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KANBAN SIMULATOR USING SIMAN AND LOTUS 1-2-3

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ABSTRACT

The simulator documented in this paper was developed in response to a contest challenge for the first SIMAN User's Meeting. The problem posed was to develop and collect statistics from a simple production line simulation consisting of a receiving station, three machines in series and a shipping station. Both a traditional "Push" and a "Kanban" or "Pull" mode of production control were to be simulated with an ability to switch between the two modes. It was desired to compare the two production modes based on work-in-process (WIP) levels and part flow-time. No specific data was provided for the simulation model. The model presented in this paper won first prize in the contest.

1 APPROACH

This paper documents the approach taken to solve the problem posed by the contest rules. First the SIMAN model structure is introduced to support the Push and Pull production modes. Next the corresponding SIMAN experiment frames are presented. Then some simulation results are reviewed based on analysis using the SIMAN output processor. Finally a Lotus 1-2-3 worksheet based simulator approach is presented.

2 SIMAN NETWORK MODEL STRUCTURE

The contest rules implied that one set of SIMAN network model code should support both the Push and Pull production modes. Figures 1 and 2 illustrate generalized flowcharts for the two production modes. Table 1 lists the corresponding SIMAN network model.

2.1 Push Model

The Push mode illustrated in Figure 1 represents the tradition queueing model approach. Incoming orders are sequentially processed through the three machine and one shipping station. No explicit station is provided for order arrival processing. The part throughput time represents the total processing time plus any queueing at at the machine stations. This model includes no parts inventory except for the work-in-process.

2.2 Pull Model

Figure 2 illustrates the Pull mode Kanban modeling approach. Completed parts from each machine are placed in a Kanban inventory or queue named PARTS. This Kanban inventory must initially be loaded with the desired inventories. Incoming orders are entered in a queue named CARDS. Incoming orders are matched with available Kanban inventory. If a match is possible the order is immediately filled by

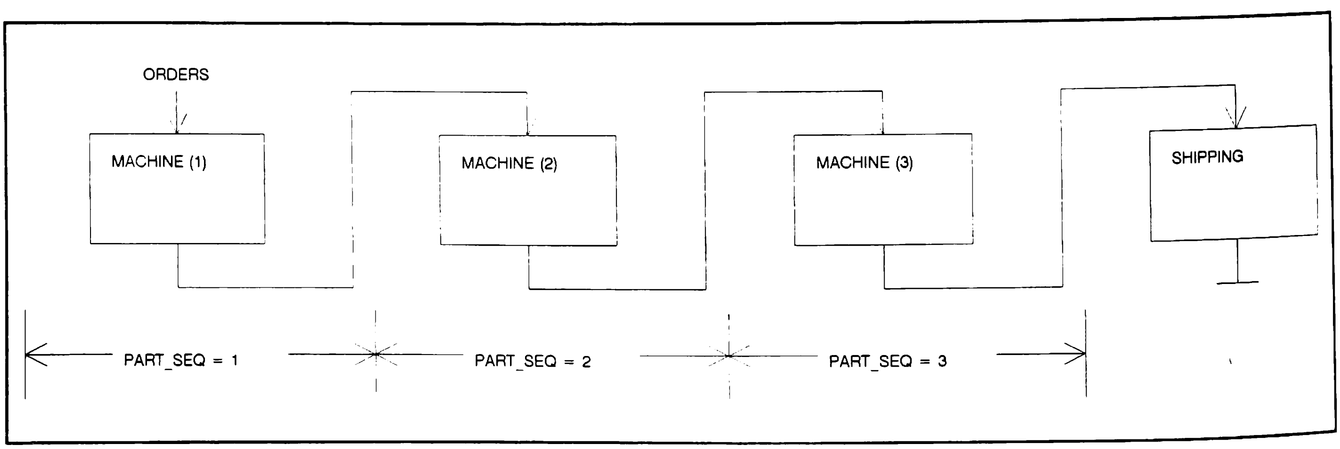


Figure 1: *Three Machine Push Mode Flow Diagram*

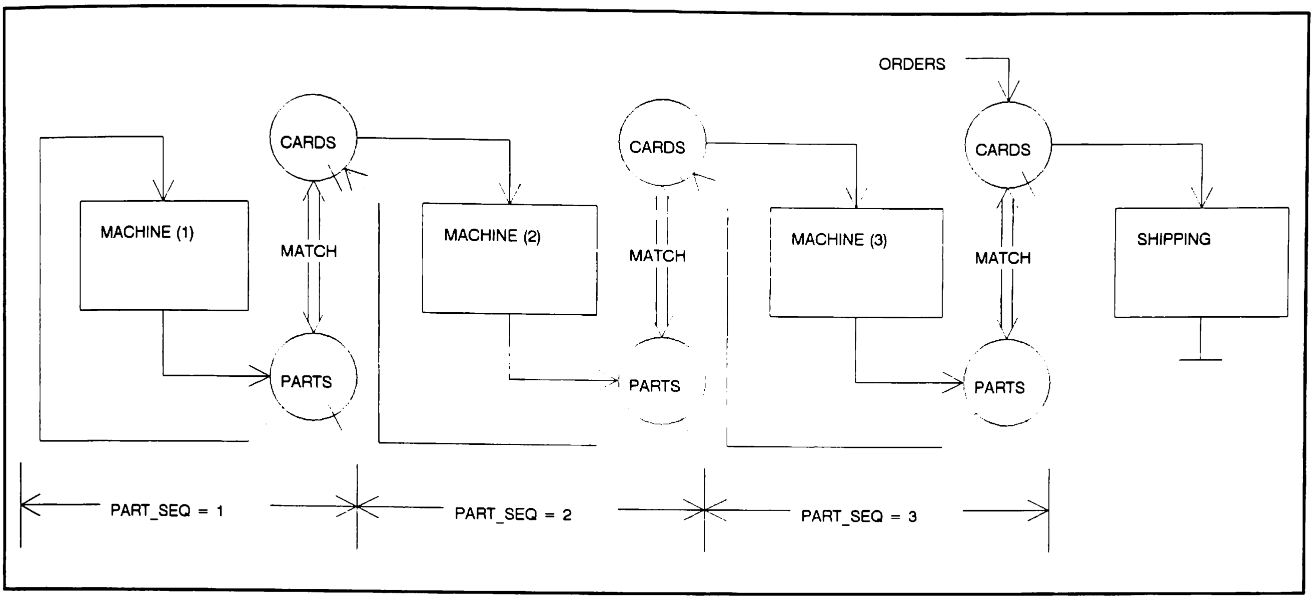


Figure 2: *Three Machine Pull Mode Flow Diagram*

transferring the part to the shipping station. This transaction triggers an order for the part processed by machine station number 3. Again a match between queues CARDS and PARTS is attempted. When a match becomes possible, the part is sent to machine station number 3 for processing and an order is sent to station number 2. This cycle is repeated backward through the manufacturing system. No match is required for machine station number 1 because a supply of incoming raw materials is assumed to be available.

2.3 Network Model Code

The network model code presented in Table 1 is used for both production modes. Block number 1 generates all incoming orders using an exponential inter-arrival time with mean, INTER_ARRIVAL_TIME. Random number generator stream MAX_MACHINES + 1 is exclusively used to generate arrivals. The order arrival time is recorded in attribute ORDER_TIME and the number of order arrivals is counted in block number 2. Block number 3 controls the flow of parts. Variable TYPE indicates the model type; TYPE = 0 implies the Push mode, while TYPE = 1 indicates the Pull mode. Incoming Push mode parts are sent directly to the block labeled MAKE_IT to be processed on MACHINE (1). Incoming Pull mode orders are sent to the block labeled FIRST to be marked with the high machine number, LAST_MACHINE. All other Pull mode parts are sent to the block labeled PART to be matched with orders.

Block number 4 routes parts to the machine processing or shipping stations. Block numbers 5 through 10 represent the machine processing station. This includes updating the part sequence number as attribute PART_SEQ, controlling resource MACHINE (M), and holding the part for its processing time. For the three machine contest problem, the station number or M, ranges from 1 to 3. The machine processing time follows the normal distribution with mean, TIME (M); coefficient of variation, COEFF_VAR; and random number generator stream, M. The ten available SIMAN random number generator streams can support independent random number generation for order arrivals and for up to nine machines. Independent random number generator stream assignment assures a minimum variance comparisons of the two production modes.

Block numbers 11 and 12 represent the shipping station where the part throughput time is accumulated in by tallying the time interval since the order arrival time as recorded in attribute ORDER_TIME.

The remaining network blocks control the Pull mode logic. Block numbers 13, 15, and 16 control the matching of orders and available Kanban inventories. Incoming Pull mode orders are sent to block number 14, FIRST, to be marked with the highest machine number or the value of variable LAST_MACHINE which equals 3 for the contest model. From here the order is placed in queue CARDS. Pull mode parts are placed in queue PARTS.

The matching of orders and available Kanban inventories by block number 16 is the heart of the Pull

Table 1: *Kanban Simulator SIMAN IV Network Model, KANBAN.MOD*

```
1          CREATE:  EXPO (INTER_ARRIVAL_TIME,
                      MAX_MACHINES + 1);            Generate Orders
2          COUNT:   1, 1:!                          Count Order Arrivals
                    MARK (ORDER_TIME);              Record the Order Time

3 WHICH    BRANCH, 1:!                              Check System Type
                    IF, TYPE .EQ. 0, MAKE_IT:!      Push System
                    IF, M .EQ. 0, FIRST:!           1st Kanban
                    ELSE, PART;!                    Other Kanbans

4 MAKE_IT  ROUTE:   , PART_SEQ + 1;                 Make next Part

5          STATION, 1 - MAX_MACHINES:               Machine Processing Station
6          ASSIGN:  PART_SEQ = M;
7          QUEUE,   M;
8          SEIZE:   MACHINE (M);
9          DELAY:   TIME (M) * NORM (1.0, COEFF_VAR, M);
10         RELEASE: MACHINE (M): NEXT (WHICH);

11         STATION, SHIPPING;                       Shipping Station
12         TALLY:   1, INT (ORDER_TIME): DISPOSE;   Ship Complete Part

13 PART    QUEUE,   PARTS: DETACH;                  Put in Kanban Inventory

14 FIRST   ASSIGN:  PART_SEQ = LAST_MACHINE;        Ship from final Kanban
15 CARD    QUEUE,   CARDS: DETACH;                  Backlog Order Cards

16         MATCH,   PART_SEQ:!                      Match Kanban Needs
                    CARD, MAKE_IT:!                 Make Current Part
                    PART, REQUEST;                  Request Prior Part

17 REQUEST ASSIGN:  PART_SEQ = PART_SEQ - 1;        Get Prior Part
18         BRANCH, 1:!
                    IF, PART_SEQ .EQ. 0, MAKE_IT:!  Make First Part
                    ELSE, CARD;                     Send Order to Make Part
```

model. The matching is based on the value of attribute PART_SEQ, the part sequence number. Figure 2 illustrates the range of definition for the various values of attribute PART_SEQ. When a match is found, the part is sent ahead to the next station and an order is transmitted back to the prior operation to request a replacement. Hence the basic Pull mode control structure is executed.

Block numbers 17 and 18 control the feedback of orders to the prior machine station. Special processing is required for machine number 1 because an unlimited supply of raw materials has been assumed.

3 SIMAN EXPERIMENT FRAMES

Table 2 lists the SIMAN experiment frame for the Pull mode version of the Kanban simulator. The Push mode experiment frame is similar except for a substitution of the word PUSH for PULL and two changes. The value of variable TYPE is set to 0 for the Push mode or 1 for the Pull mode. The Push mode version of the experiment frame does not need an ARRIVALS element.

4 SIMULATOR RESULTS

The objective of the Kanban simulator is to compare the two production modes based on work-in-process levels and part flow-times. The work-in-process levels were tracked using a SIMAN discrete statistic and

Table 2: *Kanban Simulator Pull Mode SIMAN IV Experiment Frame, PULL.EXP*

```
BEGIN, NO:   3/24/1992 SYSTEM EXAMPLE
PROJECT, PULL SYSTEM EXAMPLE, Productive Systems, 3/24/1992;
ATTRIBUTES: PART_SEQ:
            ORDER_TIME;
VARIABLES:  COEFF_VAR, 0.1:
            INTER_ARRIVAL_TIME, 2:
            LAST_MACHINE, 3:
            TIME (3), 1.7, 1.8, 1.9:
            TYPE, 1;
QUEUES:     3: CARDS: PARTS;
ARRIVALS:   QUEUE (PARTS),, 6, 1:
            QUEUE (PARTS),, 8, 2:
            QUEUE (PARTS),, 10, 3;
RESOURCES:  1 - 3, MACHINE, 1;
STATIONS:   3, MAX_MACHINES:
            SHIPPING;
COUNTERS:   Number of Arriving Orders;
TALLIES:    PULL Mode Order Processing Time, "PULL_OPT.DAT";
DSTAT:      NR(1) +NQ(1) +NR(2) +NQ(2) +NR(3) +NQ(3), PULL Mode WIP,
            "PULL_WIP.DAT";
REPLICATE,  10, 0, 1000, NO, YES, 0;
```

saved on SIMAN output file, PULL_WIP.DAT or PUSH_WIP.DAT. The part flow-times are recorded as each part is shipped by using a SIMAN tally statistic and saved on a SIMAN output file, PULL_OPT.DAT or PUSH_OPT.DAT. Replication summary statistics are available in the standard SIMAN report file, PULL.OUT or PUSH.OUT.

4.1 Work-In-Process Levels

The Work-In-Process (WIP) levels were tracked using a SIMAN discrete statistic and saved on SIMAN output files, PULL_WIP.DAT and PUSH_WIP.DAT. It was desired to determine if the WIP inventory differed between the two modes. In a three machine system a WIP greater than three indicates that parts are waiting for machine processing. The Pull mode automatically restricts the WIP to the initial Kanban inventory level or 24 parts for the example case. The Pull mode will constantly maintain a total inventory of 24 parts, a portion of which will be WIP. Thus, the Pull mode will only reduce the total inventory if the average Push mode WIP inventory is greater than 24.

It was desired to directly compare the WIP levels between the two modes. Figure 3 illustrates the SIMAN output processor's Interval command plot window for a Filter interval of 100 time units. The non-overlapping confidence intervals indicate a difference in WIP levels between modes. The SIMAN output processor's Oneway comparison confirmed this observation. The SIMAN output processor's Sdinterval command was executed on the WIP DSTAT output files. It was found that the Push mode WIP standard deviation, 5.44, was slightly smaller than the 5.94 observed for the Pull mode.

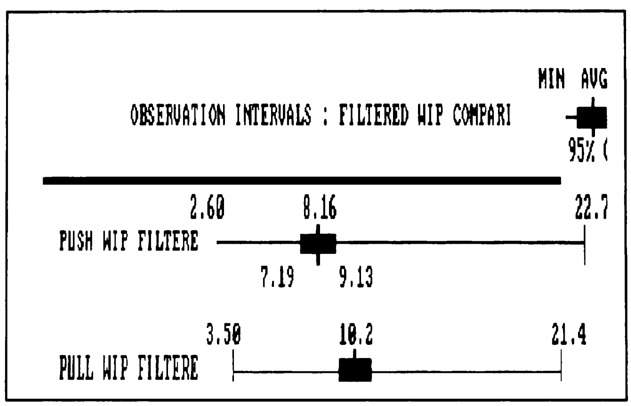


Figure 3: *Kanban Simulator Mean WIP Level Observation Intervals, Filter Interval = 100 Time Units*

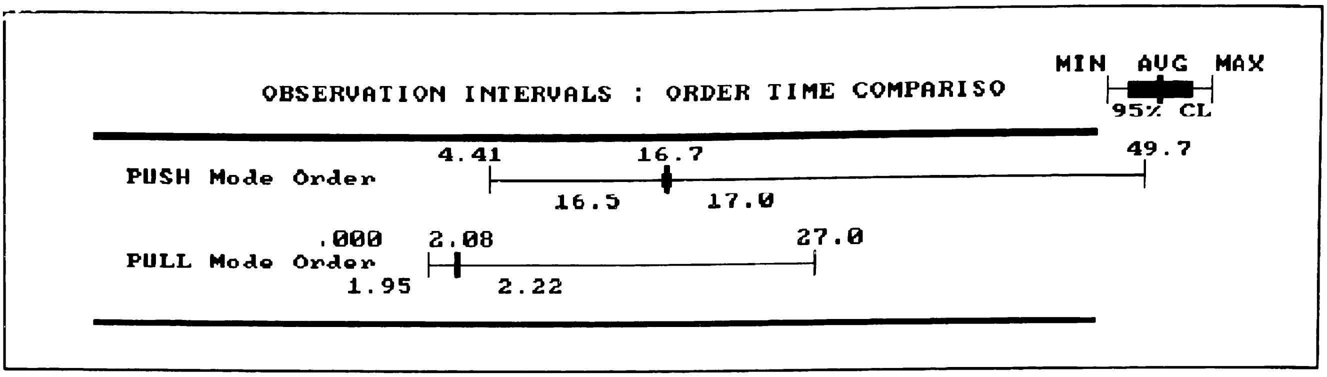


Figure 4: *Kanban Simulator Mean Order Processing Times Observation Intervals*

4.2 Part Flow-Times

The part flow-times or Order Processing Times were tracked at each part shipping event by using a SIMAN tally statistic and saved on a SIMAN output files, PULL_OPT.DAT and PUSH_OPT.DAT. It was desired to determine if the Order Processing Times differed between the two modes.

It was desired to directly compare the Order Processing Time levels between the two modes. Figure 4 illustrates the SIMAN output processor's Interval command plot window. Pull mode Order Processing Time varied from 0.0 to 27.0 time units with an average of 2.08. Push mode Order Processing Time varied from 4.41 to 49.7 time units with an average of 16.7. Clearly the Pull mode had a significantly lower Order Processing Time. The SIMAN output processor's Oneway comparison confirmed this observation.

4.3 Analysis Conclusions

The above analysis based on the simulator results using the example data set indicates the following:

The Pull mode requires more total inventory than the Push mode.

The Pull mode fills orders much more quickly than the Push mode.

The best mode would have to selected based on the tradeoff between inventory holding and order delay costs. Further simulation experimentation might find cases which clearly favors one mode over the other. The next section develops an effective means to conduct the required experimentation.

5 LOTUS 1-2-3 BASED SIMULATOR

The user of the Kanban simulator described above could test alternative modes by modifying the SIMAN experiment frame listed in Table 2. The only required change to switch from the Pull mode to the Push mode is to switch the value of the VARIABLE TYPE from 1 to 0. Other changes can be made in the order arrival and part processing times by changing the VARIABLE initial values. The initial Kanban inventories can be changed in the ARRIVALS element. The number of processing steps or machines can be changed by altering the QUEUES, RESOURCES, and STATIONS elements. Adjustments to the VARIABLES and ARRIVALS elements.

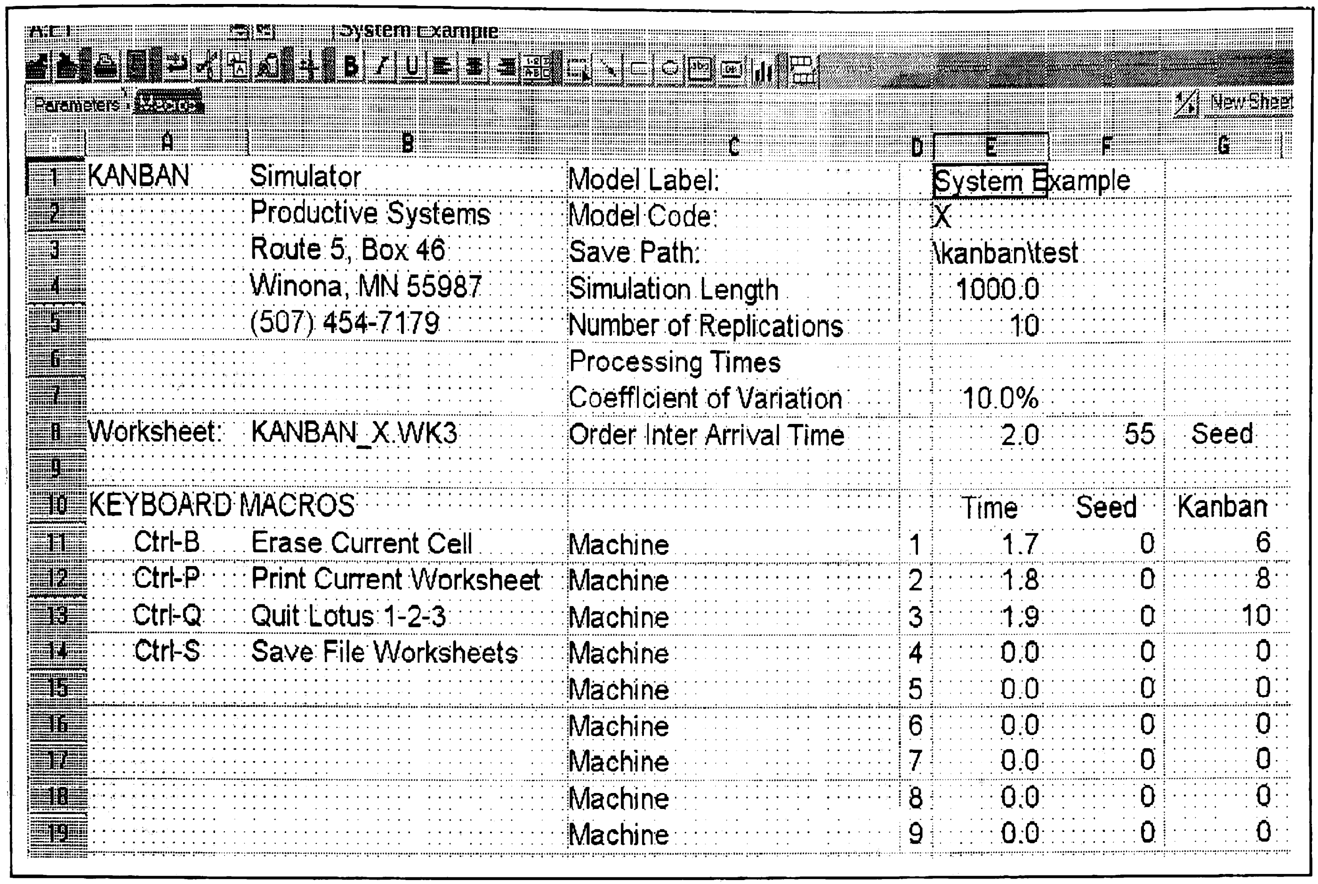
5.1 Lotus 1-2-3 Model Worksheet

Many beginning simulation users do not have the time or desire to modify the SIMAN experiment frame in order to conduct the required experimentation. As an alternative the author has developed many simulators which use Lotus 1-2-3 as the user data input medium. This format is known or easily learned by a wide range of potential simulation users.

Figure 5 illustrates the Kanban simulator Lotus 1-2-3 worksheet which contains all the required simulation control information. Cell Range E1..F8 identifies the system being simulated and its general structure. Cell Range E11..G13 range defines the individual processing machines and their characteristics including initial Kanban inventory levels. The Kanban simulator supports up to nine processing machines. The additional machines are simply defined in Cell Range E14..G19. The simulator allows the user to set the random number generator seed values. The zero values illustrated in Figure 5 invoke the SIMAN defaults. Positive worksheet values are used directly as the seeds. Negative worksheet values cause the simulator to generate the seeds based on the time of day.

5.2 Kanban Simulator Information Flow

After the Kanban simulator user has updated the worksheet based model, the model is saved by press-



	A	B	C	D	E	F	G
1	KANBAN	Simulator	Model Label:		System Example		
2		Productive Systems	Model Code:		X		
3		Route 5, Box 46	Save Path:		\kanban\test		
4		Winona, MN 55987	Simulation Length		1000.0		
5		(507) 454-7179	Number of Replications		10		
6			Processing Times				
7			Coefficient of Variation		10.0%		
8	Worksheet:	KANBAN_X.WK3	Order Inter Arrival Time		2.0	55	Seed
9							
10	KEYBOARD MACROS				Time	Seed	Kanban
11	Ctrl-B	Erase Current Cell	Machine	1	1.7	0	6
12	Ctrl-P	Print Current Worksheet	Machine	2	1.8	0	8
13	Ctrl-Q	Quit Lotus 1-2-3	Machine	3	1.9	0	10
14	Ctrl-S	Save File Worksheets	Machine	4	0.0	0	0
15			Machine	5	0.0	0	0
16			Machine	6	0.0	0	0
17			Machine	7	0.0	0	0
18			Machine	8	0.0	0	0
19			Machine	9	0.0	0	0

Figure 5: *Kanban Simulator Lotus 1-2-3 Worksheet*

ing the **Alt-S** keys. The worksheet can be printed by pressing the **Alt-P** keys. The **Alt-Q** keys are pressed to exit from Lotus 1-2-3. From this point the simulation is automatically executed. Figure 6 illustrates the general flow of Kanban simulator information. The worksheet model file KANBAN.WK3 is converted to a DIF format file, KANBAN0A.DIF. This is read by the Model Preparation Program which generates a report file, KANBPREP.RPT.

Data file KANBPREP.PRN is used to provide a model selection menu as Lotus 1-2-3 is entered. Batch command file KANBSAVE.BAT is used to save the simulator results in the MS-DOS path specified in worksheet cell E3. SIMAN experiment files PUSH.EXP and PULL.EXP (Table 2) are used to drive the simulation of the two alternative modes. These files are linked with the network model, KANBAN.MOD, (Table 1) and used to automatically execute both mode alternatives.

6 POTENTIAL KANBAN SIMULATOR EXTENSIONS

The Kanban simulator presented in this paper has been designed to be easily extended to incorporate new features as they are required. The simulator has been modified to handle multiple parts, each with different routing and processing times. These changes are incorporated into a model worksheet similiar to Figure 5. The author can supply a diskette which contains the model, model preparation program, and worksheet illustrated in this paper.

REFERENCES

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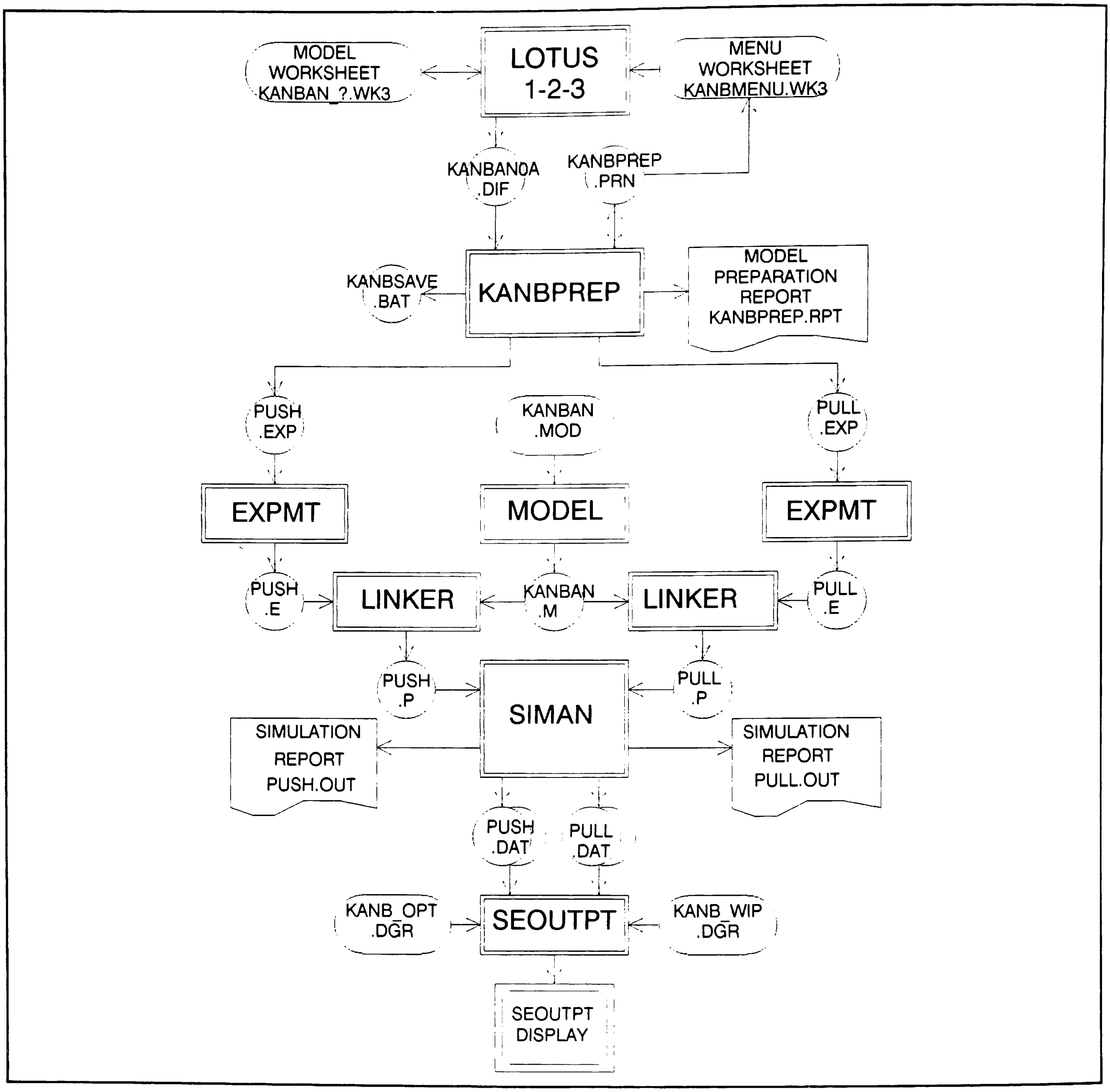

Figure 6: *Kanban Simulator Information Flow Diagram*

AUTHOR BIOGRAPHY

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