - Another disadvantage is that AP systems require more memory and execute slower than a nonstructured equivalent simulation program. However, this disadvantage is not as significant as in prior years because computers are now faster and have more memory.

In comparing the IDI and IGI for the Symbolics systems, the following observations are made:

- The IGI had 3,500 lines of code versus 1,500 lines for the IDI. Interestingly, the code production was similar for both systems.
- The IGI, or object oriented approach, is preferred by the user.

10.0 ACKNOWLEDGEMENTS

In addition to the funds received from NASA/MSFC, a contract was received in 1988 from the Science, Technology, and Energy Division, Alabama Department of Economic and Community Affairs (ADECA) (Reference Contract ADECA-UH-9001) and a grant in 1989 from the Alabama Industrial Development Training (AIDT).

11.0 REFERENCES


Pegden, C. Dennis, 1985. Introduction to SIMAN, Systems Modeling Corp., College Station, PA.


Appendix A

GPSS macros for AMPS
GPSS Assembly station subroutine

2370 ****************************
2380  *  ASSEMBLY STATION  *
2390 ****************************
2400  ASM ASSIGN 3,MX$STAN(P2,1)
2410  ASSIGN 7,MX$STAN(P2,2)
2420  ASSIGN 6,MX$STIME(P2,1)
2430  ASSIGN 8,1
2440  ASSIGN 9,2
2450  QUEUE  P3
2460  PAQ ASSIGN 8+,2
2470  ASSIGN 9+,2
2480  ASSING 5,MX$STAN(P2,P8)
2490  ASSIGN 10,MX$PART(P5,1)
2500  ASSIGN 20,MX$STAN(P2,P9)
2510  QUEUE  P10
2520  TRANSFER SBR,TAKEP,RTRN2
2530  DEPART  P10
2540  LOOP  7,PAQ
2550  SEIZE  P3
2560  DEPART  P3
2570  ADVANCE  V*6
2580  RELEASE  P3
2590  TRANSFER  P,RTRN1,1

GPSS Task station subroutine

1980 ****************************
1990  *  TASK STATION  *
2000 ****************************
2010  TASK ASSIGN 3,MX$STAN(P2,1)
2020  ASSIGN 6,MX$STIME(P2,1)
2030  QUEUE  P3
2040  SEIZE  P3
2050  DEPART  P3
2060  ADVANCE  V*6
2070  RELEASE  P3
2080  TRANSFER  P,RTRN1,1
GPSS Inspection station subroutine

2090 ***********************************************
2100 * INSPECTION STATION *
2110 ***********************************************
2120 INSP ASSIGN 3, MX$STAN(P2,2)
2130 ASSIGN 4, MX$IPERC(P3,1)
2140 ASSIGN 5, MX$ITIME(P3,1)
2150 ASSIGN 6, MX$ITIME(P3,2)
2160 QUEUE MX$STAN(P2,1)
2170 DEPART MX$STAN(P2,1)
2180 TRANSFER ,FN*4
2190 CHECK QUEUE MX$ISTA(P3,1)
2200 SEIZE MX$ISTA(P3,1)
2210 DEPART MX$ISTA(P3,1)
2220 ADVANCE V*5
2230 RELEASE MX$ISTA(P3,1)
2240 ASSIGN 4, MX$IPERC(P3,2)
2250 TRANSFER ,FN*4
2260 REPAIR QUEUE MX$ISTA(P3,2)
2270 SEIZE MX$ISTA(P3,2)
2280 DEPART MX$ISTA(P3,2)
2290 ADVANCE V*6
2300 RELEASE MX$ISTA(P3,2)
2310 ASSIGN 4, MX$IPERC(P3,3)
2320 TRANSFER ,FN*4
2330 PASS TRANSFER P,RTRN1,1
2340 SCRAP QUEUE MX$ISTA(P3,3)
2350 DEPART MX$ISTA(P3,3)
2360 TERMINATE
* MANUFACTURING CELL *

**MANUFACTURING CELL**

- **MFG** - ASSIGN 13, MX$CELL(P12,1)
- **ASSIGN** - 14, MX$CTIME(P12,1)
- **ASSIGN** - 16, MX$CTIME(P12,2)
- **MFG ASSIGN 13, MX$CELL(P12,1)**
- **ASSIGN** - P13
- **ASSIGN** - 7, MX$CSIZE(P12,1)
- **CARTQ ASSIGN** - 17, MX$ITEM(P12,1)
- **ASSIGN** - 8, 0
- **ASSIGN** - 9, 1
- **ASSIGN 8+,2**
- **ASSIGN 9+,2**
- **ASSIGN 5, MX$ITEM(P12,P8)**
- **ASSIGN 10, MX$SPART(P5,1)**
- **ASSIGN 20, MX$ITEM(P12,P9)**
- **QUEUE** - P10
- **TRANSFR SBR, TAKEP, RTRN2**
- **DEPART** - P10
- **LOOP** - 17, PARTQ
- **LOOP** - 7, CARTQ
- **FAC SEIZE** - P13
- **DEPART** - P13
- **ADVANCE** - V*14
- **ADVANCE** - V$MTIME
- **MTIME** - FVARIABLE V*16#MX$CSIZE(P12,1)
- **RELEASE** - P13
- **TRANSFER** - P, RTRN3, 1

GPSS Manufacturing cell subroutine
2600 *******************************************
2610 *         INVENTORY CONTROL            *
2620 *******************************************
2630 TAKEP  TEST E                  MX$PART(P5,2),1,PULL
2640 PUSH   TEST GE                 S*10,P20
2650 LEAVE  *10,P20
2660 TRANSFER P,RTRN2,1
2670 PULL    ASSIGN                  30,MX$CART(P5,1)
2680 TEST GE S*10,P20,NEEDC
2690 MINUSP LEAVE                    *10,P20
2700 SPLIT  1,USEP
2710 TRANSFER P,RTRN2,1
2720 NEEDC  ASSIGN                   20-,S*10
2730 LEAVE  *10,S*10
2740 SPLIT  1,USEP
2750 TEST GE S*30,1
2760 LEAVE  *30
2770 ENTER  *10,MX$CSIZE(P5,1)
2780 TEST GE S*10,P20,NEEDC
2790 LEAVE  *10,P20
2800 SPLIT  1,USEP
2810 TRANSFER P,RTRN2,1
2820 USEP   TEST G                   S*10,0,EMPTYC
2830 TERMINATE
2840 EMPTYC SPLIT                    1,ORDER1
2850 TEST GE S*30,1
2860 LEAVE  *30,1
2870 ENTER  *10,MX$CSIZE(P5,1)
2880 TERMINATE
2890 ORDER1 ASSIGN                    26,MX$FGIG(P5,1)
2900 ASSIGN                      16,MX$CTIME(P5,1)
2910 ASSIGN                      36,MX$MTIME(P5,1)
2920 QUEUE                        P26
2930 SEIZE                        P26
2940 DEPART                       P26
2950 ADVANCE                      V*36
2960 RELEASE                      P26
2970 SPLIT  1,GET1F
2980 ASSIGN                       12,P5
2990 ASSIGN                      15,MX$SCART(P5,1)
3000 GET1C TRANSFER               SBR,MFG,RTRN3
3010 ENTER                        *15,1
3020 TERMINATE
3030 GET1F ASSIGN                 31,MX$SCART(P5,1)
3040 QUEUE                        P31
3050 TEST GE S*31,1
3060 LEAVE                        *31,1
3070 DEPART                       P31
3080 SEND1F QUEUE                 P26
3090 SEIZE                        P26
3100 DEPART                       P26
3110 ADVANCE                      V*36
3120 RELEASE                      P26
3130 ENTER                        *30,1
3140 TERMINATE

GPSS Inventory transfer subroutine
Appendix B

GPSS macros for ANPS
ACTIVITY TIME SIMULATION GENERATOR

VENT_A SEIZE P2
ASSIGN 99, MX*WORK_TIME(P3,1)
ASSIGN ETIME, V*99
ASSIGN 98, MX*F_TIME(P3,1)
ASSIGN MTTF, V*98
TEST L P*MTTF, P*ETIME, NOFAIL
ADVANCE P*MTTF
ASSIGN ROW, P3
TRANSFER SBR, FAIL, RTRN1
ASSIGN REST_TIME, V*ETIME3
FVARIABLE P*ETIME-P*MTTF
ASSIGN ETIME, P*REST_TIME
TRANSFER, BACK3
ADVANCE P*ETIME
RELEASE P2
TRANSFER P, RTRN2, 1

CONTINUOUS ACTIVITY TIME SIMULATION GENERATOR

VENT_2 SEIZE P2
ASSIGN 98, MX*F_TIME(P3,1)
SAVEVALUE FTS, V*98
FVARIABLE X*FTS
FVARIABLE X*FTS/100
TEST L V*TIME9, 100, BACK6
ASSIGN TIM3, 1
ASSIGN BSUM, V*TIME9
TRANSFER .BACK5
ASSIGN TIM3, V*TIME8
ASSIGN BSUM, 100
ASSIGN NR_LOOPS, P*BSUM
GATE LR MX*SWITCH1(P3,1), ENDA
ADVANCE P*TIM3
LOOP NR_LOOPS, BACK4
ASSIGN ROW, P3
TRANSFER SBR, FAIL, RTRN1
TRANSFER .BACK5
ENDA RELEASE P2
TRANSFER P, RTRN2, 1

B-2
1060 * 
1070 * ACTIVITY FAILURE SIMULATION GENERATOR (DIRECTLY)
1080 * 
1090 FAIL ASSIGN NR_ACTS,X*ACTS
1100 ASSIGN COL,1
1102 ASSIGN 100,MX$R_TIME(P$ROW,1)
1105 MSAVEVALUE R1_TIME,P$ROW,1,V*100
1110 BACK0 TEST NE MX$ACT_NAME(P$ROW,P$COL),0,AA
1120 GATE U MX$ACT_NAME(P$ROW,P$COL),AA
1130 SPLIT 1,AB
1140 TRANSFER ,AA
1150 AB MARK DELAY
1160 FREEMPT MX$ACT_NAME(P$ROW,P$COL)
1170 ASSIGN ADELAY,MP$DELAY
1180 TEST LE P$ADELAY,0,XACT_DELAY
1190 MSAVEVALUE R2_TIME,P$ROW,P$COL,MX$R1_TIME(F$ROW,1)
1200 BACK1 ADVANCE MX$R2_TIME(P$ROW,P$COL)
1210 BUFFER
1220 RETURN MX$ACT_NAME(P$ROW,P$COL)
1230 TERMINATE
1240 AA ASSIGN COL+,1
1250 LOOP NR_ACTS,BACK0
1260 TRANSFER P,RTRN1,1

1270 * LOGIC WHEN ACTIVITY ALREADY IS INTERRUPTED
1290 * 
1300 XACT_DELAY ADVANCE
1310 MSAVEVALUE R2_TIME,P$ROW,P$COL,V$NEWDELAY
1320 NEWDELAY FVARIABLE MX$R1_TIME(P$ROW,1)-P$ADELAY
1330 TEST L MX$R2_TIME(P$ROW,P$COL),0,BACK1
1340 MSAVEVALUE R2_TIME,P$ROW,P$COL,0
1350 TRANSFER ,BACK1

B-3
Appendix C

SIMAN macros for AMPS
*** Assembly station model ***

ASM
ASSIGN:A(1)=M;
ASSIGN:A(2)=0;

BACKASM
ASSIGN:A(2)=A(2)+1;
BRANCH,1:
  IF,A(2).GT.A(4),OUT:
  ELSE,DOWN1;

DOWN1
BRANCH,2:
  ALWAYS,BACKASM:
  ALWAYS,DOWN2;

DOWN2
ASSIGN:M=3+2*A(2);
ASSIGN:A(5)=A(M);
ASSIGN:A(6)=A(M+1);
ASSIGN:A(11)=A(5)+3;
BRANCH,2:
  IF,P(A(11),2).EQ.2,PULL1:
    ALWAYS,PICKPT;

PICKPT
ASSIGN:M=A(5);
QUEUE,M+1;
SEIZE:PART(M),A(6);

DOWN3
ASSIGN:M=A(1);
QUEUE,M;
SEIZE:STATIONN(M);
DELAY:ED(A(3));
RELEASE:STATIONN(M):NEXT(LOOP);

PULL1
ASSIGN:A(11)=A(5)+3;
ASSIGN:A(12)=A(5)+1;
BRANCH,1:
  IF,NR(A(12)).GE.P(A(11),4),PICKCAR:
    ELSE,OUT;

PICKCAR
ASSIGN:M=P(A(11),5);
QUEUE,M+4;
SEIZE:CAR(M);
QUEUE,M+5;
SEIZE:SCAR(M);
BRANCH,2:
  ALWAYS,VECHIC:
  ALWAYS,MAKE;

VECHIC
ASSIGN:M=P(A(11),8);
QUEUE,M+7;
SEIZE:ROBOT(M);
ASSIGN:A(12)=P(A(11),9);
DELAY:ED(A(12));
RELEASE:ROBOT(M);
ASSIGN:M=P(A(11),5);
RELEASE:CAR(M);
ASSIGN:M=A(5);
RELEASE:PART(M),P(A(11),4):DISPOSE;
MAKE

ASSIGN: A(1) = A(5);
ASSIGN: A(2) = 0;
ASSIGN: A(4) = P(A(11), 13);

BACKMAK

ASSIGN: A(2) = A(2) + 1;
BRANCH, 1:
    IF, A(2).GT.A(4), OUT:
    ELSE, DOWNM1;

DOWNM1

BRANCH, 2:
    ALWAYS, BACKMAK:
    ALWAYS, DOWNM2;

DOWNM2

ASSIGN: A(3) = 2*A(2) + 12;
ASSIGN: A(5) = P(A(11), A(3));
ASSIGN: A(3) = A(3) + 1;
ASSIGN: A(6) = P(A(11), A(3));
ASSIGN: M = A(5);
BRANCH, 2:
    ALWAYS, MAKEPT:
    ALWAYS, CHKPUL;

MAKEPT

ASSIGN: A(12) = A(6) * P(A(11), 4);
QUEUE, M + 12;
SEIZE: PART(M), A(12);

DOWNM3

ASSIGN: M = P(A(11), 10);
QUEUE, M + 6;
SEIZE: MCELL(M);
ASSIGN: A(12) = P(A(11), 12);
DELAY: ED((A(12)) * P(A(11), 4);
ASSIGN: M = P(A(11), 10);
RELEASE: MCELL(M);
ASSIGN: A(12) = P(A(11), 11);
DELAY: ED((A(12)));
ASSIGN: M = P(A(11), 5);
RELEASE: SCAR(M): DISPOSE;

CHKPUL

ASSIGN: A(5) = M;
ASSIGN: A(11) = A(5) + 3;
BRANCH, 1:
    IF, P(A(11), 2).EQ.2, PULL1:
    ELSE, OUT;

OUT

DELAY: 0.0: DISPOSE;
; *** Inspection station model ***

INSP
BRANCH, 1:
    WITH, A(4), CHECK:
    ELSE, PASS;

CHECK
QUEUE, M;
SEIZE: STATIONN(M);
DELAY: ED(A(3));
RELEASE: STATIONN(M);
BRANCH, 1:
    WITH, A(5), REPAIR:
    ELSE, PASS;

REPAIR
ASSIGN: M = A(B);
QUEUE, M + B;
SEIZE: REPAIR(M);
DELAY: ED(A(7));
RELEASE: REPAIR(M);
BRANCH, 1:
    WITH, A(6), SCRAP:
    ELSE, PASS;

SCRAP
PASS
DELAY: O: DISPOSE;
DELAY: O: NEXT(LOOP);

; *** Task station model ***

TASK
QUEUE, M;
SEIZE: STATIONN(M);
DELAY: ED(A(3));
RELEASE: STATIONN(M): NEXT(LOOP);
Model-8-stations
Parameters of Example Model Model-8-Stations

Starting Point of Line
- Name of line: Y
  - Interarrival time distribution: NORMAL
    - Mean: 100
    - Standard deviation: 5

Starting Point of Line
- Name of line: X
  - Interarrival time distribution: EXPONENTIAL
    - Mean: 300

Starting Point of Line
- Name of line: Z
  - Interarrival time distribution: NORMAL
    - Mean: 75
    - Standard deviation: 5

Final Product from Assembly Line
- Part name: R
  - Capacity and initial inventory at the stock point:
    - Maximum number of parts at stock point: 2000
    - Initial number of parts at stock point: 8

Demand Stock Point
- Part name: F
  - In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
  - Capacity and initial inventory at the stock point:
    - Current cart capacity (number of parts per cart): 4
    - Initial number of carts at demand stock point: 4
    - Initial number of carts at supply stock point: 4
  - Vehicle used to move carts between stock points: TRUCK2
  - Moving time distribution: UNIFORM
    - Minimum: 6
    - Maximum: 14

Supply Stock Point
- Part name: F
  - In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
  - Capacity and initial inventory at the stock point:
    - Current cart capacity (number of parts per cart): 4
    - Initial number of carts at demand stock point: 4
    - Initial number of carts at supply stock point: 4
  - Vehicle used to move carts between stock points: TRUCK2
  - Moving time distribution: UNIFORM
    - Minimum: 6
    - Maximum: 14
Supply Stock Point
Part name: N
- In a pull system, parts are assumed to be ordered, 
  needed, and shipped by carts. Two stockpoints: supply 
  and demand are created.
Capacity and Initial Inventory at the stock point:
  Current cart capacity (number of parts per cart): 4
  Initial number of carts at demand stock point: 4
  Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK3
Moving time distribution: UNIFORM
Minimum: 8
Maximum: 12

Demand Stock Point
Part name: N
- In a pull system, parts are assumed to be ordered, 
  needed, and shipped by carts. Two stockpoints: supply 
  and demand are created.
Capacity and Initial Inventory at the stock point:
  Current cart capacity (number of parts per cart): 4
  Initial number of carts at demand stock point: 4
  Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK3
Moving time distribution: UNIFORM
Minimum: 8
Maximum: 12

Supply Stock Point
Part name: E
- In a pull system, parts are assumed to be ordered, 
  needed, and shipped by carts. Two stockpoints: supply 
  and demand are created.
Capacity and Initial Inventory at the stock point:
  Current cart capacity (number of parts per cart): 4
  Initial number of carts at demand stock point: 4
  Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK1
Moving time distribution: UNIFORM
Minimum: 8
Maximum: 12

Demand Stock Point
Part name: E
- In a pull system, parts are assumed to be ordered, 
  needed, and shipped by carts. Two stockpoints: supply 
  and demand are created.
Capacity and Initial Inventory at the stock point:
  Current cart capacity (number of parts per cart): 4
  Initial number of carts at demand stock point: 4
  Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK1
Moving time distribution: UNIFORM
Minimum: 8
Maximum: 12

Supply Stock Point
Part name: I
- In a pull system, parts are assumed to be ordered, 
  needed, and shipped by carts. Two stockpoints: supply 
  and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 4
Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK3
Moving time distribution: UNIFORM
Minimum: 0
Maximum: 12

Demand Stock Point
Part name: I
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 4
Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK3
Moving time distribution: UNIFORM
Minimum: 0
Maximum: 12

Supply Stock Point
Part name: B
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 4
Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK2
Moving time distribution: UNIFORM
Minimum: 6
Maximum: 14

Demand Stock Point
Part name: G
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 4
Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK2
Moving time distribution: UNIFORM
Minimum: 6
Maximum: 14

Supply Stock Point
Part name: C
In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.
Capacity and initial inventory at the stock point:
Current cart capacity (number of parts per cart): 4
Initial number of carts at demand stock point: 4
Initial number of carts at supply stock point: 4
Vehicle used to move carts between stock points: TRUCK1
**Demand Stock Point**

*Part name: C*

In a pull system, parts are assumed to be ordered, made, and shipped by carts. Two stockpoints: supply and demand are created.

**Capacity and Initial Inventory at the stock point:**
- Current cart capacity (number of parts per cart): 4
- Initial number of carts at demand stock point: 4
- Initial number of carts at supply stock point: 4
- Vehicle used to move carts between stock points: TRUCK1

**Moving time distribution:** UNIFORM
- Minimum: 0
- Maximum: 12

**Push stock point**

*Part name: B*

**Capacity and Initial Inventory at the stock point:**
- Maximum number of parts at stock point: 2000
- Initial number of parts at stock point: 120

**Push stock point**

*Part name: B*

**Capacity and Initial Inventory at the stock point:**
- Maximum number of parts at stock point: 2000
- Initial number of parts at stock point: 120

**Ordered from outside**

*Part name: J*

**Capacity and Initial Inventory at the stock point:**
- Maximum number of parts at stock point: 10000
- Initial number of parts at stock point: 10000

Will Part J be replenished during the simulation? No

**Ordered from outside**

*Part name: K*

**Capacity and Initial Inventory at the stock point:**
- Maximum number of parts at stock point: 10000
- Initial number of parts at stock point: 10000

Will Part K be replenished during the simulation? No

**Ordered from outside**

*Part name: L*

**Capacity and Initial Inventory at the stock point:**
- Maximum number of parts at stock point: 10000
- Initial number of parts at stock point: 10000

Will Part L be replenished during the simulation? No

**Inspection Station**
Station name: INSP4  
Name of inspector: INSPECTOR  
Name of repairman: REPAIRMAN  
Name of place for scrap parts: SCRAP4  
Inspection time distribution: NORMAL  
Mean: 50  
Standard deviation: 5  
Repair time distribution: NORMAL  
Mean: 400  
Standard deviation: 10  
Inspection rate (between 0 and 1): 1  
Reject (repair) rate (between 0 and 1): 0.2  
Scrap rate (between 0 and 1): 0.5

Task Station  
Station name: TASK6  
Task time distribution: NORMAL  
Mean: 100  
Standard deviation: 5

Task Station  
Station name: TASK2  
Task time distribution: NORMAL  
Mean: 300  
Standard deviation: 10

Assembly Station  
Station name: ASYS5  
Parts required for assembly:  
Name of part P1: E  
Number of part P1: 2  
Assembly time distribution: NORMAL  
Mean: 100  
Standard deviation: 5

Assembly Station  
Station name: ASYS1  
Parts required for assembly:  
Name of part P1: E  
Number of part P1: 3  
Name of part P2: C  
Number of part P2: 2  
Assembly time distribution: NORMAL  
Mean: 300  
Standard deviation: 10

Assembly Station  
Station name: ASYS3  
Parts required for assembly:  
Name of part P1: D  
Number of part P1: 4  
Assembly time distribution: NORMAL  
Mean: 300  
Standard deviation: 10
Assembly Station
Station name: A57
Parts required for assembly:
  Name of part #1: H
  Number of part #1: 1
Assembly time distribution: NORMAL
  Mean: 75
  Standard deviation: 5

Assembly Station
Station name: A57
Parts required for assembly:
  Name of part #1: F
  Name of part #2: G
  Number of part #2: 1
Assembly time distribution: NORMAL
  Mean: 75
  Standard deviation: 5

Manufacturing Cell — F
Cell name: MC2
Items required to make the part F:
  Number of item types required: 1
  Name of item #1: L
  Number of item #1: 2
Setup time for a set of parts: CONSTANT
  Constant: 0
Manufacturing time for a part: NORMAL
  Mean: 10
  Standard deviation: 1

Manufacturing Cell — E
Cell name: MC2
Items required to make the part E:
  Number of item types required: 2
  Name of item #1: J
  Name of item #2: K
  Number of item #2: 1
Setup time for a set of parts: CONSTANT
  Constant: 0
Manufacturing time for a part: NORMAL
  Mean: 10
  Standard deviation: 1

Manufacturing Cell — I
Cell name: MC2
Items required to make the part I:
  Number of item types required: 2
  Name of item #1: J
  Name of item #2: K
  Number of item #2: 1
Setup time for a set of parts: CONSTANT
  Constant: 0
Manufacturing time for a part: NORMAL
  Mean: 5
  Standard deviation: 1
Manufacturing Cell -- C
Cell name: MC2
Items required to make the part C:
Number of item types required: 1
Name of item #1: K
Number of item #1: 2
Setup time for a cart of parts: CONSTANT
Constant: 0
Manufacturing time for a part: NORMAL
Mean: 10
Standard deviation: 1

Manufacturing Cell -- M
Cell name: MC1
Items required to make the part M:
Number of item types required: 1
Name of item #1: I
Number of item #1: 1
Setup time for a cart of parts: CONSTANT
Constant: 0
Manufacturing time for a part: NORMAL
Mean: 30
Standard deviation: 3

Manufacturing Cell -- C
Cell name: MC1
Items required to make the part C:
Number of item types required: 1
Name of item #1: I
Number of item #1: 1
Setup time for a cart of parts: CONSTANT
Constant: 0
Manufacturing time for a part: NORMAL
Mean: 30
Standard deviation: 3
GPSS Code of Example Model Model-8-Stations

ANDY-TAYLOR::>dwan>amps>gpss-8-stations.lisp.2

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100 ####################################################################
110
120 This is a 8-stations model.
130
140 ####################################################################
150
160 This is a GPSS program automatically created from
170
180 AMPS - (Automatic Manufacturing Programming System)
190
200 developed at
210
220 The University of Alabama in Huntsville, 1988.
230
240 ####################################################################
250 SIMULATE
260 UNIFORM FUNCTION RNI,C2
0,6/1.1
270 GFORM FUNCTION RNI,C2
0.75-RNI086,-4,.-0135,-3,-30631,-2.5,.-02275,-2
.06681,-1.5,-1587,-1,27356,-1,21186,-6,27425,-6
.34459,-4,-42074,-2.5,0,57926,-2,65442,-4
72575,-6,79814,6,84134,1,88455,1.27,95419,1.5
97725,9,39979,5.2,99865,5,99974,4.1,5
280 HPDIS FUNCTION RNI,C2
9,8/1.1,184/3.1,222/3.1,355/4.5,589/4.5,69/6.1,915/7.2,75.1,39
.6,1,8/4.1,88/6.2,2,92,92,92.2,94,2,91,95,2,99.4,96,3,2
.97,3,5,2,99,3,5,2,99,5,8,2.7,59862,2.9,27425,2.3,99973.6
290 ### MAIN PARAMETERS ###
300 PER1, FUNCTION RNI,D2
1,CHECK/2,PASS
310 PER2, FUNCTION RNI,D2
0,2,REPAIR/1,PASS
320 PER3, FUNCTION RNI,D2
0.5,SCRAP/1,PASS
330 TIMES1 FVARIABLE 6-8BNFSUMIFN
340 TIMES2 FVARIABLE 0
350 TIMES3 FVARIABLE 10-18BNFISONRM
360 TIMES4 FVARIABLE 0-8BNFSUMIFN
370 TIMES5 FVARIABLE 5-18BNFISONRM
380 TIMES6 FVARIABLE 90-18BNFISONRM
390 TIMES7 FVARIABLE 60008F8HPDIS
400 TIMES8 FVARIABLE 300-108BNFISONRM
410 TIMES9 FVARIABLE 50-5AFNSHORN
420 TIMES10 FVARIABLE 400-108BNFISONRM
430 TIMES11 FVARIABLE 100-5AFNSHORN
440 TIMES12 FVARIABLE 75-5AFNSHORN
450 ### DEFINITION OF MATRIX ###
460 PART MATRIX .12,2
470 STIME MATRIX .8,1
480 STRM MATRIX .8,6
490 TTIME MATRIX .1,2
500 SRDA MATRIX .1,3
510 SPRM LENGTH .1,3
520 ATIME MATRIX .7,1
530 FGIN MATRIX .7,1
540 SRMS Matrix .7,1
550 CMT Matrix .7,1
560 CTIME Matrix .7,2
570 FGIN Matrix .7,1
580 FGIN Matrix .7,1
590 IEM Matrix .7,5
600 ### CAPACITY OF PART & CMT COUNTERS ###
610 PAR STORAGE 2000
620 PAR STORAGE 4
630 CARF STORAGE 8
640 SCARF STORAGE 8
650 PAR STORAGE 4
660 CAT STORAGE 8
670 SCAT STORAGE 8
680 PAR STORAGE 4
690 CAT STORAGE 8
700 SCAT STORAGE 8

D-10

ORIGINAL PAGE IS OF POOR QUALITY
ANDY-TAYLOR::dwan::amps::gpss-8-stations.fisp.2 3/18/89 02:04:38 Page 3

1440 \texttt{NSAVEVALUE ITEM,5,1,1 ; part H requires 1 part type(s).}
1450 \texttt{NSAVEVALUE ITEM,5,2,4 ; part I.}
1460 \texttt{NSAVEVALUE ITEM,5,3,1 ; 1 unit(s).}
1470 \texttt{NSAVEVALUE ITEM,5,3,2 ; 2 unit(s).}
1480 \texttt{NSAVEVALUE ITEM,5,1,2 ; part E requires 2 part type(s).}
1490 \texttt{NSAVEVALUE ITEM,5,1,3 ; 3 unit(s).}
1490 \texttt{NSAVEVALUE ITEM,5,2,3 ; part J.}
1500 \texttt{NSAVEVALUE ITEM,5,4,0 ; part K.}
1510 \texttt{NSAVEVALUE ITEM,5,4,1 ; 1 unit(s).}
1520 \texttt{NSAVEVALUE ITEM,5,4,2 ; 2 unit(s).}
1530 \texttt{NSAVEVALUE ITEM,5,1,2 ; part I requires 2 part type(s).}
1540 \texttt{NSAVEVALUE ITEM,5,2,9 ; part J.}
1550 \texttt{NSAVEVALUE ITEM,5,3,2 ; 2 unit(s).}
1560 \texttt{NSAVEVALUE ITEM,5,1,4 ; part E.}
1570 \texttt{NSAVEVALUE ITEM,5,1,1 ; 1 unit(s).}
1580 \texttt{NSAVEVALUE ITEM,5,2,8 ; part K.}
1590 \texttt{NSAVEVALUE ITEM,5,3,2 ; 2 unit(s).}
1600 \texttt{NSAVEVALUE ITEM,5,1,4 ; part C requires 1 part type(s).}
1610 \texttt{NSAVEVALUE ITEM,5,1,1 ; part E.}
1620 \texttt{NSAVEVALUE ITEM,5,2,4 ; 2 unit(s).}

1630 *** STATION SERVICE TIME ***
1640 \texttt{NSAVEVALUE TIME,6,1,$TIME1 ; time of TASK6 is TIME1}
1650 \texttt{NSAVEVALUE TIME,2,1,$TIME8 ; time of TASK2 is TIME8}
1660 \texttt{NSAVEVALUE TIME,5,1,$TIME11 ; time of ASSY5 is TIME11}
1670 \texttt{NSAVEVALUE TIME,5,1,$TIME12 ; time of ASSY5 is TIME12}
1680 \texttt{NSAVEVALUE TIME,5,1,$TIME11 ; time of ASSY6 is TIME11}
1690 \texttt{NSAVEVALUE TIME,6,1,$TIME10 ; time of ASSY6 is TIME10}
1700 \texttt{NSAVEVALUE TIME,7,1,$TIME12 ; time of ASSY7 is TIME12}
1710 *** TIME TO MOVE A CART BETWEEN SUPPLY AND DEMAND POINTS ***
1720 \texttt{NSAVEVALUE TIME,6,1,$TIME1 ; moving time of a cart of part F is TIME1}
1730 \texttt{NSAVEVALUE TIME,5,1,$TIME4 ; moving time of a cart of part H is TIME4}
1740 \texttt{NSAVEVALUE TIME,5,1,$TIME4 ; moving time of a cart of part E is TIME4}
1750 \texttt{NSAVEVALUE TIME,4,1,$TIME4 ; moving time of a cart of part I is TIME4}
1760 \texttt{NSAVEVALUE TIME,5,1,$TIME1 ; moving time of a cart of part G is TIME1}
1770 \texttt{NSAVEVALUE TIME,5,1,$TIME1 ; moving time of a cart of part C is TIME1}
1780 *** SETUP TIME FOR A CART OF PARTS AND ***
1790 *** MANUFACTURING TIME FOR A PART ***
1800 \texttt{NSAVEVALUE TIME,2,1,$TIME2 ; setup time for a cart of part F is TIME2}
1810 \texttt{NSAVEVALUE TIME,5,1,$TIME4 ; setup time for a cart of part H is TIME4}
1820 \texttt{NSAVEVALUE TIME,5,1,$TIME4 ; setup time for a cart of part K is TIME4}
1830 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part H is TIME6}
1840 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part H is TIME6}
1850 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part K is TIME6}
1860 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part E is TIME6}
1870 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part E is TIME6}
1880 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part I is TIME6}
1890 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part G is TIME6}
1890 \texttt{NSAVEVALUE TIME,5,1,$TIME6 ; manufacturing time for part C is TIME6}
1890 *** CELL WHERE EACH PART IS MADE ***
1900 \texttt{NSAVEVALUE CELL,2,1,$MC2 ; part F is made on machine MC2}
1900 \texttt{NSAVEVALUE CELL,2,1,$MC2 ; part F is made on machine MC2}
1900 \texttt{NSAVEVALUE CELL,5,1,$MC1 ; part H is made on machine MC1}
1900 \texttt{NSAVEVALUE CELL,5,1,$MC1 ; part H is made on machine MC1}
1900 \texttt{NSAVEVALUE CELL,5,1,$MC1 ; part H is made on machine MC1}
1910 *** NAME OF EACH STATION ***
1920 *** INSPECTION STATION INDEX ***
1930 \texttt{NSAVEVALUE STN,4,1,$INSPP ; the id of station INSPP is 4}
1940 *** INSPECTION STATION INDEX ***
1950 \texttt{NSAVEVALUE IPER,1,1,$PERI1 ; inspection rate of INSPP is 1}
1960 \texttt{NSAVEVALUE IPER,1,2,$PERI2 ; repair rate of INSPP is 2}
1970 \texttt{NSAVEVALUE IPER,1,3,$PERI3 ; scrap rate of INSPP is 3}
1980 \texttt{NSAVEVALUE IPER,1,4,$PERI4 ; inspection rate of INSPP is 1}
1990 \texttt{NSAVEVALUE IPER,1,5,$PERI5 ; repair rate of INSPP is 2}
2000 \texttt{NSAVEVALUE IPER,1,6,$PERI6 ; scrap rate of INSPP is 3}
2010 \texttt{NSAVEVALUE IPER,1,7,$PERI7 ; inspection rate of INSPP is 1}
2020 \texttt{NSAVEVALUE IPER,1,8,$PERI8 ; repair rate of INSPP is 2}
2030 \texttt{NSAVEVALUE IPER,1,9,$PERI9 ; scrap rate of INSPP is 3}
2040 *** INSPECTION STATION INDEX ***
2050 *** INSPECTION STATION INDEX ***
2060 *** INSPECTION STATION INDEX ***
2070 *** INSPECTION STATION INDEX ***
2080 *** INSPECTION STATION INDEX ***
2090 *** INSPECTION STATION INDEX ***
2100 *** INSPECTION STATION INDEX ***
2110 *** INSPECTION STATION INDEX ***
2120 *** INSPECTION STATION INDEX ***
2130 *** INSPECTION STATION INDEX ***
2140 *** INSPECTION STATION INDEX ***
2150 *** INSPECTION STATION INDEX ***
2160 *** INSPECTION STATION INDEX ***
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2170  DEFINE  TIME,1,1,$TIME9  /inspection time of INSPECTION is TIME9
2180  DEFINE  TIME,1,2,$TIME10 /inspection time of INSPECTION is TIME10
2190  *** PART (12) REQUIRED AT EACH STATION ***
2200  DEFINE  STATION,4,$STATION5 requires 1 part type(s).
2210  DEFINE  STATION,5,$STATION5 requires 1 part type(s).
2220  DEFINE  STATION,6,$STATION5 requires 2 part type(s).
2230  DEFINE  STATION,7,$STATION5 requires 1 part type(s).
2240  DEFINE  STATION,8,$STATION5 requires 2 part type(s).
2250  DEFINE  STATION,9,$STATION5 requires 1 part type(s).
2260  DEFINE  STATION,10,$STATION5 requires 1 part type(s).
2270  DEFINE  STATION,11,$STATION5 requires 1 part type(s).
2280  DEFINE  STATION,12,$STATION5 requires 1 part type(s).
2290  DEFINE  STATION,13,$STATION5 requires 1 part type(s).
2300  DEFINE  STATION,14,$STATION5 requires 2 part type(s).
2310  DEFINE  STATION,15,$STATION5 requires 1 part type(s).
2320  DEFINE  STATION,16,$STATION5 requires 1 part type(s).
2330  DEFINE  STATION,17,$STATION5 requires 1 part type(s).
2340  DEFINE  STATION,18,$STATION5 requires 1 part type(s).
2350  DEFINE  STATION,19,$STATION5 requires 1 part type(s).
2360  DEFINE  STATION,20,$STATION5 requires 1 part type(s).
2370  DEFINE  STATION,21,$STATION5 requires 1 unit(s).
2380  *** SUPPLY SYSTEM OF EACH PART ***
2390  DEFINE  PART,1,1,,$PART5 F is in push mode
2400  DEFINE  PART,2,2,,$PART5 F is in pull mode
2410  DEFINE  PART,3,3,,$PART5 H is in pull mode
2420  DEFINE  PART,4,4,,$PART5 E is in pull mode
2430  DEFINE  PART,5,5,,$PART5 I is in pull mode
2440  DEFINE  PART,6,6,,$PART5 B is in pull mode
2450  DEFINE  PART,7,7,,$PART5 G is in pull mode
2460  DEFINE  PART,8,8,,$PART5 K is ordered from outside
2470  DEFINE  PART,9,9,,$PART5 L is ordered from outside
2480  *** CART COUNTER AT EACH DESTINATION ***
2490  DEFINE  CART,1,1,,$CART5 F
2500  DEFINE  CART,2,2,,$CART5 H
2510  DEFINE  CART,3,3,,$CART5 E
2520  DEFINE  CART,4,4,,$CART5 I
2530  DEFINE  CART,5,5,,$CART5 G
2540  DEFINE  CART,6,6,,$CART5 C
2550  *** CART COUNTER AT SOURCE ***
2560  DEFINE  SCART,1,1,,$SCART5 F
2570  DEFINE  SCART,2,2,,$SCART5 H
2580  DEFINE  SCART,3,3,,$SCART5 E
2590  DEFINE  SCART,4,4,,$SCART5 I
2600  DEFINE  SCART,5,5,,$SCART5 G
2610  DEFINE  SCART,6,6,,$SCART5 C
2620  *** UNLOADS TO MOVE PARTS ***
2630  DEFINE  FIG,2,1,,$FIG5 F is transported by TRUCK2
2640  DEFINE  FIG,3,1,,$FIG5 G is transported by TRUCK2
2650  DEFINE  FIG,4,1,,$FIG5 H is transported by TRUCK2
2660  DEFINE  FIG,5,1,,$FIG5 I is transported by TRUCK2
2670  DEFINE  FIG,6,1,,$FIG5 J is transported by TRUCK2
2680  DEFINE  FIG,7,1,,$FIG5 K is transported by TRUCK2
2690  DEFINE  FIG,8,1,,$FIG5 L is transported by TRUCK2
2700  *** TERMINATE ***
2710  TERMINATE
2720  GENERATE  VTIME11
2730  ASSIGN  2,5 /station 5 is ASSY1
2740  GENERATE  VTIME12
2750  TRANSFER  GR,ASH,RTNH
2760  ASSIGN  2,6 /station 6 is TASK6
2770  TRANSFER  GR,TASK,RTNH
2780  ENTER  PR,0,1
2790  TERMINATE
2800  GENERATE  VTIME13
2810  ASSIGN  3,1 /station 1 is ASSY1
2820  TRANSFER  GR,ASH,RTNH

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3630 DEPART P10 leave the queue
3640 LOOP P,PA0 received all parts req'd?
3650 RETURN P3 return to the calling statement
3660 DEPART P3 leave the queue
3670 ADVANCE U46 assembling parts
3680 RELEASE P3 release the facility
3690 TRANSFER P,ATRN1,1

3700 # INVENTORY CONTROL
3710 # INVENTORY CONTROL
3720 # INVENTORY CONTROL
3730 TAKEF TEST E NHMPART(P5,2),1,PULL pull or push node?
3740 PUSH TEST GE $10,P20 available = req'd
3750 LEAVE $10,P20 take units requested
3760 TRANSFER P,TRRN2,1 return
3770 PULL RELEASE 30,NEEDC none of cart for the part
3780 TEST GE $10,P20,NEEDC available = requested?
3790 NHMPART LEAVE $10,P20 take units requested
3800 SPLIT 1,USEP signal use of parts
3810 TRANSFER P,TRRN2,1 return
3820 NEEDC ASSIGN 20-,S10 requested = available = unfilled
3830 LEAVE $10,S10 take remaining
3840 SPLIT 1,USEP signal use of parts
3850 TEST GE $30,1 any full carts available?
3860 LEAVE $30 take 1 cart
3870 TEST GE $10,NEEDC none of cart available
3880 SPLIT 1,USEP signal use of parts
3890 LEAVE $10 take 1 empty cart
3900 TRANSFER P,TRRN2,1 return
3910 USEP TEST GE $10,0,EMPTY check if cart empty
3920 TERMINATE TEST GE terminate the transaction
3930 TERMINATE TERMINATE terminate the transaction
3940 EMPTY SPLIT 1,ORDER1 terminate the transaction
3950 TEST GE $30,1 any full carts available
3960 LEAVE $30 take 1 cart
3970 TEST GE $10,NEEDC none of cart available
3980 TERMINATE TERMINATE terminate the transaction
3990 ORDER ASSIGN 26,NEEDC(P5,1) none of the vehicle
4000 ASSIGN 36,NEEDC(P5,1) moving time
4010 QUEUE P20 wait on the vehicle
4020 RERISE P20 leave the vehicle
4030 DEPART P20 leave the queue
4040 ADVANCE U36 moving the empty cart
4050 RELEASE P26 release the vehicle
4060 SPLIT 1,GETIF signal to get a full cart
4070 ASSIGN 12,P5 assign part id
4080 ASSIGN 15,NEEDC(P5,1) assign none of the cart
4090 GETIF TRANSFER 008,NE,RE,TRRN3 order a cart or parts
4100 ENTER $13,1 receive a cart
4110 TERMINATE TERMINATE terminate the transaction
4120 GETIF ASSIGN 31,NEEDC(P5,1) index for a full cart
4130 QUEUE P31 wait on a full cart
4140 TEST GE $31,1 whether a full cart is available
4150 LEAVE $31 take 1 cart
4160 DEPART P31 leave the queue
4170 RENHDF QUEUE P26 wait on the vehicle
4180 RERISE P26 leave the vehicle
4190 DEPART P26 leave the queue
4200 ADVANCE U36 moving the full cart
4210 RELEASE P26 release the vehicle
4220 RELEASE P26 release the vehicle
4230 TERMINATE TERMINATE terminate the transaction
4240 # MANUFACTURING CELL
4250 # MANUFACTURING CELL
4260 # MANUFACTURING CELL
4270 NFC ASSIGN 13,NECELL(P12,1) none of nanuf. cell
4280 ASSIGN 14,NECELL(P12,1) setup time of a cart
4290 ASSIGN 16,NECELL(P12,2) nanuf. time of a part
4300 QUEUE P13 wait on the facility
4310 ASSIGN 7,NECELL(P12,1) no. of parts in a cart
4320 CARTO ASSIGN 17,NEITEM(P12,1) no. of item types req'd
4330 ASSIGN 8,8 index for item type
4340 ASSIGN 5,1 index for units of item
4350 PARTO ASSIGN 8,2 points to next type
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4360 ASSIGN 9+,2 ; point to next no. of units
4370 ASSIGN 5,MAITEM(P12,P0) ; iid of the item req'd
4380 ASSIGN 10,NAME(P5,1) ; name of the item
4390 ASSIGN 20,MAITEM(P12,P9) ; units of the item req'd
4400 QUEUE P18 ; wait on the item
4410 TRANSFER 600,TAKEP,TRM2 ; get item
4420 DEPART P18 ; leave the queue
4430 LOOP 1,PAR10 ; loop for next item type req'd
4440 LOOP 7,DIAT0 ; loop for next part to be made
4450 FAC SEIZE P13 ; seize the facility
4460 DEPART P13 ; leave the queue
4470 ADVANCE V=14 ; set up facility
4480 ADVANCE V=TIME ; manufacturing time
4490 HTIME FVARITABLE V=16+X4CHCSIZE(P12,1) ; manufacturing complete
4500 RELEASE P13 ; release the facility
4510 TRANSFER P,TRM3,1 ; manufacturing complete

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