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, queuing 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
Phase I
Formulate problem → Conceptual model

Phase II
User Interface
→ Problem specification

Phase III
Automatic code generator
→ Library of modules
Programmed model

Phase IV
Verify and validate model

Phase V
Experiment with model → Model results

Phase VI
Maintain model

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-0 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.

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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### Table II. Operational dependencies between activities

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</tbody>
</table>
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 III  Comparison of platforms

<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>IGI</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: 110

   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

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
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>🛠️</td>
<td>Assembly station</td>
</tr>
<tr>
<td>🔄</td>
<td>Starting point of an assembly line</td>
</tr>
<tr>
<td>🥷</td>
<td>Demand stock point of pull inventory system</td>
</tr>
<tr>
<td>🍔</td>
<td>Ending stock point for final product</td>
</tr>
<tr>
<td>🧑‍🔧</td>
<td>Inspection station</td>
</tr>
<tr>
<td>🏭</td>
<td>Manufacturing cell</td>
</tr>
<tr>
<td>🛒</td>
<td>Stock point for part ordered from outside</td>
</tr>
<tr>
<td>🔗</td>
<td>stock point for Push inventory system</td>
</tr>
<tr>
<td>🌋</td>
<td>Supply stock point of pull inventory system</td>
</tr>
<tr>
<td>🕵️‍♂️</td>
<td>Task station</td>
</tr>
</tbody>
</table>

Figure 14. Library of AMPS/Graphics icons
![Figure 15. Valid AMPS/graphics icon connections](image-url)
Assembly station

Function: Adding parts stored at the source stock points to a part coming from another source and then transferring the assembled part to the destination.

Rules:
- Must have one and only one source from one of the following:
  - A station, or
  - A starting point.
- Must have at least one source from one of the following:
  - A demand stock point, an ordered-from-outside stock point, or a push stock point.
- Must have one and only one destination from one of the following:
  - A push stock point, an ending stock point, or a station.
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 specification. 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 WGIG 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: wqiq
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: wqiq
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
The 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-UAH-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$STIME(P2,1)
2430 ASSIGN 8,1
2440 ASSIGN 9,2
2450 QUEUE P3
2460 PAQ ASSIGN 8+,2
2470 ASSIGN 9+,2
2480 ASSIGN 5,MX$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 *

ASSIGN MFG 13,MX$CELL(P12,1)
ASSIGN 14,MX$CTIME(P12,1)
ASSIGN 16,MX$CTIME(P12,2)
QUEUE 13
ASSIGN 7,MX$CSIZE(P12,1)
CARTQ ASSIGNED 17,MX$ITEM(P12,1)
ASSIGN 8,0
ASSIGN 9,1
PARTQ ASSIGNED 8+,2
ASSIGN 9+,2
ASSIGN 5,MX$ITEM(P12,P8)
ASSIGN 10,MX$PART(P5,2)
ASSIGN 20,MX$ITEM(P12,P9)
QUEUE • P10
TRANSFER 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
GPSS Inventory transfer subroutine
Appendix B

GPSS macros for ANPS
1360 * ACTIVITY TIME SIMULATION GENERATOR
1370 *
1390 VENT_A SEIZE P2
1395 ASSIGN 99,MX*WORK_TIME(P3,1)
1400 ASSIGN ETIME,V*99
1405 BACK3 ASSIGN 98,MX*F_TIME(P3,1)
1410 ASSIGN MTTF,V*98
1420 TEST L P*MTTF,P*ETIME,NOFAIL
1430 ADVANCE P*MTTF
1440 ASSIGN ROW,P3
1450 TRANSFER SBR,FAIL, RTRN1
1460 ASSIGN REST_TIME,V*ETIME3
1470 TIME3 FVARIABLE P*ETIME-P*MTTF
1480 ASSIGN ETIME,P*REST_TIME
1490 TRANSFER ,BACK3
1500 NOFAIL ADVANCE P*ETIME
1510 RELEASE P2
1520 TRANSFER P,RTRN2,1
1530 *
1832 * CONTINUOUS ACTIVITY TIME SIMULATION GENERATOR
1834 *
1840 VENT_P SEIZE P2
1842 ASSIGN 98,MX*F_TIME(P3,1)
1843 SAVEVALUE FTS,V*98
1845 TIME9 FVARIABLE X*FTS
1850 TIMES FVARIABLE X*FTS/100
1855 TEST L V*TIME9,100, BACK6
1860 ASSIGN TIM3,1
1865 ASSIGN BSUM,V*TIME9
1870 TRANSFER BACK5
1875 BACK6 ASSIGN TIM3,V*TIME8
1880 ASSIGN BSUM,100
1885 BACK4 ASSIGN NR_LOOPS,P*BSUM
1890 BACK4 GATE LR MX*SWITCH1(P3,1),ENDA
1895 ADVANCE P*TIM3
1900 LOOP NR_LOOPS,BACK4
1905 ASSIGN ROW,P3
1910 TRANSFER SBR,FAIL, RTRN1
1915 TRANSFER BACK5
1920 ENDA RELEASE P2
1925 TRANSFER P,RTRN2,1

B-2
* ACTIVITY FAILURE SIMULATION GENERATOR (DIRECTLY)

1070 * ASSIGN NR_ACTS, X*ACTS
1080 * ASSIGN COL, 1
1090 FAIL ASSIGN 100, MX$R_TIME(P$ROW, 1)
1100 ASSIGN 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, MF$DELAY
1180 TEST LE P$ADELAY, 0, XACT_DELAY
1190 MSAVEVALUE R2_TIME, P$ROW, P$COL, MX$R1_TIME(P$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

* LOGIC WHEN ACTIVITY ALREADY IS INTERRUPTED

1300 XACT_DELAY ADVANCE
1310 MSAVEVALUE R2_TIME, P$ROW, P$COL, V$NEWDELAY
1320 NEWDELAY FYVARIABLE MX$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
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),PICKAR:
  ELSE,OUT;

PICKAR
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);
   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;
DOWNM3
   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;

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C-3
; *** 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(8);
  QUEUE,M+B;
  SEIZE:REPAIR(M);
  DELAY:ED(A(7));
  RELEASE:REPAIR(M);
BRANCH,1:
  WITH,A(6),SCRAP:
  ELSE,PASS;

SCRAP
  DELAY:O:DISPOSE;

PASS
  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

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Parameters of Example Model Model-8-Stations

Starting Point of Line
Name of line: Y
Interarrival time distribution: NORMAL
Mean: 180
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: 0

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, 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

Demand Stock Point
Part name: N
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: E
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

Demand Stock Point
Part name: E
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

Supply 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

Demand Stock Point
Part name: 1
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: 0
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: 0
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

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Moving time distribution: UNIFORM
Minimum: 0
Maximum: 12

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: TRUCK
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: INSPECTION
Name of inspector: INSPECTOR
Mean: 50
Standard deviation: 5
Inspection time distribution: NORMAL

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: ASSEMBLY
Parts required for assembly:
Name of part #1: E
Number of part #1: 2
Assembly time distribution: NORMAL
Mean: 100
Standard deviation: 5

Assembly Station
Station name: ASSEMBLY
Parts required for assembly:
Name of part #2: C
Number of part #2: 2
Assembly time distribution: NORMAL
Mean: 300
Standard deviation: 10

Assembly Station
Station name: ASSEMBLY
Parts required for assembly:
Name of part #3: D
Number of part #3: 4
Assembly time distribution: NORMAL
Mean: 300
Standard deviation: 10
Assembly Station
Station name: ASY8
Parts required for assembly:
Name of part 81: H
Number of part 81: 1
Assembly time distribution: NORMAL
Mean: 75
Standard deviation: 5

Assembly Station
Station name: ASY7
Parts required for assembly:
Name of part 81: F
Number of part 81: 1
Name of part 82: G
Number of part 82: 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 81: L
Number of item 81: 1
Setup time for a set of parts: CONSTANT
Constant: 8
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 81: J
Number of item 81: 2
Name of item 82: K
Number of item 82: 1
Setup time for a set of parts: CONSTANT
Constant: 8
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 81: J
Number of item 81: 2
Name of item 82: K
Number of item 82: 1
Setup time for a set of parts: CONSTANT
Constant: 8
Manufacturing time for a part: NORMAL
Mean: 5
Standard deviation: 1
Manufacturing Cell -- G
Cell name: MC2
Items required to make the part G:
Number of item types required: 1
Name of item #1: X
Number of item #1: 2
Setup time for a cart of parts: CONSTANT
Constant: 0
Manufacturing time for a part: NORMAL
Mean: 18
Standard deviation: 1

Manufacturing Cell -- H
Cell name: MC1
Items required to make the part H:
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: 38
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: 38
Standard deviation: 3
GPSS Code of Example Model Model-8-Stations

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100
110 This is a 8-stations model.

120

140
150 This is a GPSS program automatically created from
160

180 • RAMS - (Automatic Manufacturing Programming System)
190

200 • developed at
210

220 • The University of Alabama in Huntsville, 1988.
230

250

260 UNIFORM FUNCTION, RHI.C2
269

275
280 EXACT FUNCTION, RN1.C2

290 ...

300 PERI, FUNCTION, RHI.C2
310 PERI, FUNCTION, RHI.C2
320 PERI, FUNCTION, RHI.C2
330 PERI, FUNCTION, RHI.C2

340 TIMES VARIABLE 6-8NFH0UNIF
350 TIMES VARIABLE 6-8NFH0UNIF
360 TIMES VARIABLE 6-8NFH0UNIF
370 TIMES VARIABLE 6-8NFH0UNIF

380 TIMES VARIABLE 6-8NFH0UNIF
390 TIMES VARIABLE 6-8NFH0UNIF
400 TIMES VARIABLE 6-8NFH0UNIF
410 TIMES VARIABLE 6-8NFH0UNIF

420 TIMES VARIABLE 6-8NFH0UNIF
430 TIMES VARIABLE 6-8NFH0UNIF
440 TIMES VARIABLE 6-8NFH0UNIF

450 DEFINITION OF MATRIX ***
460 PART MATRIX .13.2
470 TIME MATRIX .3.1
480 START MATRIX .3.8
490 TIME MATRIX .1.2
500 START MATRIX .1.3
510 PERC MATRIX .1.3
520 ATIME MATRIX .7.1
530 FGID MATRIX .7.1
540 SGRAPH MATRIX .7.1

550 GRAPH MATRIX .7.1
560 CTIME MATRIX .7.2
570 CELL MATRIX .7.1
580 SIZE MATRIX .7.1
590 ITEM MATRIX .7.5

600 CAPACITY OF PART & CART COUNTERS ***
610 PAR.A STORAGE 2000
620 PAR.F STORAGE 4
630 CART.F STORAGE 6
640 SCART.F STORAGE 8
650 PAR.M STORAGE 4
660 CART.M STORAGE 6
670 SCART.M STORAGE 8
680 PAR.E STORAGE 4
690 CART.E STORAGE 6
700 SCART.E STORAGE 8

D-10

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710 PA_I STORAGE 4
720 CART_I STORAGE 4
730 SCART_I STORAGE 4
740 PA_C STORAGE 4
750 CART_C STORAGE 4
760 SCART_C STORAGE 4
770 PA_C STORAGE 4
780 CART_C STORAGE 4
790 SCART_C STORAGE 4
800 PA_B STORAGE 2000
810 PA_D STORAGE 2000
820 PA_J STORAGE 10000
830 PA_K STORAGE 10000
840 PA_L STORAGE 10000
850 **************************************
860 * INITIAL VALUES *
870 **************************************
880 GENERATE ... ,
890 *** PART ID ***
900 NSAVEVALUE PART,10,1,PA_A ; the id of part A is 10
910 NSAVEVALUE PART,2,1,PA_F ; the id of part F is 2
920 NSAVEVALUE PART,5,1,PA_H ; the id of part H is 5
930 NSAVEVALUE PART,3,1,PA_E ; the id of part E is 3
940 NSAVEVALUE PART,4,1,PA_I ; the id of part I is 4
950 NSAVEVALUE PART,7,1,PA_O ; the id of part O is 7
960 NSAVEVALUE PART,6,1,PA_C ; the id of part C is 6
970 NSAVEVALUE PART,11,1,PA_B ; the id of part B is 11
980 NSAVEVALUE PART,12,1,PA_D ; the id of part D is 12
990 NSAVEVALUE PART,9,1,PA_J ; the id of part J is 9
1000 NSAVEVALUE PART,1,1,PA_L ; the id of part L is 1
1010 NSAVEVALUE PART,1,1,PA_L ; the id of part L is 1
1020 *** THE SIZE OF EACH CART ***
1030 NSAVEVALUE C_SIZE,5,1,4
1040 NSAVEVALUE C_SIZE,6,1,4
1050 NSAVEVALUE C_SIZE,9,1,4
1060 NSAVEVALUE C_SIZE,4,1,4
1070 NSAVEVALUE C_SIZE,5,1,4
1080 NSAVEVALUE C_SIZE,6,1,4
1090 *** INITIAL INVENTORY LEVEL AT EACH STOCK POINT ***
1100 ENTER CART_F,4
1110 ENTER SCART_F,4
1120 ENTER CART_H,4
1130 ENTER SCART_H,4
1140 ENTER CART_E,4
1150 ENTER SCART_E,4
1160 ENTER CART_I,4
1170 ENTER SCART_I,4
1180 ENTER CART_O,4
1190 ENTER SCART_O,4
1200 ENTER CART_C,4
1210 ENTER SCART_C,4
1220 ENTER PA_6,120
1230 ENTER PA_6,120
1240 ENTER PA_6,1000
1250 ENTER PA_6,1000
1260 ENTER PA_6,1000
1270 *** MAKE ONE CART READY AT EACH DEPAND STOCK POINT ***
1280 LEAVE CART_F,1
1290 ENTER PA_F,H SIZE(2,1)
1300 LEAVE CART_H,1
1310 ENTER PA_H,H SIZE(5,1)
1320 LEAVE CART_E,1
1330 ENTER PA_E,H SIZE(9,1)
1340 LEAVE CART_I,1
1350 ENTER PA_I,H SIZE(4,1)
1360 LEAVE CART_O,1
1370 ENTER PA_O,H SIZE(7,1)
1380 LEAVE CART_C,1
1390 ENTER PA_C,H SIZE(6,1)
1400 *** ITEMS REQUIRED TO MAKE EACH PART ***
1410 NSAVEVALUE ITEX,2,1,1 ; part F requires 1 part type(s).
1420 NSAVEVALUE ITEX,2,2,1 ; part L.
1430 NSAVEVALUE ITEX,2,3,2 ; 2 unit(s).
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1440 NSAVEVALUE ITEM, 5, 1, 1 ; part H requires 1 part type(s).
1450 NSAVEVALUE ITEM, 5, 2, 4 ; part I.
1460 NSAVEVALUE ITEM, 5, 3, 1 ; 1 unit(e).
1470 NSAVEVALUE ITEM, 5, 4, 2 ; part E requires 2 part type(s).
1480 NSAVEVALUE ITEM, 5, 5, 9 ; part J.
1490 NSAVEVALUE ITEM, 5, 3, 2 ; 2 unit(e).
1500 NSAVEVALUE ITEM, 5, 4, 8 ; part K.
1510 NSAVEVALUE ITEM, 5, 5, 1 ; 1 unit(e).
1520 NSAVEVALUE ITEM, 4, 1, 2 ; part I requires 2 part type(s).
1530 NSAVEVALUE ITEM, 4, 2, 9 ; part J.
1540 NSAVEVALUE ITEM, 4, 3, 2 ; 2 unit(e).
1550 NSAVEVALUE ITEM, 4, 4, 0 ; part K.
1560 NSAVEVALUE ITEM, 4, 5, 1 ; 1 unit(e).
1570 NSAVEVALUE ITEM, 4, 7, 1 ; part G requires 1 part type(s).
1580 NSAVEVALUE ITEM, 4, 7, 2 ; part K.
1590 NSAVEVALUE ITEM, 4, 3, 2 ; 2 unit(e).
1600 NSAVEVALUE ITEM, 4, 1, 1 ; part C requires 1 part type(s).
1610 NSAVEVALUE ITEM, 4, 2, 4 ; part I.
1620 NSAVEVALUE ITEM, 4, 9, 2 ; 2 unit(e).

1630 *** STATION SERVICE TIME ***
1640 NSAVEVALUE TIME, 6, 1, TIME11 ; time of TASK6 is TIME11
1650 NSAVEVALUE TIME, 2, 1, TIME8 ; time of TASK2 is TIME8
1660 NSAVEVALUE TIME, 5, 1, TIME11 ; time of ASSY5 is TIME11
1670 NSAVEVALUE TIME, 1, 1, TIME8 ; time of ASSY1 is TIME8
1680 NSAVEVALUE TIME, 3, 1, TIME8 ; time of ASSY3 is TIME8
1690 NSAVEVALUE TIME, 8, 1, TIME12 ; time of ASSY8 is TIME12
1700 NSAVEVALUE TIME, 7, 1, TIME12 ; time of ASSY7 is TIME12

1710 *** TIME TO MOVE A CART BETWEEN SUPPLY AND REPAIR POINTS ***
1720 NSAVEVALUE MTIME, 2, 1, MTIME1 ; moving time of a cart of part F is TIME1
1730 NSAVEVALUE MTIME, 4, 1, MTIME4 ; moving time of a cart of part H is TIME4
1740 NSAVEVALUE MTIME, 4, 1, MTIME4 ; moving time of a cart of part E is TIME4
1750 NSAVEVALUE MTIME, 4, 1, MTIME4 ; moving time of a cart of part I is TIME4
1760 NSAVEVALUE MTIME, 4, 1, MTIME4 ; moving time of a cart of part C is TIME4

1770 *** SETUP TIME FOR A CART OF PARTS AND ***
1780 *** MANUFACTURING TIME FOR A PART ***
1790 NSAVEVALUE CTIME, 2, 1, CTIME2 ; setup time for a cart of part F is TIME2
1790 NSAVEVALUE CTIME, 6, 1, CTIME6 ; setup time for a cart of part H is TIME6
1790 NSAVEVALUE CTIME, 5, 1, CTIME5 ; setup time for a cart of part E is TIME5
1790 NSAVEVALUE CTIME, 8, 1, CTIME8 ; setup time for a cart of part I is TIME8
1790 NSAVEVALUE CTIME, 6, 1, CTIME6 ; setup time for a cart of part C is TIME6

1800 NSAVEVALUE CTIME, 6, 1, CTIME6 ; setup time for a cart of part C is TIME6
1810 *** CELL WHERE EACH PART IS MADE ***
1820 NSAVEVALUE CELL, 2, 1, MC2 ; part F is made on machine MC2
1830 NSAVEVALUE CELL, 5, 1, MC1 ; part H is made on machine MC1
1840 NSAVEVALUE CELL, 9, 1, MC2 ; part E is made on machine MC2
1850 NSAVEVALUE CELL, 4, 1, MC4 ; part I is made on machine MC4
1860 NSAVEVALUE CELL, 7, 1, MC2 ; part C is made on machine MC2
1870 *** NAME OF EACH STATION ***
1880 NSAVEVALUE STNM, 4, 1, INSF4 ; the id of station INSF4 is 4
1890 NSAVEVALUE STNM, 6, 1, TASK6 ; the id of station TASK6 is 6
1890 NSAVEVALUE STNM, 2, 1, TASK2 ; the id of station TASK2 is 2
1890 NSAVEVALUE STNM, 5, 1, ASSY5 ; the id of station ASSY5 is 5
1890 NSAVEVALUE STNM, 1, 1, ASSY1 ; the id of station ASSY1 is 1
1890 NSAVEVALUE STNM, 3, 1, ASSY3 ; the id of station ASSY3 is 3
1890 NSAVEVALUE STNM, 8, 1, ASSY8 ; the id of station ASSY8 is 8
1890 NSAVEVALUE STNM, 7, 1, ASSY7 ; the id of station ASSY7 is 7

1900 *** INSPECTION STATION INDEX ***
1910 NSAVEVALUE STNM, 4, 2, 1 ; the index of inspection station INSF4 is 1

1920 *** INSPECTION STATION ***
1930 NSAVEVALUE INS, 4, 1, IDR1 ; inspection rate of INSF4 is 1
1940 NSAVEVALUE INS, 1, 2, INSR1 ; repair rate of INSF4 is 0.2
1950 NSAVEVALUE INS, 3, 1, INSR3 ; scrap rate of INSF4 is 0.3
1960 NSAVEVALUE INS, 1, 1, INSP ; inspector of INSF4 is INSPECTOR
1970 NSAVEVALUE INS, 1, 2, INSPIR ; inspector of INSF4 is INSPECTOR
1980 NSAVEVALUE INS, 1, 3, INSCTR ; scrapped items of INSF4 are sent to SCRAP4

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2170 MSLVALUE  TIME,1,1,$TIME9 ; inspection time of INSPE4 is $TIME9
2180 MSLVALUE  TIME,1,2,$TIME10 ; repair time of INSPE4 is $TIME10

2190 *** PART (12) REQUIRED AT EACH STATION ***

2200 MSLVALUE  STAN,5,2,1 ; station ASSY5 requires 1 part type(s).
2210 MSLVALUE  STAN,5,3,1 ; part E.
2220 MSLVALUE  STAN,5,4,1 ; 2 units(s).
2230 MSLVALUE  STAN,1,2,2 ; station ASSY1 requires 2 part type(s).
2240 MSLVALUE  STAN,1,3,1 ; part C.
2250 MSLVALUE  STAN,1,4,1 ; 3 units(s).
2260 MSLVALUE  STAN,1,5,1 ; part C.
2270 MSLVALUE  STAN,1,6,1 ; 2 units(s).
2280 MSLVALUE  STAN,5,3,1 ; station ASSY5 requires 1 part type(s).
2290 MSLVALUE  STAN,3,9,12 ; part B.
2300 MSLVALUE  STAN,9,4,1 ; 4 unit(s).
2310 MSLVALUE  STAN,9,5,1 ; station ASSY8 requires 1 part type(s).
2320 MSLVALUE  STAN,9,6,1 ; part H.
2330 MSLVALUE  STAN,9,4,1 ; 1 unit(s).
2340 MSLVALUE  STAN,7,2,2 ; station ASSY7 requires 2 part type(s).
2350 MSLVALUE  STAN,7,3,2 ; part F.
2360 MSLVALUE  STAN,7,4,2 ; 2 units(s).
2370 MSLVALUE  STAN,7,5,7 ; part E.
2380 MSLVALUE  STAN,7,6,1 ; 1 unit(s).

2390 *** SUPPLY SYSTEM OF EACH PART ***

2400 MSLVALUE  PART,1,2,1 ; part A is in push node
2410 MSLVALUE  PART,2,2,0 ; part F is in pull node
2420 MSLVALUE  PART,5,2,0 ; part H is in pull node
2430 MSLVALUE  PART,3,2,0 ; part E is in pull node
2440 MSLVALUE  PART,4,2,0 ; part I is in pull node
2450 MSLVALUE  PART,7,2,0 ; part E is in pull node
2460 MSLVALUE  PART,6,2,0 ; part C is in pull node
2470 MSLVALUE  PART,11,2,1 ; part G is in pull node
2480 MSLVALUE  PART,12,2,1 ; part B is in push node
2490 MSLVALUE  PART,9,2,1 ; part J is ordered from outside
2500 MSLVALUE  PART,9,2,1 ; part K is ordered from outside
2510 MSLVALUE  PART,1,2,1 ; part L is ordered from outside

2520 *** CART COUNTER AT EACH DESTINATION ***

2530 MSLVALUE  CART,2,1,1;CART_F
2540 MSLVALUE  CART,5,1,1;CART_H
2550 MSLVALUE  CART,3,1,1;CART_E
2560 MSLVALUE  CART,4,1,1;CART_I
2570 MSLVALUE  CART,7,1,1;CART_G
2580 MSLVALUE  CART,6,1,1;CART_C

2590 *** CART COUNTER AT SOURCE ***

2600 MSLVALUE  SRCRT,2,1,1;SRCRT_F
2610 MSLVALUE  SRCRT,5,1,1;SRCRT_H
2620 MSLVALUE  SRCRT,3,1,1;SRCRT_E
2630 MSLVALUE  SRCRT,4,1,1;SRCRT_I
2640 MSLVALUE  SRCRT,7,1,1;SRCRT_G
2650 MSLVALUE  SRCRT,6,1,1;SRCRT_C

2660 *** UNABLE TO MOVE PARTS ***

2670 MSLVALUE  FGIG,2,1,1;TRUCK2 ; part F is transported by TRUCK2
2680 MSLVALUE  FGIG,5,1,1;TRUCK3 ; part H is transported by TRUCK3
2690 MSLVALUE  FGIG,9,1,1;TRUCK1 ; part I is transported by TRUCK1
2700 MSLVALUE  FGIG,4,1,1;TRUCK2 ; part E is transported by TRUCK2
2710 MSLVALUE  FGIG,7,1,1;TRUCK2 ; part G is transported by TRUCK2
2720 MSLVALUE  FGIG,6,1,1;TRUCK1 ; part C is transported by TRUCK1

2730 TERMATE

2740 ******************************************************

2750 = ASSEMBLY LINE Y

2760 ******************************************************

2770 GENERATE VTIME11
2780 ASSIGN 2,5 ; station 5 is ASSYS
2790 TRANSFER GBR, ASH, TRKNI
2800 ASSIGN 2,5
2810 TRANSFER GBR, TASK, TRKNI
2820 ENTER PA, 0,1

2830 TERMINATE

2840 ******************************************************

2850 = ASSEMBLY LINE X

2860 ******************************************************

2870 GENERATE VTIME1
2880 ASSIGN 2,1 ; station 1 is ASSY1
2890 TRANSFER GBR, ASH, TRKNI

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2900 ASSIGN 2,2 ;station 2 is TASK2
2910 TRANSFER GR, TASK, TRIM1
2920 ASSIGN 2,3 ;station 3 is ASSY3
2930 TRANSFER GR, ASY, TRIM1
2940 ASSIGN 2,4 ;station 4 is ASH3
2950 TRANSFER GR, ASH, TRIM1
2960 ENTER P4,1
2970 TERMINATE
2980 ********************************************
2990 # ASSEMBLY LINE 2
3000 ********************************************
3010 GENERATE W41HE12
3020 ASSIGN 2,7 ;station 7 is ASW7
3030 TRANSFER GR, ASW, TRIM1
3040 ASSIGN 2,0 ;station 8 is ASW8
3050 TRANSFER GR, ASW, TRIM1
3060 ENTER P8,1
3070 TERMINATE
3080 ********************************************
3090 # INSPECTION STATION
3100 ********************************************
3110 IMP ASSIGN 3, MSSTM(P2,2) ;insp. station
3120 ASSIGN 4, HSEP(P2,1) ;inspection rate
3130 ASSIGN 5, MTIME(P2,1) ;time for inspection
3140 ASSIGN 6, MTIME(P2,2) ;time for repair
3150 QUEUE MSTM(P2,1) ;count entering parts
3160 DEPART MSTM(P2,1) ;and pass
3170 CHECK TRANSFER FHM4 ;to be checked?
3180 CHECK MSTM(P2,1) ;wait on the insp. facility
3190 SEIZE MSTM(P2,1) ;leave the insp. facility
3200 DEPART MSTM(P2,1) ;leave the insp. queue
3210 ADVANCE F4S ;inspecting part
3220 RELEASE MSTM(P2,1) ;release the insp. facility
3230 ASSIGN 4, HSEP(P2,2) ;repair rate
3240 TRANSFER FHM4 ;to be repaired?
3250 REPAIR QUEUE MSTM(P2,2) ;wait on repairing facility
3260 SEIZE MSTM(P2,2) ;leave the repairing facility
3270 DEPART MSTM(P2,2) ;leave the queue
3280 ADVANCE F4S ;repairing parts
3290 RELEASE MSTM(P2,2) ;release the repairing facility
3300 ASSIGN 4, HSEP(P2,2) ; scrap rate
3310 TRANSFER FHM4 ;to part scrapped?
3320 PASS TRANSFER P, TRIM1 ;finish inspection and return
3330 SCRAP QUEUE MSTM(P2,3) ;count scrapped parts
3340 DEPART MSTM(P2,3) ;and pass
3350 TERMINATE ;terminate the transaction
3360 ********************************************
3370 # TASK STATION
3380 ********************************************
3390 TASK ASSIGN 3, MSTM(P2,1) ;none of the task station
3400 ASSIGN 6, MTIME(P2,1) ;time for operation
3410 QUEUE P3 ;wait on the facility
3420 SEIZE P3 ;leave the facility
3430 DEPART P3 ;leave the queue
3440 ADVANCE F4S ;perform operation
3450 RELEASE P3 ;release the facility
3460 TRANSFER P, TRIM1 ;finish and return
3470 ********************************************
3480 # ASSEMBLY STATION
3490 ********************************************
3500 ASH ASSIGN 5, MSTM(P2,1) ;none of the station
3510 ASSIGN 7, MTIME(P2,2) ;no. of part types required
3520 ASSIGN 6, MTIME(P2,1) ;assembly time
3530 ASSIGN 9,1 ;index for part type
3540 ASSIGN 9,2 ;index for units of part
3550 QUEUE P3 ;wait on the facility
3560 PROV ASSIGN 9,2 ;point to next type
3570 ASSIGN 9,2 ;point to next no. of units
3580 ASSIGN 5, MSTM(P2,3) ;part fid
3590 ASSIGN 18, MTIME(P2,1) ;none of part
3600 ASSIGN 20, MSTM(P2,3) ;number of units of part
3610 QUEUE P18 ;wait to get parts
3620 TRANSFER GR, TAKES, TRIM2 ;get parts

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3630 DEPART P10
3640 LOOP P,PA0
3645 LOOSIZE P3
3650 DEPART P3
3660 ADVANCE U46
3670 RELEASE P3
3680 TRANSFER P,TRH2,1
3690 RETURN to the deling statement
3700 # INVENTORY CONTROL
3710
3720 TAKEP TEST E
3730 PUSH TEST GE
3740 LEAVE 18,P20
3750 TRANSFER P,TRH2,1
3760 PULL 38,HEEDC
3770 TEST GE
3780 IMUSP LEAVE 18,P20
3790 SPLIT 1,USEP
3800 TRANSFER P,TRH2,1
3810 NEEDC ASSIGN 29, E10
3820 LEAVE 18, E10
3830 SPLIT 1,USEP
3840 TEST GE
3850 SPLIT 1,USEP
3860 LEAVE 30
3870 ENTER 18,HEEDC
3880 TEST GE
3890 LEAVE 18,P20
3900 SPLIT 1,USEP
3910 TRANSFER P,TRH2,1
3920 USEP TEST E
3930 TERMINATE
3940 EMPTY SPLIT
3950 TEST GE
3960 LEAVE 36,1
3970 ENTER 18,HEEDC
3980 TERMINATE
3990 ORDERI ASSIGN 26,HEEDC
4000 ASSIGN 36,HEEDC
4010 QUEUE P26
4020 SIZE P26
4030 DEPART P26
4040 ADVANCE V=36
4050 RELEASE P26
4060 SPLIT 1,GETIF
4070 ASSIGN 12,P5
4080 ASSIGN 15,HEEDC
4090 GETIF TRANSFER 60,HEEDC
4100 ENTER P15,1
4110 TERMINATE
4120 GETIF ASSIGN 31,HEEDC
4130 QUEUE P31
4140 TEST GE
4150 LEAVE 31,1
4160 DEPART P31
4170 HENDF QUEUE P31
4180 SIZE P31
4190 DEPART P31
4200 ADVANCE V31
4210 RELEASE P31
4220 TERMINATE
4230 "Manufacturing Cell"
4240
4250 12,HEEDC
4260 ASSIGN 14,HEEDC
4270 ASSIGN 16,HEEDC
4280 QUEUE P16
4290 ASSIGN 17,HEEDC
4300 CARTO ASSIGN 8,HEEDC
4310 ASSIGN 5,1
4320 ASSIGN 8,2
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4360     ASSIGN  9+,2   ;point to next no. of units
4370     ASSIGN  5,MI$ITEM(P12,P8) ;id of the item req'd
4380     ASSIGN  10,MI$PART(P5,1)  ;name of the item
4390     ASSIGN  20,MI$ITEM(P12,P9) ;units of the item req'd
4400     QUEUE   P18    ;wait on the item
4410     TRANSFER  g68,TAKEP,RTRN2 ;get items
4420     DEPART   P18    ;leave the queue
4430     LOOP    17,PARIO ;loop for next item type req'd
4440     LOOP    7,PARIO ;loop for next part to be made
4450     FAC SEIZE   P13  ;seize the facility
4460     DEPART   P13    ;leave the queue
4470     ADVANCE V+14    ;set up facility
4480     ADVANCE V+TIME ;manufacturing
4490     MTIME FVARABLE V+16$NMHC$SIZE(P12,1); manufacturing time
4500     RELEASE  P13  ;release the facility
4510     TRANSFER  P,RTRN3,1 ;manufacturing complete