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MODELING MANUFACTURING SYSTEMS USING MANUPLAN AND SIMSTARTER - A TUTORIAL

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ABSTRACT

MANUPLAN® and SIMSTARTER™ are software tools that enable rapid modeling and analysis of manufacturing systems. This paper begins by discussing the benefits of rapid analysis in today's competitive manufacturing world. Next, we state a sample problem regarding decision making for a manufacturing cell, and give a detailed tutorial showing how this problem can be addressed with **MANUPLAN**. Subsequently, we describe the main features of **SIMSTARTER** (a simulation generator) and give examples of its use for the sample problem. We also discuss the integration of these two tools with well-known tools such as **Lotus 1-2-3**, **SIMAN/CINEMA**, and **SLAMSYSTEM/TESS**, and the benefits of this integration for manufacturing analysis.

1. MANUFACTURING NEED FOR RAPID MODELING

The design and analysis of modern manufacturing systems is a complex task, and using computer simulations to evaluate systems can be time-consuming. Time is a luxury that cannot be taken for granted if a manufacturing company wishes to remain successful in today's competitive world. An alternative to detailed simulation modeling has been recently developed that can save corporations valuable time and money. Known as the rapid modeling technique (RMT), it uses mathematical models (instead of simulation) to predict the impact of manufacturing decisions on system performance. RMT has a broad range of applications: it can assist in improving utilization, reducing work-in-process (WIP) and lead times, and meeting production targets [Suri 1988, 1989].

This paper gives a tutorial on **MANUPLAN**, a manufacturing modeling tool based on RMT, and a brief overview of **SIMSTARTER**, a tool that helps link **MANUPLAN** to detailed simulations. **MANUPLAN** is a software tool, based on a state-of-the-art mathematical model, which enables designers to evaluate manufacturing systems quickly and easily. In typical cases, systems that would take several weeks to evaluate using simulation can be evaluated in only a few days with **MANUPLAN** [Anderson 1987; Brown 1988]. **MANUPLAN II** is a PC-based implementation that uses **Lotus 1-2-3** as its user interface. In this tutorial we will refer to **MANUPLAN** when speaking of the general modeling tool, and refer to **MANUPLAN II** when illustrating specific features and screens in the PC-based implementation.

A concrete example of how **MANUPLAN** and **SIMSTARTER** can be applied is in reducing lead times. Lead time reductions are an effective method for a company to achieve significant advantages over its competitors [Suri 1989]. There are two classes of lead time in manufacturing. First, there is the lead time required to develop a new product. To remain competitive and gain the edge in efficiency, managers and designers need to study as many decision alternatives, in as short a time, as possible. Getting a product to market six months before your competitors can mean higher pricing and a chance to capture the market, both resulting in improved profitability. **MANUPLAN** allows many different ideas to be rapidly explored (a run usually takes under a minute). In many cases the results may be sufficient for a decision. In other cases, it quickly narrows the candidate systems down to a few alternatives for detailed simulation. Then, using **SIMSTARTER**, these simulations can be developed very quickly. In this manner, RMT can help managers bridge the gap between manufacturing strategy and expensive simulation leading to final system design.

Second, there is the lead time required to manufacture a product. **MANUPLAN** can be used to answer "what if" questions about possible changes in the system and their impact on system performance. For example, what if demand for our product increases by twofold? What if we run overtime? What will be the impact of a faster machine on the lead time of the line? Questions like these can help managers make better, more informed decisions; decisions that will ensure an aggressive manufacturing strategy to anticipate and plan for a successful future. The use of **MANUPLAN** to answer such questions will be illustrated in this tutorial.

Some of the primary advantages of using **MANUPLAN** for rapid manufacturing analysis are: **1)** it is easy to learn and use, **2)** it has modest data requirements, **3)** it provides answers in seconds, and **4)** it can compare many alternate scenarios quickly.

In this tutorial we will focus on the application of **MANUPLAN** and **SIMSTARTER** to a typical manufacturing problem, and use this problem to illustrate the main features of the two packages. For details of industrial applications of RMT, we refer the reader to applications at Siemens [Anderson, 1987], IBM [Brown, 1988], DEC [Harper and O'Loughlin, 1987], McDonnell Douglas [Mills, 1986] and Alcoa [Nymon, 1987].

2. SAMPLE PROBLEM

As an example consider the manufacturing cell in Fig. 1.

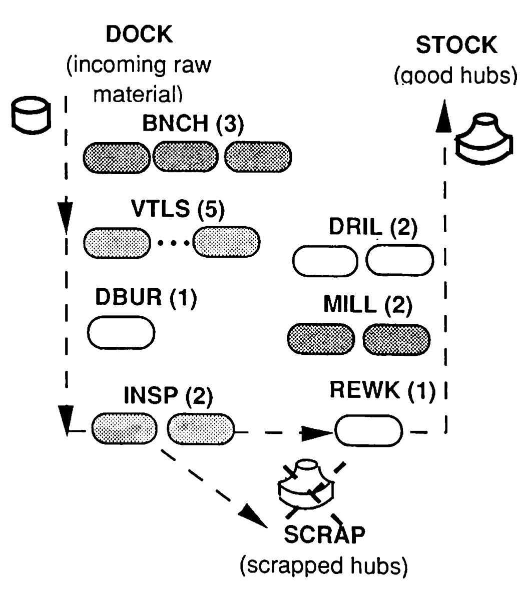

Figure 1. Manufacturing Cell for Jet Engine Hubs

This cell produces four types of jet engine hubs and consists of the following stations: a dock (DOCK) where hubs are loaded; the work benches (BNCH) where the hubs are manually prepared on one of 3 available benches; the vertical turret lathes (VTLS) where the hubs are machined on one of 5 available lathes; the deburr station (DBUR) where the hubs are deburred; the inspection station (INSP) where the hubs are inspected for defects by one of the 2 available inspectors; the rework station (REWK) where defective hubs are reworked by the repairman; the milling machines (MILL) where hubs are machined on one of the 2 available mills; the drill (DRIL) where hubs are drilled on one of the 2 available drills.

The sample problem we wish to consider is representative of two situations: 1) installing a new manufacturing system, and 2) improving the operation of an existing system. Assume for the first situation that management wishes to reorganize an existing job shop into cells. The primary objective is to obtain a one week lead time. We will consider one such cell. Some of the questions to be addressed include: Which products should be put in the cell? How many machines of each type should exist in the cell? Which setups should we reduce?

Assume for the second situation that management needs to improve the existing cell. Current problems include: 1) dissatisfied customers who are cancelling orders due to delays, 2) long lead times, 3) high levels of WIP, 4) high cost of WIP. As before, the primary objective is to reduce lead time to one week. Some of the questions to be addressed include: How many shifts to run? Where (i.e. at which equipment groups) should we introduce overtime? What are good lot sizes? Which setups should be reduced?

3. MANUPLAN DESCRIPTION OF PROBLEM

Given the benefits of rapid analysis, we will use MANUPLAN to help answer the above questions. First we will model the work cell.

3.1 Overview of MANUPLAN Structure

MANUPLAN is a user-friendly menu-driven program that defines a system using 5 basic types of input screens. The program delivers results based on this data in a matter of seconds. The inputs and outputs of MANUPLAN are summarized in Fig. 2.

The description of a system in MANUPLAN consists of the description of parts, routings, operations, and equipment groups. MANUPLAN allows the manufacturing system to make several different part-numbers. Each *part* is manufactured via a route. On a given *route*, a part will undergo a sequence of operations. Each *operation* is assigned to be done on one or more equipment groups. An *equipment group* is a collection of identical pieces of equipment, with identical capabilities. The main outputs from MANUPLAN include production and scrap rates, utilization, WIP, and part flow times.

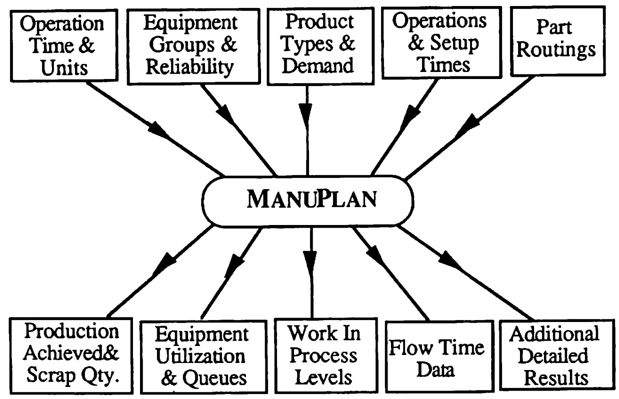

Figure 2. MANUPLAN Inputs and Outputs

3.2 MANUPLAN Inputs

In the following section of the tutorial, it is advised that the reader start up **MANUPLAN II** with the example model that is supplied with the software, and follow along with the text. Throughout the tutorial, the reader is supplied with the proper commands in order to be able to see and alter the input data and observe the results as they are described.

- Get into the directory where **MANUPLAN II** is stored.
- Type the command "manuplan gtdemo".

This command brings up a **MANUPLAN** worksheet containing the data for the jet engine work cell previously described in section 2. The screen will appear as shown in Fig. 3.

You are currently in **Lotus 1-2-3** which is being used as a "front-end" to **MANUPLAN II.** The method of selecting menus is the standard **Lotus 1-2-3** procedure. You can select a menu item in one of two ways as follows: **1)** Move the cursor using arrow keys (← or →) and press <ENTER>, or **2)** Press the first character of any menu item (do not press <ENTER> in this case). In this tutorial, a menu item to be selected will be indicated as follows: <INPUT>

The data currently displayed on the screen (see Fig. 3) is the first of five types of input data – the *System* data. The run title is a user comment that will be echoed in the output from **MANUPLAN II** and also appears in the graphs. It should be used to clearly identify the model. (Note that lines that begin with an asterisk are comment lines and ignored by **MANUPLAN.**) The second system input is the Version which identifies the version and format of the

```
 INPUT  RUN_MANUPLAN  VIEW  GRAPH  1-2-3    HELP   EXIT   UTILITIES
 Menus to input or modify data for manuplan model
          A         B         C         D         E         F         G
1  * ---- Network Dynamics Inc ---- MANUPLAN MODEL INPUT DATA
2  *
3  * run title:
     GROUP TECHNOLOGY CELL FOR ENGINE HUBS
4  *
5  *
6  * Version:
     II/1.1
7  *
8  *
9  * Opern.    Flow time      Demand     MINs worked    DAYs worked
10 *  Unit     Unit           Period       per DAY      per YEAR
      MIN       DAY            YEAR         480           210
11 *
12 *
13 *Utilization       Variability %    Variability %
14 *   limit          in Arrivals       in Equipment
     95                 30                30
```

Figure 3. MANUPLAN System Data

MANUPLAN II model. The correct value for Release 1.1 is "II/1.1". The third system input is the Available Time information which includes data items defining the units of time to be used and the amount of time that the system will be available. There are three units of time:

- Operation Unit – the unit used to specify times for individual operations (i.e. "MIN" in Fig.3).
- Flow Time Unit – the unit used to measure flow times for parts going through the entire system (i.e. "DAY" in Fig.3).
- Demand Period – the unit used to specify the period over which the part demand data applies.(i.e. "YEAR" in Fig.3).

Two parameters describe the amount of time the system is available: the number of operation units worked per flow time unit (i.e. "MINs" per "DAY"), and the number of flow time units worked per demand period (i.e. "DAYs" per "YEAR"). The fourth system input is the Utilization limit and variability. The Utilization Limit is the maximum (in %) that any equipment group may be utilized (including all set-up times, operation times, and down times). The variability parameters are for advanced users; initial users should accept the default values provided, (30,30) respectively, by **MANUPLAN II** (see the User Manual for more details).

The second type of input data is the *Equipment Group* data.

- Select <INPUT> <EQUIPMENT>.

The Equipment Group data should appear as shown in Fig. 4 (dots indicate that additional columns are omitted).

*equip	no.in	reliability-(MINs)		...
* name	group	mttf	mttr	...
*				
BNCH	3	9600	480	...
VTLS	5	9600	960	...
DBUR	1	4800	480	...
INSP	2	2400	480	...
REWK	1	9600	480	...
MILL	2	10000	240	...
DRIL	2	10000	240	...
DONE				

Figure 4. Equipment Group Data

The first column defines the names of the equipment groups. The second column specifies the number of pieces of equipment in the group. The third and fourth columns define the mean time to failure and the mean repair time for each machine (in minutes).

The third type of input data is the Part data.

- Select <PREV_MENU> <ITEMS_PARTS> <DEMAND_LOTSZ>

The Part data should appear as shown in Fig. 5.

* part	demand	lot	...
* number	per YEAR	size	...
*			
HUB.H1	2000	40	...
HUB.H2	1500	30	...
HUB.H3	2200	44	...
HUB.H4	1500	30	...
DONE			

Figure 5. Part Data

The first column defines the part name. The second column specifies the number of good pieces that are to be produced during the previously specified (i.e. "year" in our example). The third column states the number of pieces in a lot.

The fourth type of input data is the *Routing* data. A sketch of the routing for part HUB.H1 is depicted in Fig. 6. **MANUPLAN**'s treatment of routing data input helps the user to think in flow-chart terms. Routing data includes three items: **1)** an operation, **2)** the next operation(s), **3)** the routing proportion between operations. A part always starts at DOCK and continues through operations until STOCK or SCRAP is reached (denoted STOK and SCRP respectively in **MANUPLAN**).

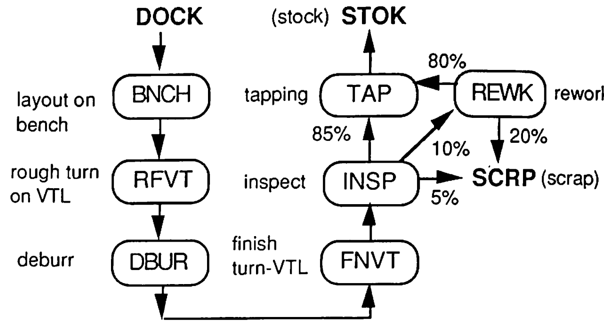

Figure 6. Routing for HUB.H1

- Select <PREV_MENU> <ROUTING>
- Position the cursor on the desired part (in this case, HUB.H1) and press <ENTER>. The routing data should appear as shown in Fig. 7.

* From	To	Proportion
* Opern	Opern	
*		
DOCK	BNCH	1
:	:	:
INSP	TAP	0.85
INSP	REWK	0.10
INSP	SCRP	0.05
REWK	INSP	0.80
REWK	SCRP	0.20
TAP	STOK	1
DONE		

Figure 7. HUB.H1 Input Routing Data

The starting point for any routing in **MANUPLAN II** is always DOCK. The first two columns are operation names that define the flow through the system. The third column defines the fraction of parts that follow that particular route. Refer to Fig. 7. Note that 85% of the lots leaving INSP are sent to TAP, 10% are sent to REWK, and 5% are sent to SCRP; 80% of the parts sent to REWK are sent back to INSP and 20% are sent to SCRP.

The last of the five types of input data is the *Operation Assignment* data. The design of **MANUPLAN** is conceived so as to separate the part-process characteristics from the system-equipment characteristics. The operation routing data describes how a part is manufactured by a series of operations. The operation assignment data describes the equipment groups the operations are performed on. By separating these types of input data, **MANUPLAN** allows a user to specify multiple operations on the same equipment group as well as to specify an operation to be performed on more than one equipment group.

- Select <PREV_MENU> <OPERATION_ASSGN>
- Position the cursor on the part you wish to view (choose HUB.H1) and press <ENTER>. The operation assignment data should appear as shown in Fig. 8.

* OPERATION ASSIGNMENT for ITEM (part)				
* HUB.H1				
* Opern	Equip	Proportn	time/lot	time/pc
* name	Name	Assigned	(setup)	(run)
*				
BNCH	BNCH	1	0	10
RFVT	VTLS	1	180	17
:	:	:	:	:
TAP	MILL	1	60	60
DONE				

Figure 8. Operation Assignment Data for HUB.H1

The two columns define the operation name and the equipment group name to which the operation is assigned. The third column defines the fraction of the operation that is assigned to that equipment group. This feature enables an operation to be performed by several equipment groups (see the User's Manual). Operation names apply only within each item's data section (i.e. the same name may be used for different items). The fourth and fifth columns display the time per lot for setup and the time per piece for run respectively (in minutes, the unit we specified).

In summary, five types of screens display all the input data required to build a model of a cell. (Note that the operation assignment data and the routing data must be defined for *each* part type.) Due to the simplicity of these screens, a user requires less than 1/2 day to build the above model, and a novice user requires a1/2 day to learn how to use **MANUPLAN**.

3.3 Running MANUPLAN

Now you are ready to run the model to evaluate this system:

- Select <MAIN_MENU> <RUN_MANUPLAN> <OVERWRITE> <QUICK_RUN>

The <OVERWRITE> command tells **MANUPLAN** to overwrite the new result onto the old results (if any exist). The <QUICK_RUN> command enables small models to be evaluated very quickly. With this option you are presented with a DOS prompt.

- Type "Q" <ENTER> when presented with the DOS prompt

Q is a mnemonic for the Quick evaluation by **MANUPLAN**, which will now execute and automatically return you to the main menu of **MANUPLAN**.

3.4 MANUPLAN Outputs

MANUPLAN returns to the main menu and displays the *Item Summary*. This report splits the screen into two windows, one displaying the input data and the other the output data (this is done with all reports). The screen should appear as shown in Fig. 9 (The dots indicate that some of the input columns are omitted and the vertical line separates the inputs and outputs).

*	Desired production can be achieved			
* part ...	Good	Scrap	WORK IN	FLOW TIME
* number...	Prodn	Prodn	PROCESS	dock-stok
*	(pieces)	(pieces)	(pieces)	in DAY s
HUB.H1 ...	2000	164.7	188.7	19.0
HUB.H2 ...	1500	140.0	75.1	9.9
HUB.H3 ...	2200	23.2	129.6	12.3
HUB.H4 ...	1500	123.5	67.7	9.0
DONE	TOTAL PIECES:		461.2	

Figure 9. Item Summary Report

The first column of output displays the number of good pieces produced (for each part type). The second column displays the number of pieces scrapped. The third column displays the average number of pieces in the system. The fourth column displays the average flow time (i.e. achieved lead time) in days. Note that the report indicates that the desired production rate can be achieved using the current system; *however, the lead time is up to 300% off the objective of one week (5 working days).* This shows the importance of early feedback – with just a little modeling effort we see that we are 300% off our objective and can quickly allocate resources to finding workable alternatives.

The *Equipment Utilization Summary* is a summary of the utilization for each of the equipment groups.

- Select <VIEW> <EQUIPMENT> <UTIL_SUMRY>.

The report should appear as shown in Fig. 10.

The first three columns of output indicate the percentage of time that each machine spends in set-up, run, and repair respectively. The final column is the sum of the previous three columns, the overall utilization of a machine.

*	EQUIPMENT UTILIZATION SUMMARY			
* equip...	% of capacity required			TOTAL
* name...	for	for	for	Utili-
*	SETUP	RUN	REPAIR	zation
BNCH ...	0.0	25.3	1.3	26.6
VTLS ...	9.6	46.6	5.6	61.8
DBUR ...	0.0	70.0	7.0	77.0
INSP ...	0.8	41.4	8.5	50.7
REWK ...	1.1	23.2	1.2	25.4
MILL ...	3.0	70.4	1.8	75.2
DRIL ...	4.0	37.2	1.0	42.2
DONE				

Figure 10. Equipment Utilization Summary

The *Equipment WIP Summary* is a summary of the work-in-process at each of the equipment groups.

- Select <PREV_MENU> <WIP_SUMRY>.

The report should appear as shown in Fig.11. The first column of output displays the average number of lots present at each of the equipment groups. The second column displays the average number of lots waiting in the queues. The third column displays the sum of the two previous columns, the total number of lots in WIP.

* equip...	WORK-IN-PROCESS (in lots)		
* name...	at	in	
	EQUIP	QUEUE	TOTAL
BNCH ...	0.76	0.06	0.81
VTLS ...	2.81	0.63	3.43
DBUR ...	0.70	1.84	2.54
INSP ...	0.85	0.49	1.33
REWK ...	0.24	0.07	0.31
MILL ...	1.47	1.57	3.04
DRIL ...	0.82	0.13	0.96
DONE			

Figure 11. WIP Summary

For a visual representation of the results, **MANUPLAN II** provides a number of *graphs*. These graphs are easy to generate, simply by following the **MANUPLAN II** menus, even for an inexperienced user. As an example we will display a graph of the Equipment Utilization summary (Fig. 10).

- Select <PREV_MENU> <UTIL_SUMRY> <GRAPH> <SHOW>

A graph should appear as shown in Fig. 12. After viewing the graph, press <ENTER> to return to the menus. Note that this graph had already been predefined. We will soon see how **MANUPLAN II** lets you easily define and build your own graphs.

In addition to the summary reports previously viewed, **MANUPLAN II** provides three additional detailed reports by part, operation, and equipment. These reports are not essential for the tutorial; interested users should refer to the **MANUPLAN II** manual for a complete description.

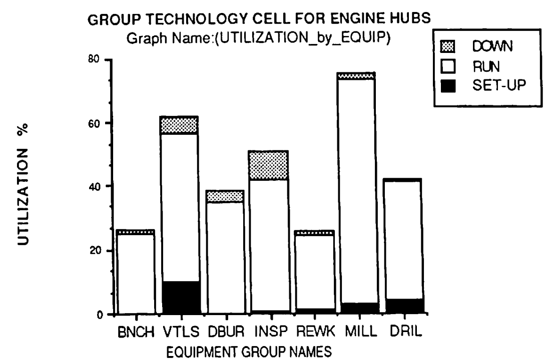

Figure 12. Graph of Equipment Utilization Summary

3.5 Achieving the Objective Using MANUPLAN

Recall that we are currently 300% off our objective of a one week lead time for the cell. We'll now use **MANUPLAN** to help achieve our objective. **MANUPLAN** provides a number of "what if" dials to make it simple to see the effects of changing system parameters including: **1)** use of overtime, **2)** setup reduction , **3)** process time reduction, and **4)** demand surges. The "what if" dials allow rapid creation of "what if" scenarios without changing the basic data. These dials are set to 1.0 when the user desires a "straight" run of **MANUPLAN**. The dials can be adjusted to change the system parameters. Examples of the use of such "what if" dials are the following:

`Overtime factor` – specifies a longer or shorter than standard day (e.g. a factor of 1.25 for an 8 hour day specifies a 25% *longer* standard day (1.25 x 8) or a 10 hour day).

`Speed-up factors` – specify faster or slower setup or process speeds (e.g. a setup speed-factor of 1.2 for a 12 minute setup specifies a *shorter* setup time of 10 minutes (12 ÷ 1.2)).

`Demand factor` – specifies a larger or smaller than expected demand (e.g. a factor of 2.0 doubles the expected demand).

Now we can use **MANUPLAN II**'s reports to enable us to see ways of improving the current system performance. Let's take another look at the Equipment WIP summary (see Fig. 11), and focus on the `in QUEUE` amounts. The largest value is at `DBUR`. This represents nonproductive time, and reducing it may have a large impact on the lead time. In order to reduce this value, let's try our first "what if". What if we add a second shift at the deburring station? With **MANUPLAN II** such a question can be answered easily and swiftly:

- Select <MAIN_MENU> <INPUT> <EQUIPMENT> <DATA_ENTRY_&_MOVE>
- Use the arrow keys to move to the overtime factor for DBUR and type "2" followed by <ENTER>.

The equipment group data should now appear as shown in Fig. 13.

*equip... * name... *	overtime factor	speed-factors setup	run ...
BNCH ...	1	1	1 ...
VTLS ...	1	1	1 ...
DBUR ...	2	1	1 ...
: :	:	:	:
DONE			

Figure 13. Equipment Group Data

In two simple steps, we have created the "what if". To evaluate the effect of this change:

- Select <MAIN_MENU> <RUN_MANUPLAN> <SAVE> <QUICK_RUN>. Note the <SAVE> option saves the previous results for comparison with the new results.
- Type "Q"<ENTER> when prompted.

It just takes a minute to make such a change and get the results! **MANUPLAN II** returns with an updated item summary (Fig. 14).

* * part ... * number... *	Desired production can be achieved Good Prodn (pieces)	Scrap Prodn (pieces)	WORK IN PROCESS (pieces)	FLOW TIME dock-stok in DAY s
HUB.H1 ...	2000	164.7	168.4	17.06
HUB.H2 ...	1500	140.0	61.1	8.08
HUB.H3 ...	2200	23.2	107.8	10.24
HUB.H4 ...	1500	123.5	54.1	7.21
DONE	TOTAL PIECES:		391.4	

Figure 14. Item Summary Report with Second Shift at `DBUR`

Notice that the `Total WIP` is down from 461 pieces to 391. Also notice that the lead times have improved. To see this improvement more clearly, we will define our own graph for comparison of "before" and "after" adding the second shift at `DBUR`. **MANUPLAN II** provides a "menu-driven" mode to define customized graphs:

- Select <GRAPH> <ITEMS_(PARTS)> <FLOW_TIME> <BUILD>

MANUPLAN II now asks if we wish to include previous results.

- Type "Y" <ENTER>
- Press <ENTER> twice to accept the default values for the next two prompts.

The graph will appear as shown in Fig. 15. As you can see clearly from the graph, the flow time for all four parts was reduced by adding a second shift at the deburr station. Press <ENTER> to return to the menus. Similarly, we could look at other reports in **MANUPLAN II** to see the effects of the extra shift at `DEBUR`. Although the second shift helped, we are still far from the lead time objective of 5 days. So let's try to reduce the lead time using a different approach. We will start by reducing the lot size of the part with the highest demand, `HUB.H3`. The analyst might think: by making this change the number of setups will increase; thus, won't the lead times *increase* ? On the other hand, since cutting lot sizes is in keeping with modern (JIT) manufacturing methods, let's try it and see what **MANUPLAN II** reveals.

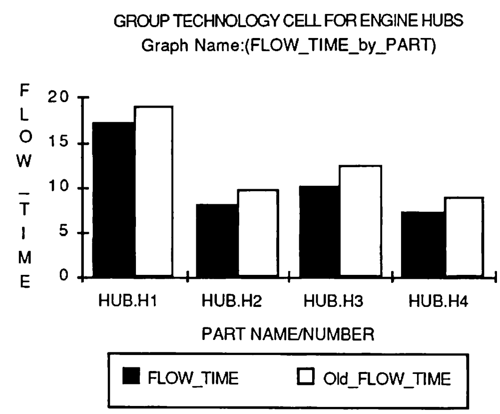

Figure 15. Flow Time by Part "Before" & "After" Second Shift at `DBUR`

Undo the second shift at `DBUR` and then change the lot size:

- Select <MAIN_MENU> <INPUT> <EQUIPMENT> <DATA_ENTRY_&_MOVE>
- Use the arrow keys to move to the `Overtime Factor` for the `DBUR` equipment and type "1" <ENTER>.
- Select <PREV_MENU> <ITEMS_(PARTS)> <DEMAND/LOTSZ> <DATA_ENTRY_&_MOVE>
- Use the arrow keys to move to the `Lot Size` for `HUB.H3`.
- Type "22" <ENTER>

Now let's run the model. We wish to compare the results of cutting the lot size of `HUB.H3` with the original run; therefore, we will overwrite the results of the second shift . Run the program using the overwrite option (see the commands in section 3.3). **MANUPLAN II** returns with an updated item summary (Fig. 16).

* * part ... * number... *	Desired production can be achieved Good Prodn (pieces)	Scrap Prodn (pieces)	WORK IN PROCESS (pieces)	FLOW TIME dock-stok in DAY s
HUB.H1 ...	2000	164.7	187.4	19.0
HUB.H2 ...	1500	140.0	72.6	9.5
HUB.H3 ...	2200	23.2	96.2	10.2
HUB.H4 ...	1500	123.5	65.2	7.2
DONE	TOTAL PIECES:		421.4	

Figure 16. Item Summary Report

Notice that the total WIP is down from 461 pieces to 421 (Refer to Fig. 9). The lead times have also improved. To clearly illustrate the effect of the reduced lot size, we will view the graph.

- Select <GRAPH> <ITEMS_(PARTS)> <FLOW_TIME> <SHOW>

The graph will appear as shown in Fig. 17. The graph clearly shows that the flow times of *all four* parts are reduced by reducing the lot size of HUB.H3. Two reasons for this are: **1)** the waiting time for other pieces in the same lot was reduced (this only affected HUB.H3), **2)** the waiting time for pieces in *other* lots was reduced for the run time of the each HUB.H3 lot (this accounts for the reduction in lead times of the other 3 part types). Note that the second reason does not always occur. If the increase in setup times overloads the system capacity, the queues (and hence, the waiting times) can *increase*. Therefore, a trade-off occurs between a reduction of waiting times due to decreased time to process a lot, and an increase of waiting times due to increased time spent in setups. The mathematical equations in **MANUPLAN** help us by predicting the result of this complex trade off.

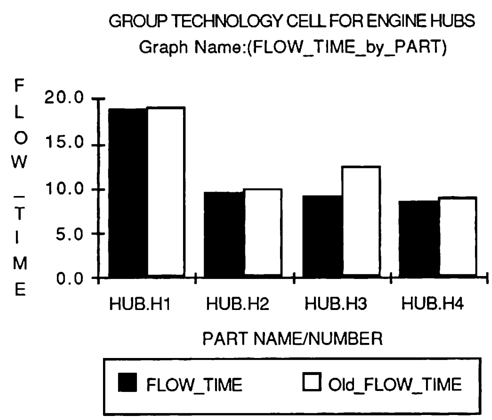

Figure 17. Flow time by Part "Before" and "After" Lot Size Reduction

Since the reduction of lot size appears to be an effective method in reducing lead times, let's reduce the lot size of all four part types:

- Press <ENTER> to return to the menus.
- Select <MAIN_MENU> <INPUT> <ITEMS_(PARTS)> <DEMAND/LOTSZ> <DATA_ENTRY_&_MOVE>
- Using the arrow keys to move between entries, change the lot sizes to 5, 10, 5, 10 respectively. Press <ENTER> after the fourth entry.

Now let's run the model.

- Select <MAIN_MENU> <RUN_MANUPLAN> <OVERWRITE> <QUICK_RUN>
- Type "Q"<ENTER> when prompted.

MANUPLAN II returns with an updated item summary shown in Fig. 18. An equipment group is overutilized if the total utilization exceeds the utilization limit defined: this is identified by a string of asterisks in the output. When any equipment group is overutilized, it is known that the desired production rate cannot be achieved; the item summary report indicates this (Fig. 18).

*	Desired production CANNOT be achieved			
:	:	:	:	:
* DONE	TOTAL PIECES:	0.0		

Figure 18. Item Summary Report

Let us determine which equipment group(s) is(are) overutilized.

- Select <View> <Equipment> <Util_sumry>.

The Equipment Utilization summary should appear as shown in Fig. 19.

The asterisks indicate that the VTLS and the MILL equipment groups are overutilized. Notice that the majority of time for VTLS is spent on setups and the majority of the time for MILL is spent on run time.

*	EQUIPMENT UTILIZATION SUMMARY			
* equip...	% of capacity required			TOTAL
* name...	for	for	for	Utili-
*	SETUP	RUN	REPAIR	zation
BNCH ...	0.0	25.3	1.3	26.6
VTLS ...	54.7	46.6	10.1	111.4**
DBUR ...	0.0	70.0	7.0	77.0
INSP ...	4.5	41.4	9.2	55.2
REWK ...	6.5	23.2	1.5	31.2
MILL ...	25.0	70.4	2.3	97.7**
DRIL ...	11.9	37.2	1.2	50.3
DONE				

Figure 19. Equipment Utilization Summary

This suggests another "what if": What if we speed up the setup time for VTLS and the run time for MILL?

- Select <MAIN_MENU> <INPUT> <EQUIPMENT> <DATA_ENTRY_&_MOVE>
- Use the arrow keys to position the cursor in the speed factor setup column for VTLS. Type "2" (this cuts the setup time for VTLS in half). Do *not* press <ENTER> yet.
- Use the arrow keys to position the cursor in the speed factor run column for MILL. Type "1.2" (this reduces the run time for MILL by approximately 16% [1 – (1÷1.2)]). Now press <ENTER>.
- Select <MAIN_MENU> <RUN_MANUPLAN> <OVERWRITE> <QUICK_RUN>
- Type "Q"<ENTER> when prompted.

MANUPLAN II returns with an updated report (Fig. 20). This report indicates that we have met our objective of a one week lead time. This example illustrates how, in just a short time, rapid modeling has assisted us in finding one way to achieve our objective. Typically, the manufacturing analyst will generate a number of such alternatives and present them to management. The above solution, for example, tells management that they should focus their engineering efforts on reducing the setup times at the VTLS and the process times on the MILL, with specific targets to be achieved in each case. Such feedback, early in a project, helps to focus effort on the key factors and saves wasted effort on non-essential aspects.

*	Desired production CANNOT be achieved			
* part ...	Good	Scrap	WORK IN	FLOW TIME
* number...	Prodn	Prodn	PROCESS	dock-stok
*	(pieces)	(pieces)	(pieces)	in DAY s
HUB.H1 ...	2000	164.7	42.4	4.2
HUB.H2 ...	1500	140.0	31.6	4.2
HUB.H3 ...	2200	23.2	34.6	3.3
HUB.H4 ...	1500	123.5	28.0	3.7
DONE	TOTAL PIECES:		136.6	

Figure 20. Item Summary Report

4. USING AN INTEGRATED TOOLKIT

Modern manufacturing systems can be very complex, embodying many of the latest technologies such as automated material handling, as well as the latest ideas such as just-in-time (JIT). Designing and maintaining such facilities can involve a number of difficult decisions. Simulation software packages are used by industry to assist in making these complex decisions. However, the reality of the manufacturing world is that managers are typically forced to make decisions under severe time pressure. Choices that have to be made in a few days may take weeks to model and analyze on the company's simulation package.

What manufacturing decision-makers would like to have is a package capable of rapid analysis, but one that considers all the complexities of their manufacturing environment. Is there a single modeling package available that can do all of this? No, but there is a close "cousin" that promises significant increases in analysis productivity: rather than being a "universal" modeling tool, it is a toolkit.

This toolkit consists of five modeling and analysis components : spreadsheets, analytical queueing models, simulation generators, simulation programs, and animation methods. An example of such a toolkit consists of the following software packages: **Lotus 1-2-3,**

MANUPLAN, **SIMSTARTER**, **SIMAN** or **SLAMSYSTEM**, and **CINEMA** or **TESS**. This toolkit provides analysis capabilities for a broad range of situations. **Lotus 1-2-3** provides data handling abilities. It enables simple engineering and financial calculations to be performed quickly and easily. **MANUPLAN** allows rough cut manufacturing system models to be built and analysis performed in as little as a couple of hours. **SIMSTARTER** allows almost instant conversion of **MANUPLAN** models into **SIMAN** or **SLAMSYSTEM** simulation code, which allows the addition of more complex features to the model, or allows advanced operations research of the model (e.g. the study of scheduling rules). Finally, **CINEMA** or **TESS** animation provides a greater opportunity to observe and communicate the results of the modeling effort. Using these tools, simple models can be built in under a day, and more complex systems can be modeled in a few days.

At this point, the reader may be concerned about time requirements for using five different packages on one project, particularly if that requires creating a number of different, non-integrated models. However, the suggested toolkit is compatible, allowing the user to build, in effect, a single model. This model can be successively refined at each stage of analysis without duplicate data entry or coding. **Lotus 1-2-3** acts ad the interface for **MANUPLAN** models, which can be directly converted to **SIMAN** or **SLAMSYSTEM** code using **SIMSTARTER**. **CINEMA** or **TESS** animation can be laid out using a CAD-like interface, and then driven directly from **SIMAN** or **SLAMSYSTEM**. This integration allows the broad range of abilities already described, while providing flexibility of choice to the analyst. Use of such a toolkit is described by [Shimizu and Van Zoest, 1988].

5. THE SIMSTARTER SIMULATION GENERATOR

SIMSTARTER is a software package that automatically generates detailed simulation code from an easily specified manufacturing system description. Users of **SIMSTARTER** can get a "head start" on writing detailed simulation programs for their manufacturing systems. When effectively used, **SIMSTARTER** can save weeks or even months of simulation development time. The need for **SIMSTARTER** is understood by considering this situation: A manufacturing engineer or analyst has successfully used **MANUPLAN** to rapidly build a system model and perform high-level "what-if" analysis. **MANUPLAN** enabled the engineer to recommend a "ballpark" decision alternative in a matter of days. Now management wants to proceed further with a detailed simulation analysis. In the past, the engineer (or another analyst) would have needed to build a simulation model from scratch, despite the fact that they had already built a **MANUPLAN** model containing much of the system data – an unnecessary duplication of effort. However, **SIMSTARTER** lets an organization leverage off the effort put into creating the **MANUPLAN** model and data – **SIMSTARTER** *will generate the first simulation model automatically*. This model can then be enhanced with additional details of the manufacturing system. A diagram showing the inputs and outputs of **SIMSTARTER** is depicted in Fig. 21.

5.1 SIMSTARTER Inputs

SIMSTARTER takes as its primary input a standard **MANUPLAN** input data file . The main aim of **SIMSTARTER** is to produce an initial simulation model which duplicates the **MANUPLAN** level of modeling of the system, but in a form that can easily be enhanced with user-defined details. In working with the **MANUPLAN** model the user will have collected a fair amount of data as well as system insight; **SIMSTARTER** begins by automatically putting all this data into appropriate simulation source code. Further, by retaining the general system structure used in **MANUPLAN** it allows the user to continue the thought processes begun in **MANUPLAN**, and build on them, instead of starting from scratch .

It is easy for the user to specify a few other parameter values for **SIMSTARTER** to incorporate directly into the **SIMAN** or **SLAMSYSTEM** program. These include parameters such as Run Length and Number of Replications, which apply only to simulation and were not specified in the **MANUPLAN** model. A new option that is particularly useful is the ability of **SIMSTARTER** to automatically insert material handling code into the simulation, based on a few parameters supplied by the user. In this paper we will describe the use of **SIMSTARTER** without the material handling option.

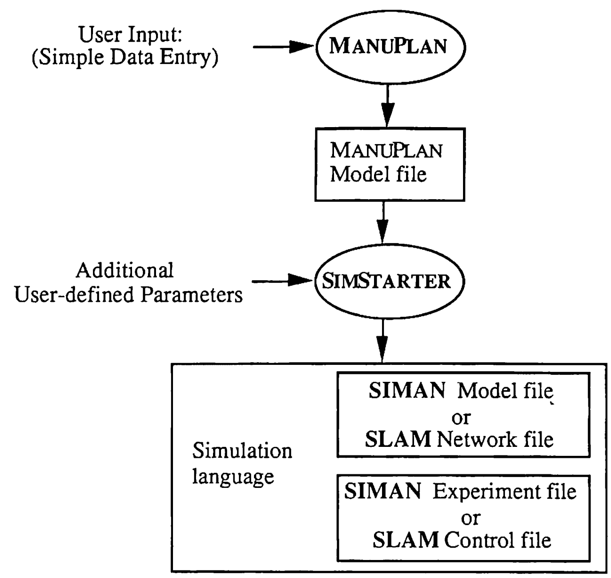

Figure 21. SIMSTARTER Inputs & Outputs

5.2 SIMSTARTER Outputs

The output files produced by **SIMSTARTER** define a completely functional simulation model in **SIMAN** or **SLAMSYSTEM** code that duplicates your **MANUPLAN** level of modeling. Each **SIMAN** or **SLAMSYSTEM** output consists of two files. The first file describes the system using the simulation data structures ("Model" in **SIMAN** and "Network" in **SLAMSYSTEM**), and the second file contains specific formatted parameter inputs ("Experiment" in **SIMAN** and "Control" in **SLAMSYSTEM**). Usually, the analyst will want to add more details and enhancements such as: **1)** Specific scheduling and priority policies, **2)** Labor allocation policies, **3)** Buffer size limits,or **4)** Details of material handling.

5.3 Benefits of SIMSTARTER

The direct benefits of using **SIMSTARTER** include: **1)** Drastic reduction in time to develop and debug initial simulation model, **2)** Error-free overall system configuration, **3)** Reduction in time to create parameter files, **4)** Error-free placement of large amount of initial data and parameters in the files.

Once you start using **SIMSTARTER** you will find indirect, but equally important benefits are: **1)** Standardization of code and file structures, **2)** Portability of code between programmers/analysts, **3)** Analysts spend more time on important details, not on entire system program, **4)** Ability to change to a radically different system option, and quickly generate simulation code for this option, **5)** Smooth and efficient transition from High-Level analysis to Detailed analysis, **6)** Ability to use **MANUPLAN** and **SIMAN** or **SLAMSYSTEM** as complementary modeling tools.

5.4 Structure of Simulation Program Generated by SIMSTARTER

With these aims in mind, the basic structure of the simulation program generated by **SIMSTARTER** is easy to grasp (see Fig. 22). Each "lot" of a part is modeled by an "entity" (as defined in the simulation) which appears at an area called "DOCK". From here it goes to an area denoted "DISPATCH". This does not correspond to a physical area in the plant, but is just an area where the logic for the next operation is carried out. The dispatch logic determines the next operation for the lot and the equipment at which this operation will be carried out. The entity is then routed, to the section of the simulation program that corresponds to that equipment (If material handling is to be inserted, **SIMSTARTER** does so in this section of the logic). After completion of the operation at the equipment, the entity goes back to the DISPATCH area. This sequence is repeated until it is determined by the dispatch logic that all processing for the entity has been completed, in which case it is sent to STOCK, or until (at any intermediate point in the process) the entity is scrapped (sent to SCRAP).

While the overall logic described is simple, the details become more intricate as we get into the syntax of the simulation code. Due to space constraints of this paper, we will simply give an overview of the types of code generated by **SIMSTARTER**. Further details are available in the User Manual. Also, in a previous paper [Suri and Tomsicek, 1988] we described the use of **SIMSTARTER** with **SIMAN/CINEMA**, so in this paper we will provide examples with **SLAMSYSTEM** Network and Control files.

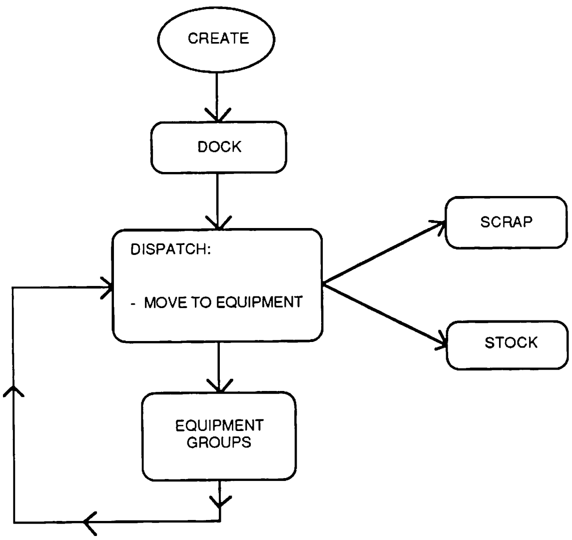

Figure 22. Structure of Simulation Program Generated by **SIMSTARTER**

5.5 Running SIMSTARTER

SIMSTARTER is executed using a batch file supplied with the software package. In order to run **SIMSTARTER** in the MS-DOS environment, type the command:

```
simstart filename
```

This will run the **SIMSTARTER** program using filename.prn as the input file (i.e. the **MANUPLAN** model). In addition, if the file filename.sim exists in this same directory, then it will be used as a second input file. (This file is optional and is used to specify material handling and other details which will not be described here.) In the case of the **SLAMSYSTEM** version, **SIMSTARTER** will produce filename.net for the Network source code, and filename.con for the Control source code. For the **SIMAN** version, **SIMSTARTER** will produce filename.mod and filename.exp as the output files for the Model and Experiment source code. If no error messages were printed by **SIMSTARTER**, you can now compile, link, and run these two source code files in the usual way for your **SLAMSYSTEM** or **SIMAN** installation.

5.6 Modeling each Equipment Group by a Distinct Station

The concept of an *Equipment Group* in **MANUPLAN** is modeled by a distinct *Station* in the simulation models produced by **SIMSTARTER**. An experienced simulation analyst will recognize that it is not necessary to duplicate each station – all the equipment groups in **MANUPLAN** *could* be modeled by one "macro" station model in the simulation. However, the concept here is that the user will most likely add more details to the simulation model, and that different equipment groups may have different characteristics which were not modeled at the **MANUPLAN** level. For example, a machine may have a particular input/output buffer arrangement; or an oven may have a particular loading policy. Hence **SIMSTARTER** separates each equipment group into a unique station, giving the user the ability to modify the code.

Like **MANUPLAN**, **SIMSTARTER** has three special areas that it models: DOCK, STOCK and SCRAP. These are modeled as stations, and are assigned the first three numbers for stations: Station 1 is DOCK, 2 is SCRAP and 3 is STOCK. DOCK is used as the starting point for the routing of entities, while STOCK and SCRAP gather statistics before disposing of entities.

Since **MANUPLAN** does not need detailed specification of probability distributions, **SIMSTARTER** needs to specify these in the simulation code. Basically there are five situations to be considered: arrival of material, service time at equipment, equipment failures, equipment repairs, and branching during routing. Appropriate choices are made for each of these cases, based on logic described in the User Manual. Because of the structured nature of the output files from **SIMSTARTER**, it is easy for the user to change any particular distribution to another one for any part or equipment item. *In fact, the* **SIMSTARTER** *Experiment/Control files are arranged to allow the user simple access to alternative parameters in case another distribution is used.* The user may also wish to modify the logic associated with these probabilities. As an example, the user might want to add *conditional* branching such as "go to the equipment with the shortest queue". Studying the effects of such conditional control is appropriate for the simulation stage of analysis, and is precisely the kind of detail that the user is expected to incorporate after **SIMSTARTER** has generated the basic simulation.

5.7 Description of SIMSTARTER Network File

This section gives samples of the **SLAMSYSTEM** Network file produced for the GTDEMO model used above. At the beginning of the Network file, **SIMSTARTER** generates the following RESOURCE blocks (dots indicate omitted lines):

```
RESOURCE/    1,DOCK    (1),         1;
RESOURCE/    2,STOK    (1),         2;
RESOURCE/    3,SCRP    (1),         3;
RESOURCE/    4,BNCH    (    3),     4;
RESOURCE/    5,VTLS    (    5),     5;
    :          :  :          :      :
RESOURCE/    10,DRIL   (    2),    10;
```

Here DOCK, STOCK and SCRAP are not actively used as resources, but are included for two reasons. First, the user may wish to enhance these sections of the Model to include procedures not detailed in **MANUPLAN** – in that case these resources can be used. Second, this keeps the station numbers and resource numbers the same. Resources 4 through 10 correspond to the Equipment Groups, along with the "number in the group", from the **MANUPLAN** model.

Before proceeding, we will show the EQUIVALENCE statement generated by **SIMSTARTER** for the Control file. This creates code that is easier to understand.

```
EQUIVALENCE /ATRIB(1),PARTTYPE/
             ATRIB(2),LOTSIZE/
             ATRIB(3),BASEOP/
             ATRIB(4),OP/
             ATRIB(5),TEMP/
             ATRIB(6),TEMP2/
                  :
             ATRIB(10),WORK1;
```

Now we can show the creation of lots for HUB.H1 :

```
P001     CREATE,GAMMA(167.6,11.1),0,8,,1;
         ASSIGN,PARTTYPE =        1;
         ASSIGN,LOTSIZE   =ARRAY(3,PARTTYPE);
         ASSIGN,BASEOP    =ARRAY(4,PARTTYPE);
         ASSIGN,OP        =BASEOP
         ACT/001,,,DISP;
```

The first three statements place data in attributes. After this, the entity attribute BASEOP is set to point to an ARRAY that contains operations data for this part. (The details of how these data are stored will not be discussed here.) The last statement routes the entity immediately to the DISPATCH area. A similar set of blocks is written for each Part type.

5.8 STATION Models for each Equipment Group

SIMSTARTER creates separate station models for each equipment group in the **MANUPLAN** data. The first such model for our example is:

```
;    EQUIPMENT NAME
;    BNCH
A004        AWAIT(4),BNCH/1,,1;;
            ASSIGN, TEMP    = ARRAY(OP,1);
            ASSIGN, TEMP2   = ARRAY(OP,2);
            ASSIGN,WORK1=GAMMA(TEMP,TEMP2,1);
            ACT/0041,WORK1;  S+R AT BNCH;
            ASSIGN,TEMP = WORK1/ ARRAY(1,4);
            ASSIGN,TEMP2 = NPSSN(TEMP,1);B004        GOON;
            ACT,,TEMP2 .LE. 0,D004;
            ACT,,TEMP2 .GT. 0,C004;
C004        ASSIGN, TEMP    = ARRAY(2,    4);
            ASSIGN, WORK1 = EXPON(TEMP,1);
            ACT/0042,WORK1;
            ASSIGN, TEMP2 = TEMP2-1;
            ACT/0043,,,B004;    # BKDWNs BNCH     ;
D004        GOON;
E004        FREE,BNCH/1;            RELEASE BNCH
            ACT/0044,,,DISPAT;  LOTS AT BNCH;    BRANCH TO
```

The first line reminds us of the **MANUPLAN** name BNCH. Next follows logic for waiting till a resource is available, calculating the length of time the entity needs for the setup and run operation at this equipment, equipment failures that may occur while this entity is at this equipment, and repair times if necessary. Finally, the entity releases the resource and goes back to the DISPATCH area for the next step in its route.

The model for STOCK (the station where "good" entities end their routing) is different, and its main function is to collect statistics and dispose of the entity. Similarly, SCRAP is the destination for "bad" entities. Appropriate statistics and counts are collected in each case (the model for STOCK is shown below).

```
STOK        GOON;
            ACT,,PARTTYPE .EQ.     1,H001;
            ACT,,PARTTYPE .EQ.     2,H002;
H001        COLCT(    1),TNOW-ARRVLTM,FLOW TIME  HUB.H1;
            COLCT(    3),LOTSIZE,GOOD PRODUCTION HUB.H1;
            TERM;
H002        COLCT(    2),TNOW-ARRVLTM,FLOW TIME  HUB.H2;
            COLCT(    5),LOTSIZE,GOOD PRODUCTION HUB.H2;
            TERM;
```

5.9 Description of SIMSTARTER Control File

This section gives samples of the **SLAMSYSTEM** Control file produced by **SIMSTARTER**. The Control file begins with the usual GEN and LIMITS blocks with comments added by **SIMSTARTER** for readability. Typically the longest set of statements in the Control file are to do with the ARRAYS, because they contain most of the data from the **MANUPLAN** model. There are several subsections of this statement, but here we will just show an excerpt. ARRAY 1 contains the MTTF value for station m in the m^{th} location. Dummy values are inserted for DOCK, STOCK and SCRAP (the first three stations):

```
     MEAN TIME TO FAILURE FOR EQUIPMENT
 ARRAY (1,    10)/1,1,1,
                 9600.0,
                 9600.0,
                 4800.0,
                    :
```

Similarly, structured arrays are used to store data for lot sizes, setup and run times, and other routing information. This completes the samples of **SLAMSYSTEM** code that we will show in this tutorial.

6. CONCLUSION

Engineers and analysts can increase their productivity by using **MANUPLAN** for rapid high-level analysis and **SIMSTARTER** for getting to the details. In many cases **MANUPLAN** will provide enough insight for a decision to be made – often within a few days of starting the analysis project. If it is necessary to proceed to simulation for more detailed evaluation, then by using **SIMSTARTER** the user can concentrate on specific details of interest, and let **SIMSTARTER** take care of generating the overall simulation program. The drudgery of generating a large simulation program is removed, and users can devote their skills to the important aspects of the details in the simulation code. Rapid response to manufacturing questions can lead to an improved operation and more competitive manufacturing strategy.

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