SCHOOL OF OPERATIONS RESEARCH
AND INDUSTRIAL ENGINEERING
COLLEGE OF ENGINEERING
CORNELL UNIVERSITY
ITHACA, NEW YORK 14853

TECHNICAL REPORT NO. 824

September 1988

THE RATE SIMULATOR

by

David Briskman

The rate simulator was designed and tested in conjunction with development efforts in the General Foods Convenience Meals Division.

The Rate Simulator

David Briskman

Abstract

The rate simulator is a PC based simulation package that has been created to help evaluate a wide variety of manufacturing system designs. By using transactions based simulation and aggregate production rates instead of the more common event based, detailed simulation, the simulator allows for easy model definition and quick simulation run time. System parameters can be modified and tested expediently. Ultimately, *the rate simulator* will aid in the development and testing of daily shop floor schedules.

The rate simulator was designed and tested in conjunction with development efforts in the General Foods Convenience Meals Division.

Table of Contents

Section 1 - Project Report

1.1 Introduction

There are many issues that can arise while designing a new facility for a multi-product, multi-stage manufacturing system. Deciding on the physical environment, the dispatching rules, the scheduling algorithms and the inventory control procedure to be implemented can be very difficult. Moreover, the interaction between these different policy decisions further complicates the selection process in choosing the best operating environment for such a facility.

The following report will outline an approach to address some of these issues. The example system parameters used are based on current development efforts going on in the General Foods Convenience Meals division. We begin by discussing some of the essential terminology.

The term "physical environment" will be used to describe the actual resources and production processes involved in the system. "Dispatching rules" are associated with the sequence by which material is processed through the factory and with the queuing of material at each set of resources during production. The "scheduling algorithms", while closely related to the dispatching rules, are used to release material to the factory floor like a "Master Production Schedule." Finally, "inventory control" procedures consist of the capabilities for monitoring and tracking material movement, as well as, the ability to maintain and process current raw stores and finished goods ordering information.

1.2 Goals

Before designing an approach to address the issues previously described, goals were created to focus efforts on specific tasks. The goals of the study are:

- Determine the number of resources of each type to meet planned throughput.
- Examine scheduling and dispatching rules and how they effect plant design and operation.
- Develop an interface with an inventory control and tracking system.
- Construct daily schedules.
- Develop an appropriate representation/display scheme for easy data manipulation, and better understanding of information.

Keep in mind that all of the above goals ignore problems with forecasting, product mix, and other system parameters beyond the control of the facility management.

1.3 Approach

To achieve the aforementioned goals, a four phase approach is used. First, we design and implement a "rate simulator" that models the system and allows us to perform "what if" analyses. Next, we simulate to measure the effects of the physical environment and the scheduling/dispatching rules on system performance. System performance will be measured relative to throughput, buffer capacity and resource utilization. Third, we allow existing inventory management software to be linked with the software discussed here. Finally, we allow for interaction and cooperation between the software packages to determine schedule of daily operations.

The inventory management software can be provided by a variety of sources. Packages such as PRISM [1] and MAPICS [2] are widely used throughout industry to help in the control of inventory. Developing software from scratch to manage inventory would not be an efficient use of time.

Thus, the immediate scope of the project was narrowed to the design and development of *the rate simulator.*

---

[1] PRISM is a trademark of the Marcham Corporation.

[2] MAPICS is a trademark of the International Business Machine Corporation.

1.4 The Rate Simulator

1.4.1 Software Environment

The rate simulator is divided into three separate components: the input routine, the simulator, and the output display program. While each of the components is run independently of the others, together they create a integrated environment for modeling and evaluating different systems.

The input routines consist of a set of Lotus 1-2-3 [1] macros that allow for easy data access and manipulation. By using a common interface (Lotus), we provide a "user-friendly" modeling environment. The Lotus program communicates with the simulator by creating an output file that is readable by the simulator.

The simulator and the output display program are both written in the C programming language. The only necessary input into the simulator is the file created by the Lotus program. Once this file is input, the simulator runs the system and outputs all of the run information into another file. This output file contains all of the transactions [2] that occurred during the simulation as well as summary statistics associated with inventory and resource utilization. The output file is then readable by the output display program which graphically displays inventory plots and Gantt charts of each set of resources.

1.4.2 Assumptions

When designing the simulator, several assumptions were made to shorten the simulator run time and to limit the amount of information needed for a system definition. These assumption are listed as follows.

- The process routing is a straight line. [3]
- The basic unit of material flow is a bin.
- Resources are limited.
- Resources are reliable and follow a given schedule.
- Resources can process items in batches or rates.
- Every product must be processed at each stage.
- Variability in process parameters is ignored.
- Yield is perfectly predictable.
- All buffers have infinite capacity. [4]

---

[1] Lotus 1-2-3 is a Trademark of the Lotus Corporation.

[2] A transaction occurs when material is moved or a resource changes state.

[3] A straight line process routing implies that there are no assembly or disassembly operations and that material flows through each production stage in sequence with no rework.

[4] A buffer is any point in the system where material can be stored.

1.5 Simulator Input

The information needed to define a system can be classified into three separate categories: the resource definitions, the product definitions, and the lot release table. Each of these categories is input as a table in the Lotus program.

The Resource Definition Table, detailed in section 2.3, sets up the physical system. Here "resource banks" are defined in the same order in which material will be processed through the system. For each resource bank, the user must name it, define its type, input the actual number of resources available in the bank and rank the queuing rules associated with the bank. Then for each resource within the resources bank, the user must input a schedule creating "up-times" and "down-times" and an efficiency rating. [1]

The Product Definition Table, detailed in section 2.4, defines the "product types" that can be run in the system. Each product type will have a name and an associated "bin" size. (Recall the system assumption that material will flow through the system in bins.) In addition, a set of parameters will be defined for each product type by resource bank. These parameters will include processing time, yield, setup time, transfer time [2], and starting inventory information. For example, Product A may have 95 % yield on resource bank #1 but 80 % yield on resource bank #2. Just as, Product B may have 85 % yield on resource bank #1.

The Lot Release Table, explained in section 2.5, creates the sequence in which material ("lots") will be released into the system. The notion of a "lot" and subsequently a "batch" is explained in greater detail in section 2.5.1. For each lot, the user must specify a product type, a lot size, a batch size, a user given priority, and an arrival time.

In addition, while the product definition table supplies processing times by resource for each product type, the user may wish to override these values for a given lot. Furthermore, the simulator defaults to processing material on the first available resource within a bank. Yet, it may be the case that a lot can only be run on one particular resource within a resource bank. For these reasons, the user has the option to change the processing times associated with a lot on each resource type, and/or assign a lot to be processed on a particular resource within a bank.

---

[1] Resource efficiency is defined with respect to the other resources in that bank.

[2] Transfer time is the time it takes material to reach the next bank of resources after it has completed processing on the previous resource. This parameter takes into account lost time due to a material handling system.

1.6 Simulator Output

The simulator itself runs until no more material is available for processing or until all the resources are unavailable for the rest of the run. The simulator output is a file that contains information about each transaction that occurred during the simulation run. This file also contains resource utilization statistics, current inventory status throughout the system, and the amount of each product in finished goods.

By using the output display routines, resource utilization can be better understood when viewed in Gantt chart format. The Gantt chart displays the state [1] of each resource during the run. Inventory can also be plotted for each resource or resource bank. While buffer capacity is assumed to be infinite, information provided by inventory plots can be very useful when evaluating buffer usage.

1.7 Next Steps

The next steps in the project development are straight-forward. After completing *the rate simulator*, we perform "what if" analyses on different system designs. Along with the physical environment characteristics, testing the dispatching rules would also be necessary.

This analysis phase may require many runs under different scenarios in order to help understand the system's behavior. Currently, as detailed in Appendix A, General Foods is conducting such a study using *the rate simulator*.

After setting the system parameters properly, the software should be linked to an inventory control package. Using the schedules developed by this external package, daily production schedules can be produced and tested using the simulator.

[1] Each resource can be in one of four possible states during the run. They are Working, Setting Up, Off, and Starved.

1.8 Summary

The rate simulator is a very powerful tool that can be helpful in manufacturing facility design and evaluation. Using a common interface, Lotus 1-2-3, *the rate simulator* allows for quick system definition and easy manipulation of data.

Inputs to the simulator incorporate information about the physical environment, the dispatching rules and the scheduling algorithms of the system. Running the simulator produces output that describes in detail the operations of the given system. Analyses of this output gives the user the ability to quickly evaluate system performance, based on throughput, resource utilization and buffer usage.

From this evaluation process, decisions can be made to determine the number of resources of each type needed as well as the effect of scheduling and dispatching rules on the plant design and operations. Once system parameters are set, the simulator can then be used to create and test daily schedules and be an integral part of the day to day plant operations management.

Section 2 - Users Manual

2.1 The System View

The rate simulator can only represent the manufacture of certain kinds of products. In particular, the type of process flow that is assumed is a straight line, with no assembly or disassembly operations. Furthermore, it is assumed that at each production stage there exists a "bank" of resources which are consumed during processing. Buffers in the system exist between each bank of resources, which are assumed to have infinite capacity. Material enters the system in front of the first resource bank in the form of "lot releases". Material flows through the system and enters "finished goods inventory" when it has finished processing on the last resource bank. Figure 1 gives a graphic representation of this type of system.

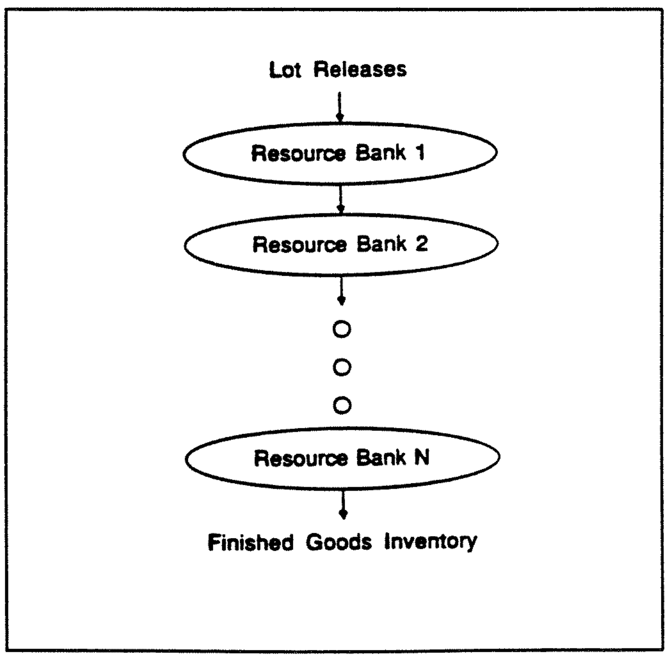

Figure 1. The Manufacturing System View

An Example

As an example, we will consider a convenience meal facility. Production for such meals is done in three phases. The first phase is an assembly operation performed in "Kitchens". The second production stage is a cooking operation, done in "Retorts". The final phase is "Packaging". Throughout the rest of the user manual, this example will be used to aid in the understanding of the program.

2.2 Lotus Interface [1]

To create a model, we use a Lotus based program to input and save information. The Lotus program itself is run through the top display panel using the usual Lotus menu type functions. To select options in the menu one can use the arrow keys or just hit the first letter of the option title.

The Lotus program automatically starts once a spreadsheet containing the program is retrieved. The first screen welcomes the user to the program and displays the top menu for the Lotus program. The top menu options are detailed in the Table 1.

Table 1: List of Each Top Menu Option and What Each Does

Menu Option	Key	Function and Purpose
	Alt-M	Restart the Top Menu
Lots	*Alt-B*	Go to the Lot Release Table
Resources	*Alt-R*	Go to the Resource Definition Table
Products	*Alt-P*	Go to the Product Definition Table
Times	*Alt-T*	Go to the Resources Schedule Table
Save	*Alt-S*	Save the Worksheet and Simulator Input File
Quit	*Alt-Q*	Quit the Program
Help	*Alt-H*	Go to the Help Menu

Alt-M is the only Alt key that should ever be used. It should also be mentioned that several inputs are done by exiting the Lotus program and using the normal Lotus environment to edit parts of the spreadsheet. If at any point the user is outside the Lotus program and wishes to re-enter the program, hitting *Alt-M* will return to the top menu (displaying the options detailed in Table 1). Nothing is changed or lost by hitting the *Alt-M* key. Subsequent explanations will refer to returning to the Lotus program in this manner.

Except for *Quit* and *Save*, each of the options will bring up a secondary menu and display the appropriate part of the spreadsheet. *Quit* will exit to the regular Lotus environment. *Save* on the other hand will save two different files. Once selected, *Save* will

---

[1] Basic familiarity with Lotus is assumed and essential for understanding parts of this section.

prompt the user for a file name. To be safe, always enter a file name different from previously named files. The two files created will have the same file name with different extensions.

The first file created by *Save* will be a standard Lotus file with the extension ".wk1". The second file will be a flatfile (ASCII file) that is readable by the simulator, and will have the extension ".sim". Thus, if the file name entered was "Test1", both "Test1.wk1" and "Test1.sim" would be saved on your disk. Make sure that there is enough space for the files to be saved. Each spreadsheet will take up at least 100 K of memory on your disk.

2.3 Resource Definitions

2.3.1 The Resource Table

The resource table, as displayed in Table 2, defines the physical environment for the system. It contains information about the processing routing through each of the resource banks, the type of resources in the system, the available number of each type of resource, and the queuing rules to be followed at each resource.

The order in which resources are defined in the table will determine the process flow for material. In other words, material will start at resource bank #1 and continue to resource bank #2, etc. until the material is processed at the last resource bank. After material is through the last resource bank it will be placed into finished goods inventory.

Table 2: Resource Definition Table

Resources:	1	2	3
Name:	Kitchen	Retort	Packaging
Type:	RATE	BATCH	RATE
Batches:			
min(in bins):		1	
max(in bins):		4	
Number Available:	2	3	3
Scheduling Rules			
Ranking			
=======			
Priorities:	1	1	1
FIFO:	2	2	2
Largest Inv:	3	3	3
SPT:	4	4	4
Pre-Emption Allowed:	0	0	1

2.3.2 The Resource Lotus Menu

After selecting *Resources* at the top menu, Lotus will display a table similar to Table 2 and the control panel will have several new options. These options and functions are as follows:

Add - Adds a resource to the table.

Delete - Displays a menu of the currently defined resources. After the user selects a resource, a confirmation prompt of *Yes* or *No* will appear. Yes will delete the resource, and No will return.

Rename - Renames a resource.

Type - After selecting a resource, *Type* prompts for either *Rate* or *Batch*. If *Batch* is selected, a batch minimum and batch maximum will also be asked for. This is explained in greater detail below.

Number - Prompts for the number of resources available in that selected resource "bank".

QueueRules - Sends the user into regular Lotus to allow for quick and easy editing of the queue rules ranking. Queue rule interpretations are explained in detail below.

Quit - Returns to the top menu.

The resource name can be defined as desired, **but must be a maximum of 7 characters and have no spaces in it.** In Table 2, we have used the names given in the example facility. The resource type must be defined as either *Batch* or *Rate*. If defined as "Rate" the resource will process a specified number of units per time unit. An example "Rate" resource would be the "Kitchen" assembly operation or "Packaging" operation. Production rate is specified in terms of meals per minute.

A "Batch" resource will process items in batches for fixed time intervals, where the batch size is specified by the user by the "Minimum" and "Maximum" batch size in the resource table. Following the example, the "Retort" cooking operation is a "Batch" operation, where meals are cooked in batches for specified cook times. Once a batch is started, no meals can enter or leave the "Retort" until the cooking is completed.

The input for the queue rules provides a ranked order of importance for the lots. Each of the rules is used to sort the queues that exist in the system. The available rules are "Priorities","FIFO", "Largest Batch" and "SPT". Each of these rules is explained in greater detail in section 3. The only specifications to be followed for inputing the queue rule rankings is that each rule must be ranked 1 to 4, and that no rules can be ranked the same for a given resource type.

The Pre-Emption Allowed field is a true/false flag to be explained later. Inputing a 0 means false and a 1 means true.

2.3.3 The Resource Schedules

The *Times* option in the top menu displays the Resource Schedule Table, as in Table 3. For each resource in the system start and stop times are specified periods of time when the resources are and are not available for use. In addition to creating a schedule for each resource, the user may change the efficiency of a particular resource.

Each efficiency is relative to the resource type definition in the Resource Definition Table. If the efficiency is 1, the resource will operate at the normal rate. If the efficiency is 2, the resource will operate at twice the normal rate, just as an efficiency of 0.5 will cause the resource to operate at half half the given rate. For rate resources, efficiency will multiply the speed at which that resource operates. For a batch resource the efficiency will affect the batch size specification.

All editing in the Resource Schedule Table is done using the regular Lotus environment. The input must follow the same format as displayed below in Table 3.

Table 3: The Resource Schedule Table

Resource	Number	Efficiency	Start	Stop	Start	Stop
Kitchen	1	1	0	240	270	510
Kitchen	2	0.5	0	240	270	510
Retort	1	2	0			
Retort	2	1	0			
Retort	3	1	0			
Packaging	1	1	0	240	270	510
Packaging	2	1	0	240	270	510
Packaging	3	1	0	240	270	510

For example in Table 3, the first "Kitchen" is "up" during two time intervals, from time 0-240 & 270-510. If the time unit is a minute and time 0 is equal to 8 am, kitchen #1 starts at 8 am, breaks at 12 pm for 30 minutes and then starts again and operates till 4:30pm.

On the other hand, the "Retorts" have no specified stop time; therefore, all of the retorts are available from time 0 until the end of the simulation's horizon. [1] If the first start time is not specified, the resource is never available.

The resource efficiency of kitchen #2 implies that it will process meals half as fast as kitchen #1. The efficiency for retort #1 will cause batches to be twice as large as batches that can fit in retorts 2 & 3. The cycle times for each retort will remain the same.

[1] The end of the simulation occurs when all material can no longer be processed, because all resources have been made unavailable for the rest of the simulation or all material had reached finished goods.

2.4 Lot Release Definitions

2.4.1 Bins, Batches and Lots

The basic unit of material flow is a "bin". Each bin size is specified by product type, as explained in section 2.5.1. The rational behind this is that items are quite often processed in groups, where the amounts of items in each group is dictated by the size of the material handling unit or bin. For example, it is common to move meals from one production stage to another in cages. These cages will hold a certain quantity of meals. It is unlikely that meals would be carried item by item to the next stage of production. Thus, the cage would be represented by a "bin" in the rate simulator. Note, it is also possible to set the bin size to 1 item if unit by unit production is desired.

The next level of grouping is called a "batch". A "batch" consists of a certain number of "bins", and quite often is only one bin. While material flow is tracked in bins, processing and material movement is actually done in batches. Defining a batch size specifies the smallest group of material that can be processed and/or moved at once.

For instance, a batch size of two bins implies that those two bins will be together throughout the system. At rate resources, they will be processed together in sequence, and at batch resources they will be processed in the same batch. Furthermore, the batch will move as a unit between resources. It cannot be broken into its component bins at any time. It will enter the system as a unit containing a certain number of bins and it will enter finished goods as a unit multiplied by the yield loss throughout the system.

Finally we develop the notion of a "lot". A "lot" is the amount of material released into the system at once. The size of the lot is specified in bins; but each lot will also have a batch size associated with it. The batch size for each lot will represent the smallest size that the lot can be separated apart into.

Thus, a lot of 10 bins with a batch size of 2 bins, will enter the system as 5 batches of 2 bins each. If the batch size is not perfectly divisible into the lot size, the last batch contains the remainder. For instance, if the lot size was 11 bins and the batch size was 2 bins, 4 batches of 2 bins and one batch of 3 bins would enter the system.

2.4.2 The Lot Release Table

The Lot Release Table, as displayed in Table 4, defines the sequence and amounts of material to enter the system. Each lot has a product type, a lot size, a batch size, a priority, an arrival time, and a set of parameters entered by resource type.

Table 4: The Lot Release Table

Lot #	1	2	3	4	5
Product:	LASAGNA	COQAUVIN	CHILI	LASAGNA	MANICOTTI
Lot Size:	20	20	20	20	20
Batch Size:	2	1	2	1	1
Priority:	3	3	2	4	2
Arrival Time:	0	0	0	240	240
Resource:					
=======					
Kitchen	-1	-1	-1	-1	-1
Retort	-1	-1	-1	-1	-1
Packaging	2	-1	-1	-1	-1
Times By Resource:					
=======					
Kitchen	53	53	53	53	53
Retort	101	85.7	88.58	80.75	94.75
Packaging	50	50	50	50	50

The product type is chosen from the Product Table, explained in section 2.5.1. Only product types that are defined may be entered into the Lot Release Table. Yet, one need not have a Lot for each product type defined. It is the intention that all products be defined once and then the Product Table can be used as a library of product definitions.

The Lot Size is specified in bins and equals the amount of material to be released into the system. The Batch Size allows the lot to be broken up into smaller components, as explained in section 2.4.1.

The Priority is a user-specified priority to be used during the simulation for queuing at resources. There are no rules that dictate the values to be input for priorities. The greater the priority, the more important the lot is. Section 3 gives an in-depth explanation of how priorities are used throughout the system.

The Arrival Time, specifies the release time of the lot. The time is absolute, and not relative, so an Arrival Time of 240 will release the lot at time 240 regardless of the arrival time of any of the other lots.

The final two input parameters are optional and will always have default values set if the user does not input them. The "Resources:" parameter allows the user to specify a particular resource within a resource bank for that lot to be processed on. This can be used to direct all of one product type to a particular resource. The default value -1 will send the lot to the first available resource. In Table 4, Lot 1 can only be processed on "Packaging" resource #2.

The second optional parameter ("Time by Resource:") allows the user to change the processing times for each lot. The default values are the processing times specified for that product type in the Product Table. Yet, in some cases it may be desirable to change the processing times of a particular lot.

2.4.3 The Lot Release Lotus Menu

When selected, the *Lots* option at the top menu will display the Lot Release Table, Table 4, and a secondary set of menu options associated with altering the Table. Except for *Default* and *Quit*, each of the menu options will first prompt the user for a Lot number to specify which lot is to be changed. The functions are consist of the following:

Add - Adds a Lot to the table. After selecting a Lot number, all product types will be displayed in menu format. The user must then select a product type for the new lot and wait for the default values to be copied into the Lot Release Table. Selecting an existing lot number will cause that lot to be over written.

Delete - Deletes the Lot number specified.

Priority - Changes the Priority for the specified Lot.

Lot - Specifies the Lot Size.

Batch - Changes the Batch Size.

Arrival - Specifies the release time for the Lot.

Default- Goes into the regular Lotus environment and allows the user to edit the Resource specifications and the Processing Times for each Lot.

Quit - Returns to the top menu.

2.5 Product Definitions

2.5.1 The Product Table

The Product Table contains information about all of the product types that can be processed through the system. Each product type has a name, a bin size, and several other parameters specified by resource type. Note, as with the resource names, the product names must be a maximum of 7 characters long and have no spaces in them.

The bin size is specified in items per bin. To move material unit by unit, the bin size can be entered as 1. All other material flow specification is done in bins. Table 5 gives an example of 4 product type definitions.

Table 5: Product Definition Table

Products:	1	2	3	4
Name:	LASAGNA	MANICOTTI	COQAUVIN	CHILI
Bin Size (units):	414	414	414	414
Starting Inv. in bins:				
Kitchen	0	0	0	0
Retort	0	0	0	0
Packaging	10	10	0	0
Batch Size for Starting Inv:				
Kitchen	1	1	1	1
Retort	1	1	1	1
Packaging	1	1	1	1
Priority for Starting Inv:				
Kitchen	0	0	0	0
Retort	0	0	0	0
Packaging	0	0	0	0
Default Proc Times:				
Kitchen (units/time unit)	53	53	53	53
Retort(time per batch)	101	94.75	85.7	88.58
Packaging(units/time unit)	50	50	50	50
Yields (in percent) by:				
Kitchen	100.00	100.00	100.00	100.00
Retort	100.00	100.00	100.00	100.00
Packaging	95.00	95.00	95.00	95.00
Setup Time by:				
Kitchen	20	0	0	0
Retort	0	0	0	0
Packaging	0	0	0	0
Transfer time Before each:				
Kitchen	0	0	0	0
Retort	0	0	0	0
Packaging	20	0	0	0

The first three options, specify information about the starting inventory by each resource. The first field "Starting Inventory", will create a lot of that product type in the particular resource bank at time 0. The next two fields "Batch Size" and "Priority" allow the user to assign specific values to the starting inventory lots. Both fields follow the same rules as in the Lot Release Table. In Table 5, a lot of 10 bins will be released as 10 batches of 1 bin each at the "Packaging" resource bank at time 0.

The next set of inputs is the "Default Processing Times". These are input for each product by each resource and are used as the default values for lots in the Lot Release Table. Note that rate resource processing times are specified in items per time unit (not bins) and batch resource processing times explicitly define the time interval required for processing each batch.

In the example, LASAGNA would be processed at 53 meals per minute at the "Kitchen" resource bank and 50 meals per minute at the "Packaging" resource bank. At the "Retort" bank, each batch of LASAGNA would require a cycle time of 101 minutes. Also, recall that a batch resource has a specified batch "Minimum" and "Maximum", so that during a batch process cycle, it may be possible to process many individual batches. It is assumed that processing as much as possible is the preferred operating procedure. A further assumption is that only batches of the same product type can be processed in a batch resource at the same time. Thus, if the "Maximum" batch size for "Retorts" is 4 bins, then 4-1 bin of 2-2 bin batches of LASAGNA could be processed at the same time in one retort. Yet, 2 bins of LASAGNA cannot be processed with 2 bins of CHILI in the same retort. For a detailed explanation of how batches are put together for a batch resources refer to section 3.3.

Yields are specified in percentages. In the example every product has perfect yield in the "Kitchens" and "Retorts", but after "Packaging" only 95% of the meals are good. The yield factor multiplies the current size of each batch. Thus, a batch starting with 1 bin would end in finished goods with 0.95 bins worth of material or 393.3 meals. For further details section 3.3.

Setup time is in time units and places a resource into setup when the product type of the last batch processed differs from the product type of the current batch. Transfer time is the time it takes a batch to travel to the current resource. Therefore, in our example, if LASAGNA was started in a kitchen and either the kitchen was idle or the previously processed batch was not LASAGNA, the kitchen would "SET-UP" for 20 minutes before processing the batch. Also, when LASAGNA batch finished at the "Retorts" it would take 20 minutes before it arrived at the "Packaging" resource bank. Both Transfer time and Setup time are explained in greater detail in section 3.4.

2.5.2 The Product Lotus Menu

The *Products* option in the top menu will display the Product Table and allow the user to select from the following options.

Add - Adds a new Product type to the table. This also allows the user to overwrite an existing product definition.

Delete - Displays a menu of the currently defined products. After the user selects a product type, a confirmation prompt of *Yes* or *No* will appear. Yes will delete the product type, and No will return.

Rename - Renames a product type.

Note: Both *Rename* and *Delete* will not update the Lot Release Table.

BinSize - Changes the size of a bin for that product type. The Bin Size is specified in items.

Change- Goes into the regular Lotus environment and allows the user to edit the rest if the Product Table.

Quit - Returns to the top menu.

Upon completion of entering all of the appropriate data in all of the Tables, the user should save the system using the *Save* option.

2.6 Running The Rate Simulator

To invoke *the rate simulator*, the user must type "rsim" at the dos prompt. The user will then be asked to enter a ".sim" file. This file should be the file just *Saved* by the Lotus program. If a valid file is specified, the simulator will then read-in the file, attempting to correct any possible errors that are encountered. It is important to watch the screen for informational messages during this stage.

While all blank spaces are ignored by the simulator during input, it is possible to confuse the simulator. Furthermore, the Lotus program does not check the validity of any of the user data. Thus, the simulator checks all of the input file for any bad information. Simple errors will be changed to reasonable values, yet major problems will cause the simulator to print out an error message and quit.

Once all the data are read-in, the simulator will try to open a ".out" file into which it places all of the simulation's output data. If a file of the same name already exists, the user will be asked whether on not to replace the file or quit.

Finally, the simulator will run the scenario described in the ".sim" file. During the simulation run the current simulated time will be output to the display so that the user can be aware of the simulation status. At the end of the simulation run, summary statistics will be printed out containing information about the resource utilization and the finished goods inventory. This information is also saved in the output file.

2.7 The Output File

The output file contains information about the input file, the actual run time, each transaction that occurred during the simulation and some summary statistics associated with the particular run.

The first line of the output file reminds the user of the ".sim" file input to the simulator and the time and date of its creation, as well as, the time and date of the particular run.

The rest of the output file contains information about each transaction that occurred during the simulation. Each transaction or event type is listed in table 6.

Table 6: Simulation Event Types

Lot_Release	A Lot Release occurs as specified by the Lot Release Table
Batch_Arrival	A Batch arrives at a Resource Bank.
Setup_Res	A resource begins setting up for a batch.
Start_Batch	Processing starts on a batch.
Batch_Done	A batch is completed and moves onto the next resource bank.
Starve_Res	When a resource is available as specified by the Resource Schedule Table, and there is no material for processing accessible by that resource, it is starved.
Stop_Res	A resource is scheduled to Stop at that time, as input into the Resource Schedule Table.
End_of_Day	The simulation has stopped.

For each event the information provided includes the time, the type of event, the resource bank at which the event occurred, the specific resource in the bank (0 if not at one resource, the product type that caused the event, the original lot number of the current batch (0 if from starting inventory), and other information about the different queue sizes in the system. The queue representation is explained in section 3.1.

The final part of the output file is the summary statistics. First, the resource utilizations are displayed. The calculation of utilization is based on total time processing or setting up vs total time the resource was available as specified by its schedule. If the resource had no stop time, the available time was computed till the end of the simulation run.

The next statistic lists the current inventory by product (in bins) throughout the system. Since it is possible to end the simulation by turning off all the resources, leaving inventory in the system is possible, and sometimes desired. The last statistic lists the finished goods inventory by product in items. Each bin in inventory is multiplied by its appropriate bin size.

2.8 The Output Display Program

For a better understanding of the system performance, an output display program has been created to plot Gantt charts and inventory during the simulated run. To run the output display program, the user must type "plot" at the dos prompt. The user will then be asked to specify "Gantt Chart, Inventory Plot or Exit (G, I or E)". Upon selecting a desired output the user will then be prompted for a ".out" file. If specified correctly, the program will read though the output file a display the selected output format.

The hardware required to run the output routines is a CGA screen, though it is highly recommended that an EGA screen be used. If a CGA screen is used the user must type "plotcga" before running the output display program. If an EGA screen is to be used, the user must type "plotega" before running the "plot" program.

It is possible to get printouts of the display, yet it is difficult and requires special equipment. Appendix B explains this procedure.

2.8.1 Gantt Charts

Once the Gantt option has been selected and the user has specified an output file, the program will prompt the user to select a "Resource Bank" to plot. (Note, the ".sim" file must exist in the same directory as the specified ".out" file.) Then program will display a Gantt chart, as in Figure 2, of all the resources contained in the selected bank. This process may take up to a minute.

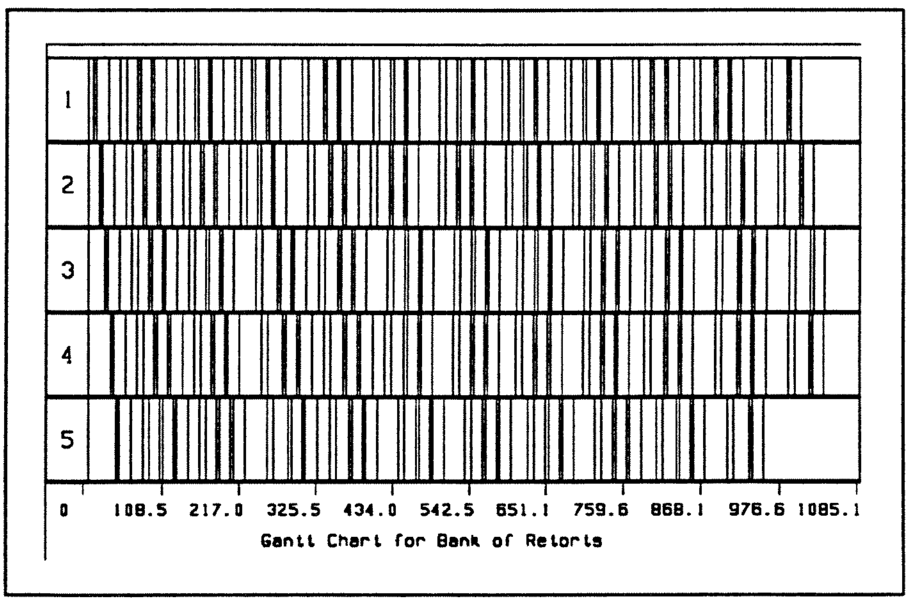

Figure 2. A Gantt Chart Display

The numbers displayed along the left border represent the particular resources within the bank. The time scale always starts at time 0 and continues to the end of the simulation, despite the state of the resources. In the screen output, color is used to display the different states of each resource. They are specified as follows:

Red -	Working
Green -	Setting-Up
Black -	Starved of Idle
Yellow -	Unavailable

2.8.2 Inventory Plots

After selecting a ".out" file, the program will prompt the user to specify three buffers to plot. Each buffer is chosen by resource type and represents the amount of material currently being processed and waiting for resources in that bank. All inventory is plotted in bins.

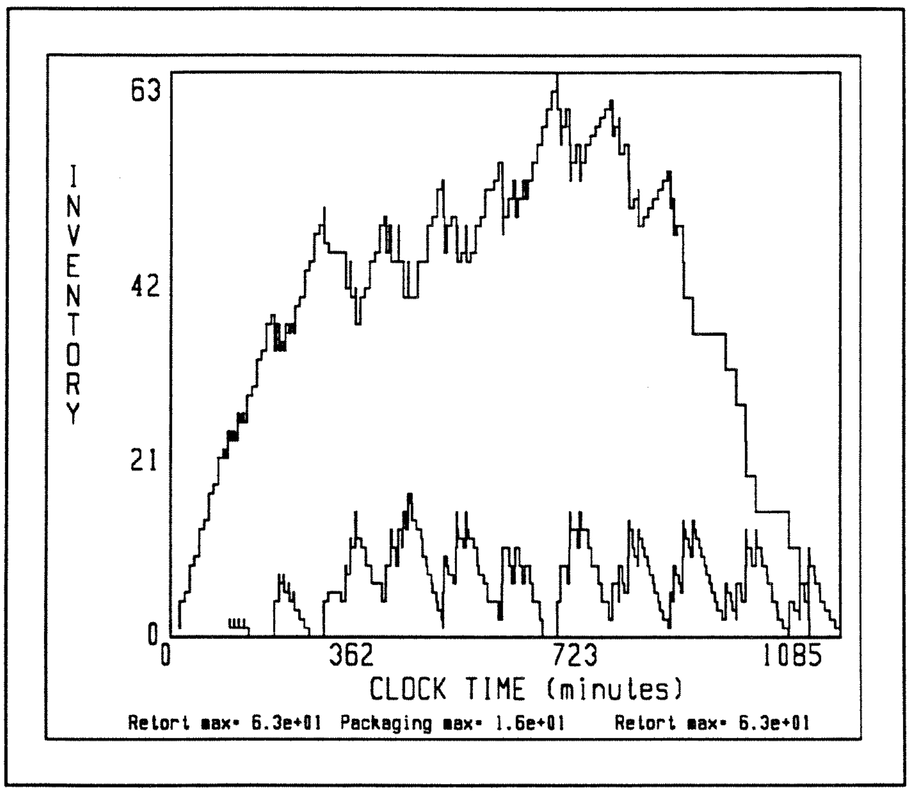

Figure 3. An Inventory Plot

Section 3 - Program Specifications

3.1 The System Queues

3.1.1 Queue Representation

To understand the queue structure created by the program can be very cumbersome. Figure 4 gives a graphic representation of one particular resource bank.

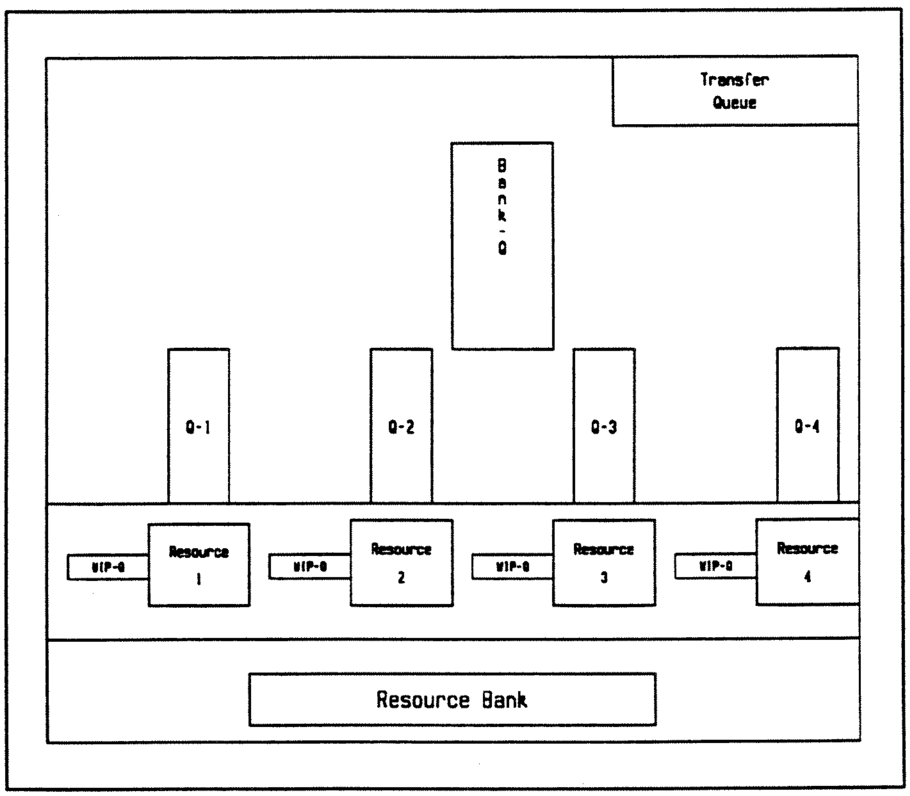

Figure 4. Graphic Display of the Queues

The terminology used in the subsequent discussion will be the following:

transfer queue - the queue of batches that have not arrived at the resource bank, but are through processing at the previous set of resources. This is explained further in section 3.4.1.

resource bank queue - the queue in front of a bank of resources.

specific resource queue - queue in front of a particular resource in a bank.

WIP queue - queue at a specific resource, where a product group is actually started.

The resource bank queue is labeled "Bank-Q" in Figure 1. The specific resource queues are labeled as "Q-1" through "Q-4" and the WIP queues and the transfer queue are labeled as such.

3.1.2 Batch Selection

The order in which batches are selected for processing is the following. First, the WIP queue is examined to see if any batches exist there. If so, the head of that queue is started. If it is empty, then the specific resource queue is examined followed by the resource bank queue. If nothing is found when looking for batches, a STARVE event is scheduled, and available time is lost.

3.1.3 The Queue Rules

Currently, there are four rules governing the insertion of batches into resource queues: SPT, [1] priority, largest process batch, and FIFO. Each rule is ranked for each bank of resources(as input into the simulator at the resource type table.) This ranking of the rules will directly affect the order in which batches are processed.

Moreover, there will be a difference in the interpretation of the rules for "BATCH" resources and for "RATE" resources. First we explain the queue rules for the rate resources, and how product groups and the largest batch rule can create another division in how the queues are sorted.

---

[1] SPT stands for Shortest Processing Time.

3.2 Rate Resource Queues

The combination of product groups and largest process batch queue rule creates a different type-class for sorting. The largest process batch rule implies that you would like to process the same product type for a while. This goes under the larger assumption that you would like to process as much of the same product without having to perform an additional setup for a different product.

If largest process batch is ranked higher than SPT, then the respective queues have a maximum of one entry for each product type. Then all of the batches in each product group are sorted within the group. Then all the product groups are sorted among each other by the highest priority in the group, the earliest arrival time within the group, by the size of the entire group and the processing time of the entire group. Remember sorting is done on these rules in the same order in which they are ranked.

Restating the process, all batches of common product type j in a queue are merged into an "intermediate lot." Intermediate lots are designed to create a sequence of units to be produced on a given resource. As long as a product of the same type exists in the queue, all batches entering that queue, will be merged into the intermediate lot. If a batch cannot be merged, it will start another intermediate lot.

If large amounts of a particular type of product keep entering the system, potential problems can arise with the product groupings. The chance exists that only one product type will be processed, or just that a queue of all other products will wait if the product doesn't run out. As a safeguard against this happening, once a product group has been started on a resource, the next product(of the same type) that enters the queue has no knowledge of the original product group currently being processed. Yet, while a product group is in the queue, any batch (of the same product type) entering the queue will join the product group to create an intermediate lot, made up of batches of the same product type.

If the SPT rule is ranked above largest process batch, then each batch will be sorted individually and no product groupings will be formed within the queues.

In addition, a resource may only stop in between batches, it must finish the current batch before it can stop. If a product group was started, it is possible for other batches from the original product group to be in the WIP queue for that resource. To insure that such WIP doesn't get left at this resource, it is re-queued, lot by lot, at the resource bank queue, unless the lots were specified for that particular resource.

3.3 Batch Resource Queues

3.3.1 Process Batches

There are no product groupings in the batch resource queues. All queues in batch resource banks contain only individual batches sorted by the appropriately ranked queue rules.

Yet, due to the different nature of "Batch" resources we introduce the notion of a "process batch". A process batch refers to the actual quantity to be processed. This process batch may contain several batches, as previously defined, due to the specification of minimum and maximum batch size at the batch resource. The notion here is that several batches may fit into one process batch, thus more material can be processed at once. For example, if 4 cages is the maximum batch size and 1 cage is the minimum batch size, a process batch could consist of 4 batches of 1 cage each, creating a process batch of 4 cages. The formation of process batches is done by "the batch algorithm".

3.3.2 The Batch Algorithm

The batch algorithm is a two pass algorithm that attempts to maximize the size of process batch as constrained by the maximum batch size for that resource type. First, a batch is selected from the head of the 3 queues, the WIP queue, the Specific queue, and the Bank queue, respectively. Note, that the only way for a batch resource to have anything in the WIP queue is if the resource performed a setup first.

As soon as a batch is selected the algorithm goes through the Specific queue and the Bank queue and creates a list of all of the products of the same product type and sorts them from greatest to smallest batch size. Next, it goes through the sorted list and sees if the size of the selected batch, now the process batch, plus the size of current one on the list is less than or equal to the maximum batch size. If so, the batch on the list is added to the process batch. Then the next batch on the sorted list is considered. When the search through the sorted list is finished, the process batch size is compared against the minimum batch size. If it is less than the minimum batch size, a check is made in all upstream resources and queues to see if any batches of the same product type exist. If so, the process batch is rejected and the algorithm starts again with the next available batch in the queues. If no feasible batch is found the resource is starved.

If the process batch size is smaller than the minimum batch size and there are no batches of the same product type upstream, the batch is processed anyway.

3.4 Setup time, Transfer Time and Yield

3.4.1 Transfer Time

If a Lot has a transfer time associated with it, it will take that long for a batch from that lot to actually arrive at the specified resource. All batches being transferred to a resource bank enter the transfer queue for that bank and are released to the bank queue or the specific queue, at the current time plus the transfer time associated with that batch. Batches in the transfer queue are invisible to the bank of resources until they actually arrive at the resource bank.

3.4.2 Setup Time

Setup time will be associated only with product changeover, and will use a resource. If a setup can be performed before the next scheduled stop on a resource, the batch will be processed, otherwise the batch will be re-queued and the resource stop time will be moved to the current time. This will also move the next scheduled start time of that resource up an appropriate amount. The assumption is that a setup will not be performed without immediately starting a product. Remember that stop and start times can also be pushed back if a batch is not completed by the scheduled stop time.

3.4.3 Yield

For each operation there is a corresponding yield that reflects the expected percent of good items that can be processed. The yield factor is specified by product type and will be multiplied by the current amount of the batch size. Thus, an original batch size of 2 (bins) may have a current amount size of 1.9 if yield on the last resource was 95%. Rate resources will adjust the processing time for smaller batches according to the direct multiplication by the rate and the current batch size.

For a Batch resource, the following will hold. The current amount will be the only factor considered by the batch algorithm explained in section 3.2.2. If the maximum batch size is 4 and a batch has a current amount size of 3.6, unless a batch of the same product type has a lot size of 0.4, the batch will be processed individually. Yet, if 3 batches have current sizes of 1.2,1.4, and 1.4 respectively, they will be processed as one process batch.

3.5 The Output File Specifications

As mentioned in section 2.7, the output file contains information about several aspects of the system. In particular each at each event information is recorded about the type of resources, the particular resource, the type of product that caused the event, the original lot that the particular batch being processed came from and some other useful information.

The batch size is the size of the actual batch being processed. Yet, since it may be possible for product groups on rate resources or process batches on batch resources to be used, the batch size will only represent the size of the first batch in the group and no the size of the entire group. Note that at a Lot_Release event the batch size is the size of the lot.

The "Spec Size" in the output file is the amount of material at that particular resource. If the resource is 0, then the spec size is also 0. The spec size includes all batches currently being processed, in the WIP queue and in the specific resource queue. No regard is made for product, it is a straight addition of the current amount of each batch in the associated with that specific resource.

The "Bank size" is the all of the spec sizes added together with the current amount of inventory in the Bank queue. So it represents all the inventory in that resource bank, including that which is currently being processed.

The "Transfer size" details the amount of material in the transfer queue, waiting to arrive at the resource bank. The "Batch Number" is a simulator assigned value to allow for tracking particular batches through the system.

3.6 Current Software Limitations

The software itself has certain global constants that bound some on the system parameters. They are as follows: the maximum number of resource types is 5, the maximum number of actual resources of a resource type is 20, the maximum number if time intervals (start and stop pairs) for a resource schedule is 12, the maximum number of product types is 20, and the time for a simulation run is 100,000 time units. Yet, the user should also be aware of the limitations of MS-Dos and the impact on the simulator. While the number of Lots and batches are not constrained by the program, dynamic memory allocation is used for each lot and batch input. It is possible to hit the memory bounds of the hardware you are working on. Using the Output Display Program with very large output files will also cause this to happen.