A User's Guide to

The Factory Modelling System

A Planning and Design Tool
for Manufacturing Engineering

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TR 84-596
March 1984

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The Factory Modelling System is a tool for the logical design of a factory. "Logical" design is concerned with capacities, production rates and the routing of flow between factory elements. It uses a schematic, idealized layout to show relative positioning and material flow, rather than exact physical dimensions and positions. In effect, FMS allows the designer to construct a working model of a factory, and then to run that model to observe its performance.

The technique employed in FMS -- discrete event simulation -- has long been used in industry for this purpose, but has previously involved custom programming and large computers. The Factory Modelling System makes this capability available in quite a different form. It is an interactive, graphical system that runs on a desktop computer. It also does not require any conventional "programming". An engineer can completely master FMS in minutes, compared to months to become accomplished with a "simulation language". One can then develop and test new factory designs in hours rather than months. In effect, FMS is the "spreadsheet" of simulation -- except that it is considerably easier to use than most spreadsheet packages.

The Factory Modelling System guides the user, step by step, in the layout of a factory "floor", by specifying a network of "Workcenters" that "process" units of product and move them from "Receiving Areas" to "Shipping Areas". The designer can also specify "Buffer Storage Areas" to absorb variations in production rate between Workcenters. The factory model constructed in this way can then be "run", so that its performance can be observed and measured. The model can be interactively modified, rerun, etc. to balance, tune and refine the design.

FMS also includes a file system in which alternative designs, and the results of factory runs can be saved.

This version of FMS is limited to designs in which the material flow path is a fixed characteristic of the factory, rather than a property of individual jobs. Such layouts are generally called "flowshops". (A subsequent "job-shop" version of FMS will relax this restriction.) This flow-shop version also does not distinguish between jobs -- that is, it counts jobs, rather than identify them individually.

Although FMS is described in factory terminology, it is actually applicable to a much wider range of applications than just factory design. FMS is capable of representing any fixed-routing, discrete unit, network flow problem. The work units could just as well be tasks in a computer system, messages in a communication network, or vehicles in a transportation grid as jobs in a factory.

1. The FMS Building Blocks

An FMS factory floor is a rectangular grid of square "areas", in numbered rows and columns. (Since at any time, the computer screen can view only a 6 by 10 portion of the floor, the "viewing window" must sometimes be shifted from one position to another.) For example, the initial view is of the Northwest corner of an empty floor, as shown in Figure 1. -

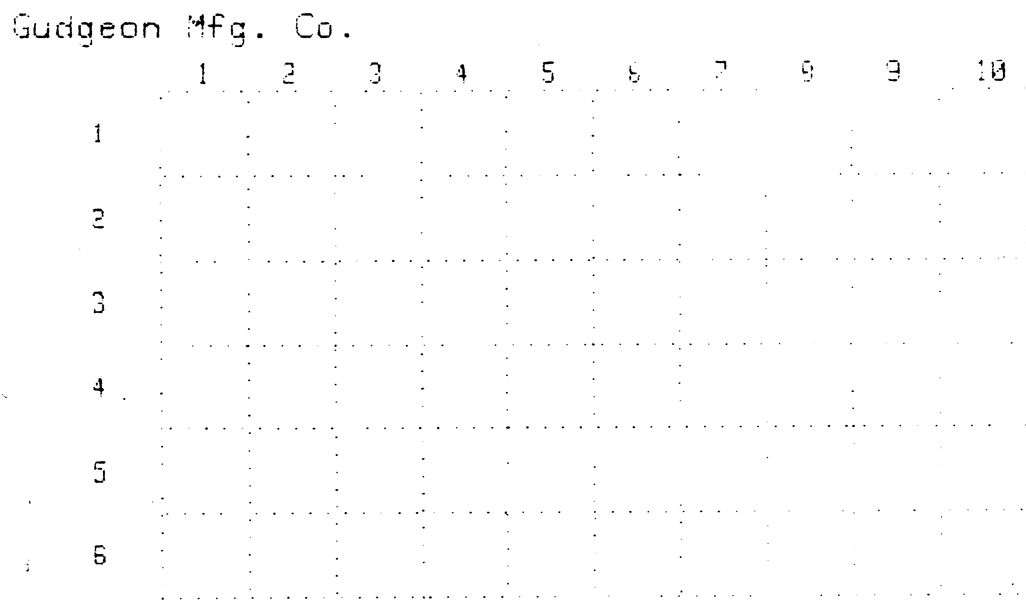

Figure 1. Empty Floor Display at the start of Design

Each area of the factory floor can accommodate one of the following types of activities:

Workcenter -- a place where an "operation" is performed on a "unit" of product. Each Workcenter can work on only one unit at a time. The time to perform the operation is called the "processing time".

Receiving Area -- an area that receives units from outside the factory for release, as needed, to Workcenters within the factory.

Shipping Area -- an area that accepts finished units from Workcenters for delivery outside the factory.

Buffer Storage Area -- An area inserted between two Workcenters to smooth out variations in production rate.

Units flow from one area to another, along "links" representing materials handling equipment. Functionally, these links correspond to overhead conveyors, since they go directly from a source area to a destination area, freely passing over other areas and crossing other links. They also represent conveyors of infinite speed and negligible storage capacity. (When necessary, conveyor delay and storage capacity can be represented by an appropriate dummy Workcenter and Buffer Storage Area.)

The design of a factory is accomplished by placing a selection of Workcenters, Receiving Areas, Shipping Areas and Buffer Storage Areas in different positions on the factory floor, and specifying links that describe material flow between these areas. For example, a simple factory model is shown in Figure 2.

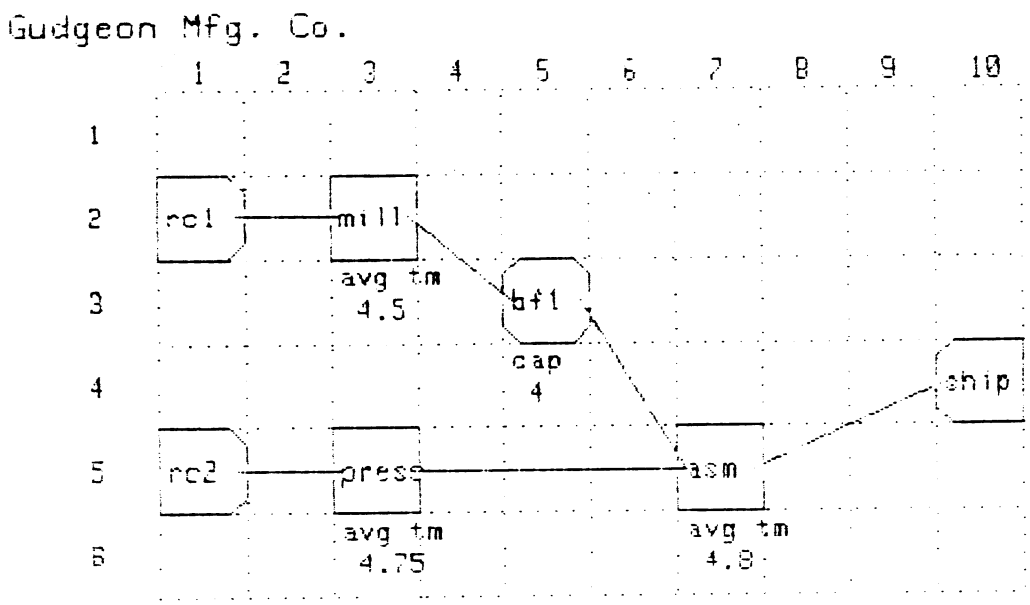

Figure 2. Floor Display during Design (normal scale)

During design, each area is automatically assigned a unique identifying name (such as **rc1**, **rc2** and **bf1** in Figure 2), which the designer can replace with a more meaningful choice (such as **mill**, **press**, **asm** and **ship** in Figure 2).

The legend below the Workcenters in Figure 2 shows the average of the distribution of processing times for that Center; the legend below each Buffer Storage Area shows the unit capacity of the area.

When appropriate, the user can examine individual areas in more detail, as shown in Figure 3, or larger areas of the factory floor in less detail, as shown in Figure 4.

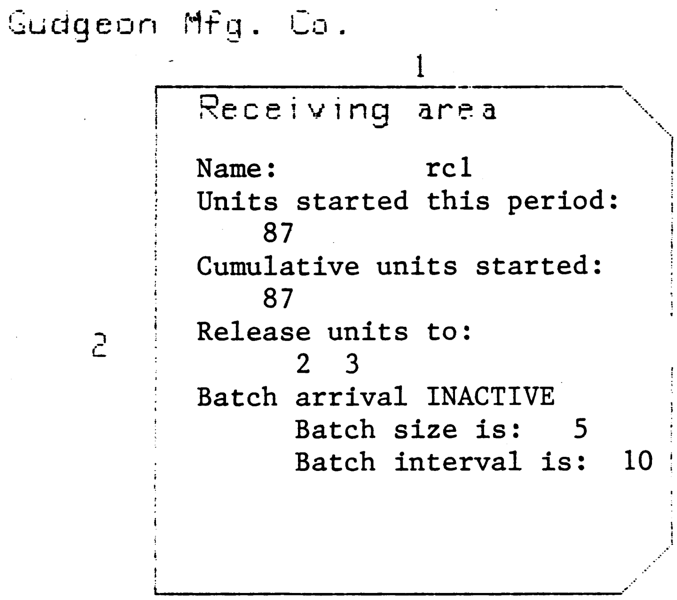

Figure 3. Expanded Display of a Single Area

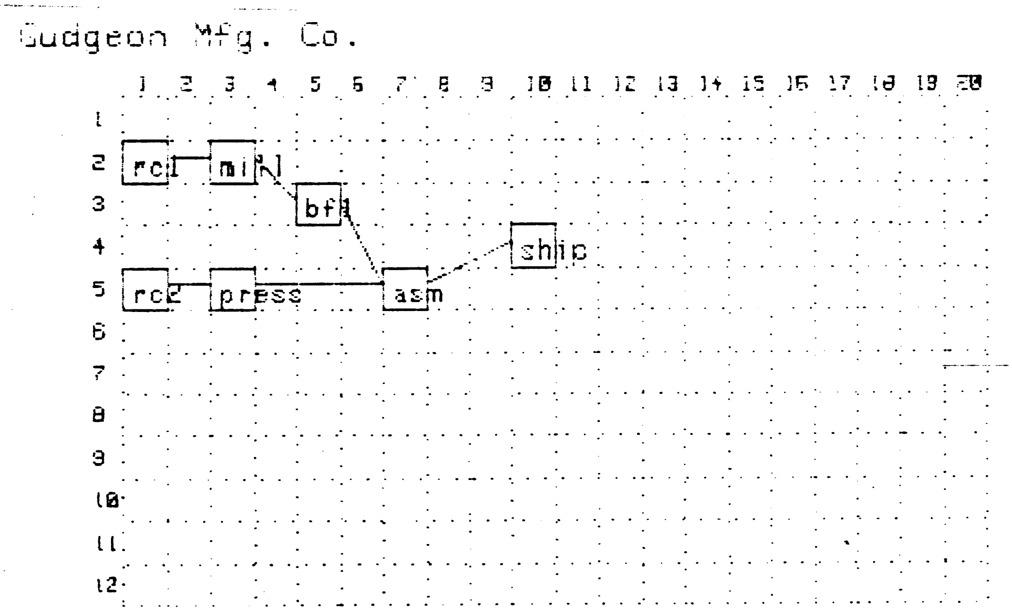

Figure 4. Reduced-scale Floor Display

2. Design Mode

While in "design mode", the user can change the characteristics of the factory -- by adding, modifying, moving or removing individual areas or links. The options are the following:

For **Workcenters:**

- location on the floor
- name
- origin of input
- origin of secondary input (for an "assembly center")
- destination of output
- minimum and maximum of distribution of processing times (default is constant time of 1 timeunit)
- yield of "good" units (default is 100%) ("bad" units simply disappear; there is no provision for "rework")

For **Receiving Areas:**

- location on the floor
- name
- location of Workcenter to be supplied with units
- location of second Workcenter to be supplied with units
- "normal" or "batch" delivery to area:
    - normal delivery is continuous and instantaneous; there is always a unit available, and it is instantaneously replaced when used (this is the default delivery mode)
    - batch delivery involves the delivery to the Receiving Area of fixed size (user specified) batches of units at regular (user specified) intervals of time (the default batch size is 5; the default delivery interval is 10 timeunits)

For **Shipping Areas:**

- location on the floor
- name
- Workcenter which is source of finished units
- second Workcenter which is source of finished units

For **Buffer Storage Areas:**

- location on the floor
- name
- storage capacity in units (default is 1 unit)
- Workcenter to supply units
- second Workcenter to supply units
- Workcenter to receive units
- second Workcenter to receive units

The design process is largely menu-controlled, and activated by the function keys on the keyboard. The role of each key at any time is shown on the screen. After each step, the current form of the design is displayed, as illustrated in Figures 2, 3 and 4.

The designer can move freely over the floor, refining the design. It is not necessary to fully specify one area before moving to another. At any point, the user can leave the design mode to either store or run the model.

3. Running an FMS Factory Model

At any point, the model can be run to determine its production capacity -- the rate at which finished units are delivered to the various Shipping Areas. The run can also identify bottlenecks that limit the factory capacity.

Even an incomplete design can be run, although obviously the results will reflect any structural omissions. For example, a particular branch may "deadend", with no outlet to a Shipping Area. Nevertheless, the model can be run. If, at some point, the model becomes deadlocked, so that no further movement is possible, the run is terminated.

The "events" in the running of an FMS model are the completion of operations at Workcenters and the delivery of batches of units to Receiving Areas, when the optional batch delivery feature is active. The run proceeds by repeatedly determining the "next event" and propagating the effect of that event throughout the factory.

For example, when a Workcenter finishes an operation, the finished unit is released to the specified output destination for that Workcenter. Then, if material is available the Workcenter begins work on the next unit. Presumably, in a perfectly balanced factory, the flow of work would be smooth and continuous and no Workcenter would ever be idle. However, with more realistic characteristics, a Workcenter occasionally will be unable to dispose of its finished output (because of congestion downstream), and be forced to wait unproductively until the congestion clears. It is then said to be "blocked". Similarly, a Workcneter may, from time to time, have to wait for needed input before beginning an operation. In particular, an Assembly Center, requiring two types of input, may have one but not the other, and cannot become begin processing until the second type of input becomes available.

A run can be periodically interrupted, in order to examine the "state" of the factory. An example of a state display is shown in Figure 5. In this display, Receiving Areas show the number of units that have been started, and Shipping Areas show the number of units that have been finished. Buffer Storage Areas show the current number of units present, and Workcenters indicate whether they are idle or busy, and if busy, when the current operation will be completed.

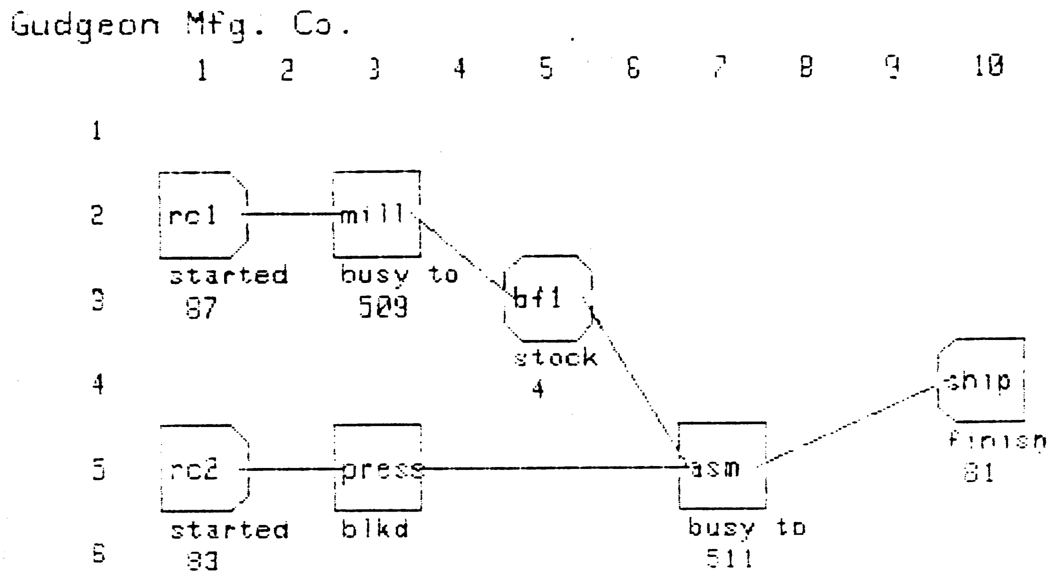

Figure 5. Factory Display during a pause in run (at time 506)

As in design mode, the pause-during-run display can be altered in scale (to show more or less of the floor), and the position of the viewing window can be moved.

3.1. RUN Controls

The user has the following controls over the run of an FMS model:

Specify the duration of the run in timeunits
(default is 31000 timeunits)
Initialize (or re-initialize) the model -- to a
state that is "empty and idle"
Start data collection (discarding results from an initial "run-in" period)
Start a new data collection "period", adding results from the previous period to the "cumulative results"
Specify that the run should automatically PAUSE at regular time intervals (default is 200 timeunits)
Specify that the run should automatically PAUSE after the occurrence of a fixed number of (completion or delivery) events (default is 50 events)
Single-step the run; PAUSE after every event
Initiate the display of results (see Section 3.3)
Modify the state of the system (see Section 3.2)
Resume the run

In addition to these options, which are effective whenever the run is PAUSED, the user can manually interrupt the run at any time.

3.2. Manual Change in the State of the Model

The state represents the results of running the model. The state changes, more or less continuously, during a run. However, whenever the run is PAUSED, the user can manually alter the state. When the run is resumed, it will start from the altered state.

Changes in state that can be made manually in a PAUSED model are the following:

For Workcenters:
- can be made "busy"
- can be made "idle"
- can be pulled "offline" (to remain unavailable for processing until manually made "busy")

For Receiving Areas:
- can change number of units "started"
- can start/stop batch deliveries
- can force batch delivery

For Storage Areas:
- can change stock-on-hand
- can change maximum stock observed todate

For Shipping Areas:
- can change number of units "finished"

3.3. Display of Results

The results of a run can be obtained for the current period, or cumulatively -- the aggregate of all periods since the beginning of data collection. (The beginning of data collection is not necessarily the beginning of the run, since the user may elect to discard the results of an initial "run-in" interval.)

Note that periods are entirely user-controlled. A new period is initiated only when the user explicitly (and manually) requests it. In particular, periods are independent of the automatic display intervals that the user can request.

The user also has the choice between "raw results" and "rates". The differences are the following:

For Workcenters:

results show the current state -- idle, busy, blocked, offline, etc.

rate shows the percentage of time the Workcenter has been busy

For Receiving Areas:

results show the number of units that have been started from this area

rate shows the number of units per timeunit started from this area

For Storage Areas:

results show the current stock-on-hand

rate shows the maximum stock level observed, as a percentage of area capacity

For Shipping Areas:

results show the number of finished units that have arrived at this area

rate shows the number of finished units per timeunit at this area

During any PAUSE in a run, the user also has the option of printing a paper copy of the results. For each area, the results and rates are printed, both for the current period and cumulatively.

4. The FMS Storage Manager

The Storage Manager manages the "FMS Models" disk. It allows models to be stored on and retrieved from that disk, the contents of the disk to be listed, and models to be erased from the disk.

Note that a factory model has both a structure -- the result of the design process, and a state -- the result of running the model. (For a model that has never been run, the state is null.) The model can be stored at any point in its design or execution, and subsequently retrieved exactly as stored. Once retrieved, a run can be resumed, reinitialized, etc., or the model structure can be modified, exactly as if the model had remained current.

5. Control Hierarchy during FMS Session

FMS employs a hierarchy of "modes" during a session. Each mode consists of a certain set of actions, which are displayed in a menu on the screen, denoting which function key controls which action. For the most part, this is simple to understand and use, but it may help to be told that the modes form an (inverted) tree and that, in general, K4 always "leaves" the current mode to move upward (toward the root) in the control tree. The other keys either shift to lower modes, take action directly, or initiate a dialog that solicits input from the keyboard.

HELP is available in most modes by pressing K0.

A partial outline of the most important, high-level modes is shown below:

Main session control
- K0 HELP
- K4 quit session
- K5 enter Design mode
- K6 create new model; then enter Design mode
- K7 enter Store/Retrieve mode
- K9 enter Run mode

Design mode (to modify current model)
- K0 HELP
- K1 move an existing area
- K2 change scale of display
- K3 shift view of display
- K4 leave Design mode (return to Main session control)
- K5 enter Design WORKCENTER mode
- K6 enter Design BUFFER STORAGE AREA mode
- K7 enter Design RECEIVING AREA mode
- K8 enter Design SHIPPING AREA mode
- K9 remove an existing area

Store/Retrieve mode
- K1 create new model
- K2 change name of current model
- K3 specify disk drive for FMS Models disk
- K4 leave Store/Retrieve mode (return to Main session control)
- K5 store current model on FMS Models disk
- K6 list contents of FMS Models disk
- K7 retrieve a model from FMS Models disk
- K9 erase model from FMS Models disk

Run mode (run the current model)
- K0 HELP
- K1 enter Set Run Control mode
- K2 change scale of display
- K3 shift view of display
- K4 leave Run mode (return to Main session control)
- K5 re-initialize run
- K6 start data collection
- K7 enter Result Display mode
- K8 enter Modify State mode
- K9 start the model running

6. Acknowledgements

The original idea for FMS arose in a discussion with Dr. Joel Birnbaum of the Hewlett-Packard Research Center. The functional design of the system subsequently benefitted in many ways from discussions with my Cornell colleagues, Professors Jack Muckstadt, William Maxwell and Lee Schruben. The FMS user interface benefitted from many suggestions by Steve Worona.

The entire field of discrete event simulation owes its existence to Dr. Harry M. Markowitz, of SIMSCRIPT fame, and many of the techniques employed in FMS originated in my collaboration with Markowitz many years ago.

Appendix A. FMS Loading Procedures

FMS runs on HP 9836A, 9836U and 9816 computers, with a minimum of 512K of memory. FMS is built upon the HP Extended Basic 2.0 System (Option 711). The system is supplied on two disks:

FMS6 contains the system program
FMS6M contains sample models

The following steps are required to run:

1. Insert the BASIC 2.0 System Disk (supplied by HP) and power-up the computer. (Usually the right-hand drive of a dual-drive unit is preferred for the system disk.)
2. When the screen confirms that "BASIC 2.0 is ready", remove the BASIC disk and replace it with the FMS6 disk. (This must be in the right-hand drive.)
3. Type **LOAD "FMS6"** and press the EXECUTE key.
4. When the "disk-active" light goes out, press the RUN key. After a few seconds, the FMS announcement should appear. Follow instructions in the key-labelling white blocks at the bottom of the screen.
5. To load and use a sample model:

   Insert the FMS6M disk in the left-hand drive.
   Press K7 for **Store/Retrieve**
   Press K3 for **Assign disk**
   Specify disk drive, as instructed on screen
   Press K6 to list Models available
   Press K7 to **Retrieve Model**
   Enter stored-model name (from list displayed previously)

   The specified model will be loaded, and the system will be in Main Session Control mode (see Section 5)

Appendix B. Limiting Dimensions and Performance

The limits on FMS dimensions are determined by various array sizes in the program. The standard limits supplied with the system are the following:

- Factory floor: 20 rows by 30 columns
- Workcenters: 30
- Buffer storage areas: 30
- Receiving areas: 10
- Shipping areas: 10
- Links between areas: 100

These limits are easily changed, and can be made substantially larger. With the limits as supplied, a factory model requires a data area of aproximately 7.5K bytes. For larger limits this would be increased proportionally -- estimate aproximately 12 bytes per individual area of the floor (assuming that the number of each type of area is proportion to the number of rows or column, and not their product).

Response time during model design is, in most contexts, independent of dimensions. However, there are a few contexts -- typically, initializations -- where response is proportional to the size of the model. But even in these contexts it is generally dependent on the number of areas actually used, rather than on the limiting dimensions of the model. (Only the store/load time in the Storage Manager is proportional to the limiting dimensions.)

The running time of a model is proportional to the sum of the number of Workcenters and Receiving Areas actually specified in the model, and not on the potential number of such areas. Note also that running time is proportional to the number of events, and not on clock time. For example, suppose a particular model was capable of processing 10 events per second of real time. Doubling the processing time values at each Workcenter (and the batch intervals at Receiving Areas with batch delivery) in this model would not materially alter the running speed. The run would still proceed at 10 events per second of real time; although the simulated factory clock would advance at twice the previous rate.

March 15, 1984