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CORNELL SIMULATOR OF MANUFACTURING OPERATIONS (COSMOS)

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Chapter 1

INTRODUCTION TO COSMOS

1.1 Abstract

The goal of this project is to develop a high-level modeling tool for manufacturing systems engineering. The basic tool will provide detailed simulation capability in the areas of facilities design, production planning, material flow planning and distribution, and routing and scheduling. The software will feature a high-level graphics interface for defining simulation models and displaying model results, a robust database permitting integrated applications, and a rich set of algorithms for solving problems with special structure.

1.2 Background

Under NSF grants over the past six years, the project director, with collaborators from other units within Cornell, from industry, and from universities both here and abroad, has developed a four-phase hierarchical approach to modeling multi-stage, multi-product, production-distribution systems. The four phases are faciltiies design, production planning, flow planning and real-time scheduling. What are most important in each of the phases and how they are interrelated is detailed in Maxwell, Muckstadt, Thomas and VanderEecken (Interfaces, December 1983). Within that hierarchical framework, significant contributions have been made at Cornell in solving the engineering problems that arise in the design and control of manufactuing systems. Prototypical software that implements these techniques has also been developed at Cornell and is being used in industry test studies. Futhermore, the framework has been used as the basis for developing a coherent research agenda in manufacturing systems and is being adopted in one form or another by academic researchers at several major universities.

One key item on the research agenda concerns the problem of integrating the issues and models of each one of the four phases.

Industry participants in a recent NSF conference identified this item as an area where academic researchers could have a sigificant impact by convincing management of the need for organization restructuring.

The COSMOS project aims to restructure a manufacturing systems database in such a way that the basic representation of process flow, resource allocation and customer service is all handled in a coherent manner. The goal is to enable an engineer to step through all the phases in the hierarchical framework and to have a consistent ste of software tools to analyze the problems that arise in each phase.

COSMOS is targeted for three groups of users: manufacturing systems engineers, engineering and business school students, and academic researchers.

1.3 Innovation

The COSMOS project has four features which make it unique.

1. Integrated Database: Over the years we have developed numerous models, techniques and software packages that address particular problem areas such as material handling system design, production planning, production scheduling, distribution system design and control, and vehicle routing. The same is true elsewhere in the academic community and in industry. When one sees how closely related the problem areas are it becomes clear that what is needed is some natural way to tie these systems together. The starting point for linking problem areas and integrating solution techniques must be a coherent view of the data and the overall manufacturing-distribution system structure. The proposed COSMOS database structure is really a mega-model capable of supporting a detailed simulation of the entire systems operations. Any particular application is unlikely to exercise the full potential of the database structure. However, given the COSMOS mega-model in the background, simpler models can be constructed very easily that will relate in a consistant manner to models developed in the other related problem areas. This is particularly important, for example, at the boundary between

manufacturing and distribution where organizational distinctions, objectives and policies sometimes work at cross-purposes.

2. Graphical Interface: User interaction with COSMOS will occur at a very high and graphical level. We are fortunate in that so many of the fundamental data structures needed in manufacturing systems engineering are graphical in nature: facilties layout, process charts, bill of material product structures, distribution networks, materials handling networks, Gantt charts, vehicle routines, and so on. Cosmos will capitalize on this by allowing the user to define models by manipulating these various data structures graphically. Model outputs such as inventory levels, queue lengths, and resource utilization also lend themselves to graphical representations in a variety of ways. Time series plots, animation, and various uses of color will be used to convey relevant information in the most effective manner possible. We have developed many prototypes of graphical interfaces at Cornell and we are convinced that computer graphics is the key to successful model building, analysis and communication

3. Applications: Through COMEPP studies, Master of Engineering projects, graduate internships, and consulting projects we have acquired and are continuing to acquire case studies that can be used to demonstrate the importance and capabilities of COSMOS. Indeed, this industrial interaction has played a significant role in the evolution of the research leading up to COSMOS. This activity is essential to the project to ensure the relevance of the models developed for COSMOS to industrial users and to provide the data sets necessary for using COSMOS in a teaching and research environment.

4. Methodology: By methodology, we refer to the particular simulation or analytical techniques used to solve problems in manufacturing system design, evaluation and control. Analytical techniques include enconomic analysis, network optimization, resource allocation procedures, queueing theory, stochastic programming, statistical analysis, and artificial intelligence. Cornell has been a leader in develioping and applying

appropriate methodologies for these problems. The challenge of the COSMOS project from a research viewpoint is, first of all, to selectively integrate these methodolgies and secondly, to fill the gaps in the research by developing new techniques. The COSMOS project is consistant with a carefully planned research agenda that is receiving support from other universities, from the National Science Foundation and from industry.

Chapter 2

INTRODUCTION

2.1 Purpose

The following chapters describe in detail the menu functions and user interaction for running the COSMOS program. In this chapter we describe the general interaction method as well as the technicalities of starting up COSMOS.

The COSMOS execution sequence consists of a main menu to which are attached a number of editing menus, the simulation menu, and menus for showing output data, as well as some utilities.

Each of the editing menus allows the user to add, delete, and modify the data records which represent: the sequence of manufacturing operations (product structure diagram); the detailed tasks required to perform each operation (process, shipping, and delivery task charts); the production schedule (lot releases), and the resources available to meet the production schedule (resource chart).

The simulaton menu allows the user to calculate the effect of running the machines with the given schedule. The output is quite precise and will indicate the usage of each resource as well as the number of units in inventory at every time.

Other menus are available for showing the utilization of the resources (resource utilization chart) and the changes in inventory (inventory plot).

Each of the sub-menus, as well as the main menu, have utilities for manipulating the data, saving and retreiving files, and help.

2.2 Editing overview

Although each of the editors is geared towards a specific function, the method used to obtain that functionality is uniform.

Each of the editors has in the upper left a set of functions which can be applied to the data. Typically these functions are ADD, DELETE, ATTRIB, MOVE, and COPY. Pressing one of these buttons causes the editor to enter the mode indicated by the button; subsequent selections of objects will be understood as requests to perform the current function on the object. See the section "Modal functions", below.

Objects are selected in two steps: first the generic type of object to be selected is indicated by pressing one of the buttons half-way down the right side of the menu; then a specific object is selected by picking one of the icons on the menu. The type of object to be selected is, like the functions, modal: after the type of object to be selected has been picked once, it need not be picked again unless you wish to change it.

In addition to the modal functions, each menu may have special function buttons which immediately perform a single function. Typically these buttons are ZOOM, PAN, EXIT, OLD (get file), SAVE, NEW FILE, RUN, HELP, etc. Details of the special functions are given in the chapters describing each menu whenever they differ from those given in the "Immediate functions" section below.

2.3 Modal functions

ADD: Creates a new element and adds it to the ones already displayed. Usually, the data required for the element should be typed on the terminal or picked from a list which is presented.

DELETE: Removes an element from those currently displayed. Usually, the element to be deleted is picked from the icons on display.

ATTRIB: Change or inquire about the data (attributes) held in a given record or icon. Usually, the element to be edited or displayed is picked from the icons on display. Sometimes it is

not possible to alter the data, but the current values are displayed anyways. In cases where the data can be modified, a list of the fields will be appear on the data terminal, with number next to those which can be altered. To change an entry, enter the number next to the feild, and at the prompt enter the new data. In some cases a sub-menu will be invoked; the procedure is the same.

COPY: Create a new element using all of the attributes from some one of the existing elements. Usually the element to be copied is selected, followed by the location of the new element.

2.4 Immediate functions

EXIT: When you pick the EXIT button, the menu will terminate and return to the next higher level. If you are in the main menu, then the program will terminate. In some cases, the EXIT item will be highlighted as a signal that you should confirm your intention to quit the menu.

HELP: In every menu, pressing the HELP button will display whatever help is available for the menu. Usually this takes the form of a list of help items; choosing one of them prints out a description of the button or topic.

MOVE: Change the display location of an icon. Typically, the element to be moved is selected and then its new location is selected.

ZOOM: When you pick the ZOOM function, you prompted for a new scale range, typically the lowest and highest X coordinate values in the new display. Enter the new range; the zoom occurs immediately.

PAN: When you pick the PAN function, the system will wait for you to pick a point on the screen and the displayed data is translated accordingly.

2.5 Files

All data used by COSMOS is stored in disk files; in most cases the files have an internal format which is not of concern to the user. The data stored in the files represents the simulated factory, the scheduling of events, and the resultant inventory levels and resource utilization data. File names are 1-8 characters long; file types are 3 characters long. The file types are:

TST - Factory simulation representation
SML - Simulation log of resource utilization
INH - Inventory History file
LTR - Lot release schedule
RSN - Resource selection file
HLP - Help data
MEN - Menu data
DAT - Other data

2.6 Icons

Cosmos uses a series of icons to represent data in the simulation display. These icons form the interface between the user's conceptual view of the factory and the records maintained in COSMOS.

Task types are represented in the task chart editors by the following icons:

Task Type	Symbol
Draw	Diamond with 'D'.
Store	Diamond with 'S'.
Setup	Rectangle.
Move	Right-pointing arrow.
Process	Ellipse.
Inspect	Circle.

Task Type	Symbol
Ship	Diamond
Receive	Diamond

Resource categories are represented in the resource editor by the following symbols:

Resource Category	Symbol
MACHINE	Rectangle with 'M'.
STORAGE	Rectangle with 'S'.
CARRIER	Rectangle with 'C'.
TRACK	Rectangle with notched corners.
STATION	Rectangle with diagonal corners.
TOOL	Rectangle with 'T'.
LABOR	Rectangle with 'L'.

2.7 Initializing COSMOS on the IBM4341/5080 system.

On the data terminal, type 'COSMOS xxx', where xxx is the number of the graphics terminal which will be used. This command defines temporary storage for use by the COSMOS programs and checks the account for correct memory size and configuration. COSMOS requires about five megabytes of virtual storage and loader table (LDRTBLS) size of 10. If you do not have this minimum, COSMOS will display an error message on your terminal and terminate. If this happens, issue the following commands:

```
SET LDRTBLS 10
DEF STOR 5M
```

Then, re-IPL CMS. If this does not correct the problem, contact COSMOS support personnel.

Chapter 3

MAIN COSMOS MENU

3.1 General Description

The main menu for Cosmos allows you to access the factory editing, simulation, and display screens. The different functions are displayed on the right side of the Main Menu in the command area. To select one, move the cursor crosshairs over your choice and press the button on the selector device.

3.2 Resource Chart

Enters the Resource Editor. The Resource Editor is responsible for creating and editing resource types, resources, and zones.

3.3 Product Structure

Enters the product structure diagram editor. The product structure diagram consists of operation and inventory icons connected by edges. Usually there is at least on inventory icon for each operation; the inventory holds the items resulting from the operation.

Each of the operation nodes (task charts) consists of a set of task nodes which, taken together, perform the manufacturing operation. The operation nodes are edited using the Process Chart, Shipping Chart, and Receiving Chart editors.

Each of the inventory nodes indicates the name of a part which will be stored there.

In contrast to the edges within each task chart, the edges between task charts (the edges in the Product Structure diagram) are provided primarily for the user's convenience and do not play a critical role in the simulation processing.

3.4 Process, Shipping, and Receiving Charts

Enters the chart editor in order to create or edit the specific charts to perform the operations described in the product structure diagram. There is exactly one chart for each operation listed in each of the operation (square) icons of the product structure diagram. The three types of charts are interchangeable except that the shipping and receiving charts each have within them a SHIPPING or RECEIVING type task node, respectively. The icons displayed in the task chart editors represent task nodes, each of which describes a specific manufacturing operation. The task nodes and the edges between them are critical to the simulation process; they are described in the chapter "SUMULATE" and in the chapter concerning the task chart editors.

3.5 Simulate

Enters the COSMOS Simulation Menu. The input used by this menu consists of the lot release file created with the lot release editor, and the manufacturing database created with product structure editor and the process/delivery/shipping chart editors.

3.6 Gantt Chart

This chart editor will be supported in future versions of COSMOS. Do not use this menu now.

3.7 Utilization Chart

Display resource utilization over time. This provides a gantt chart indicating the usage of resources, and is usually entered after the simulation has been run.

3.7.1 Inventory Plot

Display inventory levels over time. This provides a plotting of the inventory levels of all the intermediary and final products at all times during the simulation. It is usually used after the simulation has been run.

3.7.2 Lot Release Editor

Create or modify a factory schedule. The lot releases indicate the times at which the various operations indicated in the Product Structure Diagram are going to begin, and how many units they are being told to produce.

3.7.3 OLD

Read a COSMOS factory test case from disk and add it to the test case being displayed. COSMOS will display on the graphics screen a menu of available factory files.

3.7.4 SAVE

Write a edited factory test case to disk. COSMOS will ask you to enter the name of the output disk file. Enter a 1-8 character data file name. If there is a data file matching the name you enter, the original file will be overwritten. COSMOS will display 'system saved' after the factory has been successfully written to disk.

Chapter 4

RESOURCE CHART EDITOR

4.1 General Description

Using the Resource Chart Editor, you may create, edit, and delete COSMOS resource types, zones, and resources. Selecting EXIT will return you to the Main Menu screen; HELP will display a menu of all help topics available for this screen.

The resources are displayed graphically as rectangles. Each rectangle contains three lines of labelling information. The top line shows the one-character resource type (RTYPE) abbreviation, the middle shows the resource CATEGORY, and the bottom line shows the name of the resource represented The color of each rectangle is determined by its resource type.

4.2 Editing Functions

The basic editing function modes described earlier are available in this editor.

You may manipulate three things with the editing commands: Resource Types, Zones, and Resources. These are listed on the right of the screen below the editing commands. Any subclasses associated with an editing class are grouped together and below the main unit. Descriptions of the main classes follow:

4.2.1 Resource Type

A resource type describes an overall collection of resources, such as 'N/C Mill' or 'Repair Crew,' as opposed to a particular resource, such as 'Mill #3073', or 'Repairman #3.' Every resource has a resource type record consisting of a resource type name and a resource CATEGORY. The type name may be any short string of your choosing; the CATEGORY should be one of the following: MACHINE, STORAGE, FIXTURE, CARRIER, TRACK, STATION, TOOL, or LABOR. The categories provided are meant to correspond to

conceptual divisions among the resources, but do not affect the logical operation of the simulation.

For more information on the resource addresses, see the chapter "SIMULATE".

To add a resource type, select ADD followed by RESOURCE TYPE. Then, enter the name of the resource type on the data entry terminal. When a resource CATEGORY selection menu appears on the graphics screen, select the CATEGORY associated with the resource you are adding.

To delete a resource type, select DELETE followed by RESOURCE TYPE.

4.2.2 ZONE

A resource zone is the area in the factory where a resource is located. For example, 'Work Center 5' or 'Drilling.' Every zone has a type, PHYSICAL or LOGICAL: the PHYSICAL zones are meant to correspond to physical location areas in the factory; the LOGICAL zones are any other grouping of resources. All of the zones created here are level 1 zones. Level 0 zones are automatically created, one for each resource, such that the name of the level 0 zone is the same as the name of the resource. See SIMULATE for explanation of levels 0 and 1.

4.2.3 Resource

Add, modify, or delete a Resource in your factory. COSMOS will prompt you to select the location of the resource in the graphics display area. If adding a resource to your factory, enter its name on the data terminal when prompted. A menu of resource types will then appear. From this menu, select the resource type you wish to associate with the resource you are adding. If you answer Yes (1) to the question 'Does this resource belong to any level 1 zones' then you will be able to select one of the level 1 zones which you created using the ZONE editing function described below. Note: the level 0 zones will be displayed along with the level 1 zones, but you cannot choose the level 0 zones at this point.

4.3 Resource Type Editing

Entering the ATTRIB editing function mode followed by the Resource Type object selection mode allows you to change the values which define each resource type. When you select a resource type icon, the following screen appears.

```
1) Name: 3MACH                                                    |
2) Category: MACHINE                                              |
3) State Space:                                                   |
4) Task Unit:                                                     |
   Task Capacity:                                                 |
5) Min:  0.0  6) Max: 1.00                                        |
7) Storage Unit:                                                  |
   Storage Capacity:  8) Min:   0.0  9) Max:  1.00                |
10) State-zone operation (*)                                      |
```

Figure 1: Displaying/Changing Resource Type Attributes

Enter the number next to the item which you want to change, and at the prompts enter the new value. The meanings of the fields are explained in the chapter "SIMULATE".

4.4 Resource editing

Entering the ATTRIB editing function mode followed by the Resource Type object selection mode allows you to change the values which define each resource type. When you select a resource type icon, the following screen appears.

```
Resource Record:
1) Name: HSCR
   Grid Location: X:-0.43  Y: 0.32
2) Resource type: HSCR
3) Resource state: NOT_READY
4) Reserved for:
5) Reserved until:
   Utilization:
   Tasking used:   0.0  Space used:   0.0
6) Contents(*)
```

Figure 2: Displaying/Changing Resource Attributes

Most of these terms are explaned above or in the "SIMULATE" chapter. Field (6), the contents records, is a list of the inventory stored in the resource, as calculated by the simulation. Each contents record consists of a part number and a quantity. Although it is possible to change the contents of a resource, it is not advised because the simulation will force all contents to quantity 0 at initialization time. Fields (4) and (5) are for a future implementation and have no significance now.

Chapter 5

PRODUCT STRUCTURE DIAGRAM

5.1 General Description

The Product Structure Diagram describes the series of operations and intermediate products required to produce a product. The square symbols in the graphics display area represent operations, i.e. process, shipping or receiving task charts. The diamond shapes represent inventories produced by these operations. Using the Product Structure Editor, you may add and delete operations and inventory areas from the Product Structure Diagram. Selecting EXIT will return you to the Main Menu screen; HELP will display a menu of all help topics available for this screen.

5.2 Editing Functions

The basic editing function modes ADD, DELETE, MOVE, COPY, PAN described earlier are available in this editor.

Using these commands, you may manipulate two classes of objects: inventory and operation nodes, and edges. These are described below:

5.3 Nodes

To add a node to the Product Structure Diagram, select ADD and NODE with the selector device. You then select the node type from the menu.

Inventory nodes require you to enter the inventory part number of the part which will arrive on the incoming edges. Typically, this name matches the name of the DRAW type task nodes in any operation chart on the end of an outgoing edge from the inventory node; it also usually matches the name of the STORE type task node in any operation chart on the head of an edge coming into the inventory node.

The Operation Node contains the name of a Task Chart representing some series of tasks. Use the selector device to point to the screen location where the Operation icon is to go. After you have selected the icon's location, Enter the Task Chart's name from the data terminal. If the Task Chart's name is not already known to COSMOS, you will be asked to specify which chart type it is. Valid chart types are:

0: Process Chart (arbitrary graph of task nodes)
1: Shipping Chart (contains a SHIPPING type task node)
2: Receiving Chart (contains a RECEIVING type task node)

The exploded view of the operation sequence (task chart) represented by the operation node may be examined using the process, shipping, or receiving chart editors.

5.4 EDGE

Using the selector device, pick a 'from' node and an 'into' node. Enter the units name, such as pieces or pounds.

Enter the transfer coefficient. This is a multiplier for the number of units as the units flow through the edge. One the process chart level, this number doesn't make much difference but should be specified for convenience later. Use 1.0 as a default.

Enter the storage size per unit. This is a numeric value the amount of physical storage occupied by each piece of inventory produced by the 'from' operation. Use 0.0 as a default.

Chapter 6

PROCESS, SHIPPING, AND RECEIVING CHARTS

6.1 General Description

The Task Chart Editors allow you to add, edit, and delete Process, Shipping, and Receiving charts within your COSMOS factory. What is displayed is the exploded view of the Process, Shipping, and Receiving nodes represented by the rectangle or diamond icons in the Product Structure display screen.

6.2 Editing Functions

Using the modal editing functions described earlier, you may manipulate Nodes and Edges within the chart graph structures. You may also change which of the task charts is currently being edited. Because the ADD and DELETE functions have additional meaning for the task chart as a whole -- rather than just the usual operations on the elements (nodes and edges) within a single task chart -- a description for each is given below. The other operations are as described in the introductory section.

* ADD:

  Add a node or edge to the task chart currently displayed, or (when used with the CHART class selector) switch to a new Task Chart to the screen for editing.

* DELETE:

  Delete a node or edge from the Task Chart currently displayed, or (with CHART button) delete Task Chart definition from COSMOS.

6.3 Choosing a chart to edit

To edit a chart, select ADD, CHART, and the name of the chart to be added. The name of the chart is the same as the name of one of the operations (square icons) in the product structure diagram.

When you choose a new chart to edit, the old chart disappears from the screen but is not lost. In order to remove a chart, you must use the DELETE, CHART buttons.

6.4 Adding a task node

To add a node, select ADD, NODE, and the node type (DRAW, STORE, SETUP, INSPECT, PROCESS, SHIPPING, DELIVERY, or MOVE). Then, on the graphics display screen, point to the grid location where the node should go. After the point has been selected, enter the number of the primary address CATEGORY (eg., machine, storage, fixture) from the selection list displayed. Following this, a menu of resource types (RTYPE) will appear on the graphics terminal; pick one or Exit. Finally, a list of the zones (both level 0 and level 1) will appear; pick one of these, or Exit. You must pick either the RTYPE or the ZONE, or both. The CATEGORY, RTYPE, and ZONE thus selected will form the resource address for the primary resource request of every task having this task node. See the chapter, SIMULATE, for more information concerning the resource requests and the different task nodes described below.

Depending upon which node type you have selected, there may be additional fields to enter on the data terminal. These are described in detail below.

DRAW type task node: COSMOS will display 'node type is draw'; enter the draw part number. The draw part number is any short string. When this task node is activated a search will be made among all the resources for a contents record containing the part number, and the number of units in the contents record will be decreased by the number of units requested by the batch.

STORE type task node: COSMOS will display 'node type is store'; enter the store part number. The store part number is any short string. When this task node is activated, a contents record

will be created in the resource which has been used to satisfy the primary resource request of the batch, and the inventory number of units will be increased by the number of units produced by the batch.

SETUP type task node: COSMOS displays: 'node type is setup. / Enter time to setup mean.' The number you enter should represent the time to set up any of the resources matching the address of the primary request of the task node. The first time a resource of is allocated to an active task node of type SETUP, this delay will be applied by the simulation.

For SETUP type nodes, there is some additional information (the state transitions) which assumes a default value. These may be changed using the ATTRIBute editor described later.

MOVE type task node: COSMOS displays: 'node type is move / select location address type'. Enter the integer value corresponding to your choice, Relative or Absolute; use Absolute if you are unsure. Depending on which one you select, you will be asked to enter some more information.

MOVE/Relative: COSMOS displays 'location address type is relative / enter location address home of'. Enter the name of a resource level 0 zone (i.e., enter the name of a resource). When a batch whose task is represented by the task node completes, the primary resource allocated to the batch will have its grid location set equal to the grid location of the resource you indicate here.

MOVE/Absolute: COSMOS displays: 'location address type is absolute / enter location.x / enter location.y'. The x and y values you enter here give the grid location to which the primary resource will be moved, when each batch whose task is represente by this MOVE task node completes.

PROCESS type task node: The PROCESS type task node is the generic type of task node indicating any ordinary manufacturing process. COSMOS displays: 'node type is process / enter time per unit mean' The time you enter here defines the average time to perform the manufacturing process on one unit of material.

INSPECT type task node: The INSPECT task nodes are substantially the same as the PROCESS task nodes, but are used to

represent an inspection process: typically they occur at the end of PROBABILISTIC links having low probability. COSMOS displays 'node type is inspect'.

SHIPPING type task node: COSMOS displays: 'node type is shipping'. The SHIPPING nodes each have a shipping schedule, known as the "material activity records". The material activity records should be created and edited with the ATTRIB editor; they are described in the chapter, "SIMULATE".

RECEIVING type task node: COSMOS displays: 'node type is receiving'. As for the SHIPPING nodes, the RECEIVING nodes have a list of material activity records which is created and modified by the ATTRIBute editor.

6.5 Deleting a task node

Task nodes are deleted by selecting DELETE, NODE, and the icon representing the node to be deleted.

6.6 Adding an edge

The edges between the task nodes indicate the flow of material from one processing station (task node) to the next. Every edge has a source 'from' node and a destination 'to' node; this direction is indicated on the screen by a cross which is placed closer to the 'to' node than the 'from' node.

Select an edge type (PUSH, PULL, or PROBABILISTIC) from the menu directly below the EDGE button on the graphics display. With the selector device, pick a 'from' node and an 'into' node. Now, enter the units name, the numeric transfer coefficient, and the numeric storage size per unit, as follows:

The units name is the units which the number represents, e.g. pounds, or pieces. This string is strictly for your convenience and does not imply any conversion factor.

The transfer coefficient is the multiplier for the number of units. Suppose, for example, that we are creating a PUSH link where the FROM node is a sheet metal cutter (PROCESS node) and

the TO node is the next stage in processing, say, an INSPECT node. If the cutter chops one big unit into 10 little units, then for every unit processed by the cutter 10 units need to be processed by the STORE node. In this case, the transfer coefficient would be 10.

The storage size is the amount of space occupied on the primary resource of the TO node by one unit produced by the FROM node. In the previous example, the storage size would be the size occupied by one of the little pieces, after it was cut from the big piece. The storage size per unit in the edge should be the same as the storage size per unit in the TO task node. In the future, the storage size per unit will be eliminated from the edges and will only be stored in the task nodes.

PUSH edges: A PUSH edge is represented by a Green line. A PUSH edge indicates that a batch at the TO task node will always be activated when a batch at the FROM task node completes. This is used to represent normal assembly line processing.

PULL edges: Yellow line displayed. A PULL edge indicates that a batch at the FROM node will be activated as soon as a batch at the TO node is activated; the batch at the TO node will wait for the batch at the FROM node to complete before continuing. This is used to represent request-driven processing, or cases where the FROM node provides a buffer of parts or subassemblies to be joined with the unit which originally activated the TO node.

PROBABILISTIC edges: COSMOS displays: 'Enter arc probability.' Enter a numeric value between 0.0 and 1.0 This number represents the probability that output from an operation will flow along this path. For example, if a machine produces 1% scrap, then the arc probability the edge going into the STORE scrap task would be 0.01. In all other respects, the PROBABILISTIC edges are identical to the PUSH edges. A PROBLSTC edge is represented by a purple line.

6.7 Deleting an edge

Edges are deleted by selecting DELETE, EDGE, and the icon representing the node to be deleted.

6.8 Attributes editing

Using the attribute editor, you can view and edit fields within a node. Select the ATTRIB button with the selector device followed by the NODE button. When prompted to, pick the task node to be modified. A menu screen will appear listing the attributes of the node you selected. You may modify any of the entries designated with numbers. Entries without numbers are display only. Entries followed by (*) are multi-value fields and may have zero or more records associated with them.

6.8.1 Task Node attributes editing

The task node attribute editing screen is as follows:

```
Task Record:
1) Name: DRILL/HONE/ODGRIND/BLANCH.RUN.DRILL
2) Task type:  process
Priority:            0
Process Batch:
3) Min:  1.00  4) Max:  1.00
Time per unit:
5) Mean:  0.46  6) Model: constant
Primary requirements:
  Resource Address:
    7) Cat: machine
    8) RType: DRILL
    9) Zone:
  10) Task size:  1.00
  11) Storage size/unit: 1.00
  12) Acceptable (*)
13) Secondary Requirements (*)
14) (depends on task type)

Enter number of selection (0 to Exit)
```

Figure 3: Changing/Displaying a Node's Attributes

Most of these fields are described in other parts of this guide; for example, (12) is the list of state transition records described in the SIMULATE chapter.

Item (13) is a list of secondary resource requests. The secondary resource requests are similar in form to the primary resource requests, but the only role they have in the processing is that they must be satisfied before running and are released after running.

The data in (14) depends on the task type: for DRAW or STORE nodes, it is the draw part number or store part number; for MOVE nodes, it is the move destination address; for SHIPPING and RECIEVING charts it is the list of material activity records. For other task types, item 14 does not apply.

Material activity in RECEIVING & SHIPPING task nodes: how to fill in the fields. The quantity in the material activity record indicates the number of units shipped (or received). The time interval of each material activity record indicates when the shipment must be made or the delivery arrives. For the last material activity record in the list, events will be generated periodically using the time interval, ad nauseum. The model used for the random variable in the last material activity record must be 'CONSTANT'. For material activity records other than the final one, exactly one event will be generated, at the time given as the 'interval'. The type used for the material activity records should alway be BURST, and can otherwise be ignored.

6.8.2 Edge editing

The edge attributes editing screen is as follows:

```
1) Transfer coefficient:  1.00
2) Units: FAKE
3) Storage size:  1.10
Edge type is: probabilistic
4) arc probability: 0.99
Enter selection number (0 to exit)
```

Figure 4: Changing/Displaying an Edge's Attributes

Just enter the number corresponding to your choice, and follow the prompts to enter the new data.

Chapter 7

SIMULATE

7.1 Introduction

This chapter describes the simulation performed by COSMOS. The simulation uses as input the lot release files, the product structure diagram, the task chart graphs, and the resource chart; it produces as output an inventory history file and a resource utilization chart. The lot release file is created using the lot release editor, and is stored in files of type LTR; the other information is created by the other editors and is stored in a single file of type TST. In addition, a scheduling algorithm may be specially coded, compiled and linked into the simulation.

7.2 Terms

Lot release: a record indicating the number of units to be produced by a given task chart, with the time that the task chart should begin processing the release.

Task chart: a process chart, shipping chart, or delivery chart. The names of the task charts are given in the squares of the product structure diagram; the details of a given task chart are viewed by using one of the chart editors. Each task chart consists of a graph of task nodes.

Operation: the name of a task chart. The operation appears in the lot release records, and indicates the task chart to which the lot will be released.

Task node: a manufacturing description. Task nodes each have a type (DRAW, STORE, SETUP, OPERATION, INVENTORY, SHIPPING, RECEIVING, MOVE, INSPECT, PROCESS) corresponding to the intended function of the node. Each task node also has a primary resource request, and possibly some secondary resource requests. Each task node exists in a specific task chart, and in each chart there is a special task node (the 'root' node) which is the first

task node to be activated when the chart is activated (i.e. when a lot is released to the chart). The root is the node which has no outgoing pull edges and no incoming push/probabilistic edges

Lot, task, batch: the records which keep track of which units have been requested, which ones have started processing, and which ones have finished processing. The three records correspond to increasingly detailed statements about the state of the simulation. Each lot consists of the name of the lot, the task chart to which the lot was released, the current processing status of the lot (SCHEDULED, STARTED, or FINISHED), and a list of tasks. Each task consists of the task node which has been activated, the current processing status of the task (SCHEDULED, STARTED, or FINISHED), and a list of batches. Each batch consists of abatch number, the quantity being processed in this batch, the current processing status of the batch (WAITING, IN PROGRESS, or COMPLETED), a list of material requests, a list of resource requests, a list of task requests, and a list of transfers. For convenience, we refer to the task node of the task of a batch as the task node of the batch.

Material request: a record indicating a particular part number and quantity which must be obtained in order to proceed. The part number is compared against the PART_NO in the contents records of each resource. That is, each resource contains some quantity of each of some parts. Material requests are SATISFIED on a first come, first serve basis using the first resource having the requested part number and quantity. A material request which is not SATISIFIED is OUTSTANDING. Agiven batch has a material request if the type of the batch's task node is DRAW; the requested part number is the draw_part_no of the task node.

Resource request: a record indicating a set of resources, one of which must be allocated in order to proceed. The request consists of a task size and storage size (which must be met by the task capacity and storage capacity of the resource), a request type (PRIMARY or SECONDARY), and a resource address (which must match against the address of the resource). See also the state transition records described under "Information required for all task nodes ... primary resource request", below. Resource requests are SATISFIED on a first come, first serve basis using the first resource having an address matching the given address and a sufficient capacity. When more than one resource request is present and any of them is SATISFIED, then

all of them are SATISFIED. A resource request which has not been SATISFIED is called OUTSTANDING. A given batch has exactly one PRIMARY resource request, and possibly one or more SECONDARY requests; the requests are the same as the resource requests in the task to which the batch belongs.

Task request: a record indicating a single batch which must be completed before proceeding. A task request is SATISFIED as soon as the requested batch is COMPLETED. If the task request is not SATISFIED, then it is OUTSTANDING. A given batch has one task request for each batch triggered by a PULL link ending at the task node of the batch.

Transfer, transfer batches: a record indicating material to be transferred to the current batch. The transfer batches are used to keep track of how much space is being used on each resource. When each batch has resources allocated and is run, a certain amount of the tasking capacity of the resource and a certain amount of the space capacity of the resource is allocated to the batch. When the batch completes, the tasking capacity used by the batch is immediately returned to the resource; but the space used by the batch is not immediately returned to the resource. Instead, a transfer_batch is created indicating the space used and the PRIMARY resource of the completing batch, and given to the batch which will take the 'stuff' (represented by the transfer_batch) from where it 'is' in the resource and put it through the next task node in the processing sequence. The task node of the batch receiving the transfer is on the bottom of a PUSH/PROBABILISTIC link starting from (or the top of a PULL link ending in) the task node of the batch which just completed. When the PRIMARY resource request of the batch receiving the transfer is SATISFIED (the space is taken from the PRIMARY resource), the space indicated by the transfer record is returned to the resource indicated in the transfer record.

Resource address, address: a category / resource type / zone combination specifying a set of resources, possibly just one resource. The resource type (RTYP) is any string; it is compared to the resource type of the resource. The category (CATEGORY) is one of MACHINE, STORAGE, FIXTURE, CARRIER, TRACK, STATION, TOOL, or LABOR; it is compared to the CATEGORY of the resource type of the resource. The zone is a string which is compared against all the zones above the level 0 zone of the resource. The level 0 zone of a resource is the name of the resource, and a level 1

zone is a list of level 0 zones. Zones above level 1 are not implemented yet. The intention of the zones is just to provide a grouping of resources. Note: the fields of the resource address have no meaning other than the comparisons described here and the connotations imposed by the user.

Material activity record: a record attached to a task node of type SHIPPING or DELIVERY, indicating a time interval and quantity. Whenever the time interval comes around, a lot is released to the task chart containing the SHIPPING or DELIVERY task node. The name of the new lot is a small integer; the quantity of the lot is given by the quantity in the material activity record. The root node of the chart should be the SHIPPING or DELIVERY task node; usually there will also be a DRAW or STORE node in the the chart. The material activity records are just a convenience so that certain lot releases do not have to be explicitly stated with the lot release editor. The SHIPPING and DELIVERY types of task nodes exist primarily to hold the material activity records; but they must have a PRIMARY resource request and there must be a resource which could satisfy the request (e.g., a loading platform). See SHIPPING and DELIVERY types below.

7.3 Task Nodes

7.3.1 Information required for all task nodes.

Name: the name of the task node. Try to keep names short; but they must be unique.

Process batch max / process batch min: the maximum quantity allowed for any batch with this task node. If a larger quantity is requested, then it will be broken up into multiple batches.

Time per unit: the time to complete one unit when applying the manufacturing description embodied in the task node. The time to complete a batch for nodes of any type other than SETUP is the sum of the time per unit over the quantity.

Primary resource request: the PRIMARY request as described above, and a set of state transistions. Each state transition consists of a starting an ending string, which will be used by

SETUP nodes to change the state of the PRIMARY resource. The starting states in the state transitions also indicate the 'acceptable' states for any resource allocated to any batch of the task; the request cannot be satisfied if there are transition records but none of the starting states match the state of the resource.

Secondary resource requests: same as the primary resource requests except that: (1) No space is required or used on the resource (because the 'stuff' is on the PRIMARY resource), and (2) there may be zero, one or more secondary requests, and(3) there are no state transition records.

7.3.2 Types of task nodes.

DRAW, STORE: the type used for changing the current inventory of parts. These types of task nodes also contain the part number to be drawn or stored. When material is drawn, it is drawn from some resource with a contents record containing the draw part number. When material is STORED, it is stored in a contents record attached to the PRIMARY resource of the task node. Whenever material is drawn or stored, a record indicating the time, part number, and quantity is written to the inventory history file (filetype INH).

SETUP: the type used to change the state of the machine. When a SETUP node is encountered, the 'state' string in the resource is changed to the ending state of the primary resource request state transition record whose starting state matches the initial 'state' of the resource. The time required to perform the transition is given in the transition record. Typically there is a transition 'NOT READY' --> 'READY' that takes a long time, and another transition 'READY' --> 'READY' which takes no time.

SHIPPING, RECEIVING: the type of task node used to create shipment and delivery events. These types of task node each have a list of material activity records associated with them. At initialization time, each material activity records produces a SHIPPING or DELIVERY type event with material_activity_type BURST. This is effectively identical to releasing a lot with the quantity and time indicated in the material activity record (you can always subsitute the idea 'lot release' for the ideas 'SHIPPING event' and 'DELIVERY event'). In addition, the last material activity record in each SHIPPING or RECEIVING task node

will continue to produce lot releases at intervals given by the time interval in the material activity record. Notice that these lot releases cause the eventual creation of batches for the task node, not vice versa. Except for the existence of the material activity records, the SHIPPING and DELIVERY events are processed the same way as the others.

INSPECT, PROCESS: Two names for the generic task node type. No special manipulation of data is performed when these nodes are encountered. By convention, the INSPECT type is used for a node which has a single incoming PROBABILISTIC edge that has low probability, and the PROCESS type is used for the normal machining methods. The term 'INSPECT' used here is unrelated to the run_controls inspect_free button described later on.

MOVE: the type of a tasknode which moves a resource around on the grid of resources (the resource chart). This type of task node has a destination address type associated with it, and, depending on the address type, either an absolute grid location or the name of a 'home' resource. If the destination in the task node is of type ABSOLUTE, then the grid location of the PRIMARY resource of each batch is set to the given absolute location. If the destination in the task node is of type HOME_OF, then the grid location of the PRIMARY resource of each batch is set to the grid location of the resource whose name is given. All movement occurs when the resources are de-allocated from the batch, when the batch completes. Note: the use of 'address' here is unrelated to the usual meaning of the term 'address', as used for the resource CATEGORY/RTYPE/ZONE adddresses. Also note: the idea of 'movement' here just refers to the displayed grid location of the resource; it is unrelated to the movement of material and inventory described by the transfer batches and the DRAW/STORE nodes.

OPERATION, INVENTORY: Although these two task node types have extra data associated with them, the current implementation does not treat them differently from INSPECT or PROCESS nodes. Avoid using these types.

7.4 Run controls

The run controls turn certain tests on and off.

Backordering: controls the over-drawing of material from inventory. When a material request is encountered, it may be that all the contents records matching the requested part number have a current inventory quantity zero (or less!), even summing over every possible resource. In this case, if backordering is enabled, then the material request will be satisfied anyways, and the current inventory will become negative. If backordering is not enabled, the request will be denied.

Storage free: controls the over-allocation of resource space from resources. When a resource request is encountered, it may be that the space available on any one of the resources which matches the requested address is less than the requested space. In this case, if storage_free is enabled, then the resource request will be satisfied anyways, and the current space available in the resource will become negative. If storage_free is not enabled, the request will be denied.

Task free: controls the over-allocation of resource task capacity from resources. When a resource request is encountered, it may be that the task capacity of any one of the resources which matches the requested address is less than the requested task capacity. In this case, if task_free is enabled, then the resource request will be satisfied anyways, and the current tasking available in the resource will become negative. If task_free is not enabled, the request will be denied.

Setup free: controls the testing of the current state of the resource to see if it matches one of the starting transition states (see "Information common to all task nodes ... Primary resource request" above). If setup_free is enabled, then the test of initial states will never be performed. Notice that the state transitions still take place, and that the SETUP operations still take the amount of time specified in the transition records. For these two purposes, the transition applied to a resource whose state does not match one of the initial transition states is the NULL transition.

Inspect free: controls the usage of PROBABILISTIC links. If inspect_free is enabled, then the probabilistic link chosen for

the flow of material out of a task node will always be the link with the greatest probability. If inspect_free is not enabled, then the outgoing link will be chosen according to the link probabilities.

Failure free: doesn't control anything.

Access free: doesn't control anything.

Trace: controls printing of event messages. When trace is enabled, the program prints messages whenever resources are allocated, events complete, unusual situations occur, etc. Be prepared for a lot of output. If trace is not enabled, only error messages are printed.

7.5 Lot release scheduling algorithms

It is possible to write special algorithms which release lots to any of the task charts. There are currently four empty functions, S$BEGTAS, S$ENDTAS, S$BEGLOT, and S$ENDLOT, which are called when a task becomes STARTED (any of its batches are IN_PROGRESS), and when a task becomes FINISHED (all of its batches COMPLETED); as well as when a lot becomes STARTED (any of its tasks are STARTED), and when a lot becomes FINISHED (all of its tasks are FINISHED).

Writing these functions will require a solid understanding of the internal simulation data structures; to find out about this, use WHATIS on the source code and look at B$DLCOPY, S$DLCOPY, B$CNCOPY, and S$CNCOPY, as well as P$DLCOPY. BROWSE should also be useful, but is not guaranteed to reach all of the data structures. The notes accumulated during implementation are in COSMOS NOTES.

7.6 Using the simulator.

The simulation menu allows you to set the run controls, select some lot releases, select the output file names, initialize the event queue, run the simulation, BROWSE around in the data structure, and reset the simulation.

7.6.1 Setting the run controls

The run controls are set and unset by pressing the window items in the left hand column. The run control is 'set' if the window is lit up, and 'unset' if the window is not lit up.

7.6.2 Selecting lot releases

Lot releases are selected by pressing the 'Input Lots' button and selecting the lot release file from those listed. These are the files of type LTR created by the lot release editor. The lot releases are read in from the file and added to a queue of OUTSTANDING lot releases. Notice that they will not create events until the event queue is initialized, see below.

7.6.3 Selecting the output file names

Use the 'Output Log' button and enter the output filename at the terminal. Two output files will be created, one of type SML containing the resource utilization data, and one of type INV containing the inventory history data. An output file must be chosen after the simulation menu is entered and before the simulation is run the first time. WARNING: if you specify the name of a file which already exists, that file will be destroyed.

7.6.4 Initializing the event queue

The event queue is initialized by setting the end time and ending number of events using the 'End Time' and 'End Events' buttons. The end_events gives the maximum number of events to perform before the simulation returns. The end_time gives the simulation time of the last event to perform before the simulation returns, if the end_events limit has not already been reached. Typically end_time is used to control the ending, and end_events is just set to some very large number.

When the end_time is advanced, the initial events corresponding to the new time period are added to the event queue. These events include the lot release events for the apropriate lot releases on the OUTSTANDING queue, and new material activity events generated by SHIPPING and RECEIVING charts. The lot release records are marked as SATISFIED after they have generated lot release events.

When the end_time is decreased, the extra events which were scheduled to occur after the new end time are deleted from the event queue. In some cases, there could be a few batch completions which we do not want to remove because they would be hard to regenerate; in this case a message is printed which can be ignored. The lot release records are returned to wait on the OUTSTANDING list.

It is not possible to decrease the ending time below the current time. See "resetting the simulation", below.

This set of operations should be performed AFTER the lots have been released. If the simulation runs for a much shorter time than expected, it's probably because you forgot to select lot releases BEFORE setting the times, or you forgot to set BOTH the end events and end time to reasonably large values.

7.6.5 Running the simulation

After selecting lot releases, the output files, and the ending conditions, the simulation can be run, with the 'Run' button. When the ending condition (end_time or end_events) is met, the simulation will pause and enter the BROWSE menu.

After browsing around, you may be asked for a new end time or to quit; if you increase the end time then the simulation will continue and end up back in BROWSE again. If you do not increase the end time, then attention will be turned back to the simulation menu. At this point all the data structures are still in place, and you can run the simulation some more, or whatever else, without selecting a new output file.

7.6.6 The BROWSE menu

The browse menu displays the current internal data structures. At the top of the screen is some status information including the current time and the next event to be processed. After this is a line 'oOoOoOo' and then the data record currently being viewed, followed by a prompt message. Notice that every record has a status, which is displayed.

The data is organized as a tree: on the top is a root whose children are the lot releases, the event queue, and the lot records. Underneath each lot are the tasks for that lot,

underneath each task are the batches for that task, and underneath each batch are the material, resource, and task requests, and the transfers.

Each of the tree nodes consists of a set of lists, one list for each possible status at the current node. The prompt message consists of words separated by ','s: the capitalization indicates the minimum characters you type to invoke the function. The commands are:

'Status': within this node, move to and display the first record in the list of records for the next status.

'First': within this node, move to and display the first record in the list of records for the current status.

'Next': within this node, move to and display the next record in the list of records for the current status.

'Up': move to and display the first record in the node above the current node, using the current status.

'Down': move to and display the first record in the node below the current node, using the current status. If there is more than one record type below this one, then the possibilities will be displayed; enter any of them.

'Run': Leave the BROWSE menu and attempt to continue running the simulation.

'Quit': Leave the BROWSE menu and return to the simulation menu.

7.6.7 Resetting the simulation

Pressing the RESET button wipes out every list in the simulation, forces the current inventory of every part number to zero, closes the output files, and sets the time back to zero. This function does NOT affect the simulation database and the lot release files created in the other parts of COSMOS. You will have to open a new output file, select new lot releases, and re-initialize the event queue before running the simulation again.

7.7 Limitations and bugs

The number of resources which could possibly be used to satisfy the PRIMARY resource request in any given task node, and the number of resources which could possibly be used to satisfy the material request of a given DRAW task node, has a small limit. Currently the limit is 16. When the limit is exceeded, the message "PREFETCHSIZE exceeded" is printed. The number of possible satisfying resources is controlled, for PRIMARY resource requests, by the number of resources whose address matches the address given in the PRIMARY address of the task node. The number of possible satisfying resources for material requests is controlled by the number of STORE task nodes whose store part number corresponds to the draw part number of the given DRAW task node.

The time intervals specified in the material activity records should be a constant.

The resource zones must be either level 0 or level 1.

7.8 Messages

Messages generated by the simulation are in the form "name: message", where the "name" is the name of the routine producing the message.

In normal operation, the messages "s$iniact: no shipping activity" or "s$iniact: no receiving activity" may appear. These indicate that there was a shipping or receiving task chart which did not contain any task node of type SHIPPING or RECEIVING, resp. This is okay, assuming you remembered to release whatever lots you wanted to for these charts, by using the lot release editor.

When the run_controls 'trace' button is set, a profusion of messages will be generated indicating that certain events such as state transitions, batch completions, etc occurred.

Most other messages indicate that an error occured. Write down the message and send a note to programmer; make sure you can reproduce the error by stopping the program, loading up the same data and performing the same sequence of actions.

Chapter 8

RESOURCE UTILIZATION CHART

8.1 General Description

The Resource Utilization Chart plots against each resource the tasks used by it over time in the simulation. Associated with each task is an Operation, Lot, and Task, a begin time and an end time.

The resource utilization chart is used to display the SML output from the simulation.

8.2 Screen Functions

The ZOOM and PAN buttons described in the introduction are available for moving around the display. Although the ADD and DELETE buttons are available, they probably won't be of much interest.

8.3 Attributes

Selecting the ATTRIB modal function and then picking one of the utilization bars displays information about that time interval.

If you pick the NEW FILE button, then you will be prompted for the name of new files to display. You will be prompted twice; the first time is for the name of a RSN file containing the names of the resources to be plotted (the 'resource names' file), and the second time for the data to be plotted (the SML 'simulation log' file). All of the data in the simulation log file which indicates utilization of one of the resources listed in the resources name file will be plotted. The old display, if any, is wiped out. The data will automatically be scaled so that it fits on the full display area.

EDIT: choosing this function prompts for the filename of a 'resource names' file and then invokes the system editor on a file of type RSN with that filename. Use the system editor to create the resource names.

Chapter 9

INVENTORY PLOT

9.1 General Description

This menu is used to display the levels of inventory indicated by the simulation. Each of the intermediary and final parts listed on the right hand side has its inventory plotted in the corresponding color on the main display area.

There should be one part number for every different STORE part number in the simulation.

The scale on the bottom indicates time in the same units as were used when specifying time in the simulation database. The scale on the left indicates number of units produced.

9.2 Screen Functions

The interaction for this menu is essentially the same as for the resource utilization menu, except that there is no 'resource name' file, so the corresponding step is ommitted.

Chapter 10

LOT RELEASE EDITOR

10.1 General Description

The lot release editor is used to control the times at which lots are initiated in (released to) the simulation; this in turn controls the initiation of specific tasks and batches.

On the left are listed the possible operations (task charts) as entered in the product structure diagram. Across the bottom is a time scale. The icons represent specific lots which are scheduled for release; their names are also printed.

10.2 Screen Functions

The usual modal and immediate editing functions are available in this menu. In addition, the colors can be changed using the COLOR button.

COLOR: A color palette of ten colors used to change resource and time displays colors. Select a color from the color palette and then select a resource or time block.

10.3 Adding a lot release

When you invoke the ADD function, you will be prompted for the chart name, release date, and quantity of the lot release.

The chart name you enter should match the name of one of the operation nodes (task charts) in the product structure diagram. The lot release will cause the root task node of the given chart to be activated (see "SIMULATE" chapter).

The release date indicates the time at which the chart activation (i.e. root task node activation) should begin. At this time, requests for material and resources will be created, and attempts made to satisfy them.

The quantity indicates the number of units which you are requiring to be produced by the chart. The quantity will be produced as quickly as possible given the contention for resources and material, the SETUP delay time, etc.

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