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ALSS II: THE ADVANCED ASSEMBLY LINE SYSTEM SIMULATOR

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ABSTRACT

This paper introduces ALSS II, the Advanced Assembly Line System Simulator, a special purpose simulator used to model and analyze assembly line systems. The ALSS II model constructs are introduced. An assembly line system example is modeled and selected results are presented.

1. INTRODUCTION

Productive Systems developed ALSS II to quickly model and accurately simulate a broad class of assembly line systems. ALSS II is based on Systems Modeling Corporation's SIMAN IV/Cinema® simulation language. Using the interactive ALSS II model development and data analysis programs, the Manufacturing Engineer or Production Manager can model and analyze complex assembly line systems, such as, automotive body shops and modular paint shops.

The ALSS II user skips the tedious simulation language details and concentrate on the critical logic and timing which makes their assembly system function. A five symbol diagram is used to graphically model the assembly line system (Figure 7). The graphical model is entered into the computer using an interactive model development program. ALSS II examines the model structure to eliminate common errors.

The ALSS II simulation is performed by SIMAN IV. The ALSS II user may choose to view a Cinema animation of the simulation. ALSS II tracks the movement of assemblies and special tooling through the model. ALSS II randomly simulates machine downtimes, routings, assembly line cycle times, and decision attribute changes. ALSS II halts assembly line cycling for scheduled breaks and problems caused by machine downtimes, lack of jobs or tooling, or space to place jobs or tooling.

ALSS II collects utilization statistics for each model symbol. ALSS II reports results on a Simulation Run basis. The length of each Simulation Run and the number of Simulation Runs are user options. ALSS II automatically conducts statistical analysis of its results. The user can elect to allow ALSS II to determine the number of Simulation Runs using its Expert System Termination Analysis procedure (Figure 8).

ALSS II generates data files for analysis using an interactive data analysis program. The data analysis program features both statistical (Figures 9 and 11) and graphical (Figures 10 and 12) displays. The performance of up to three alternative assembly line system configurations can be graphically and statistically compared. This comparison assures that statistically valid conclusions are drawn from the ALSS II results.

2. ALSS II OBJECTIVES

The objective of ALSS II is to test alternative assembly line system configurations. Those configuration alternatives include:

- Assembly line cycle rates
- Path selection rules
- Accumulator sizes and speeds
- Machine reliability and maintenance policies
- Number of carriers and other special tooling
- Break timing plans

3. ALSS II TEMPORARY ENTITIES

ALSS II tracks the movement of Jobs and Carriers through the assembly line system using temporary entities. These temporary entities are created, moved, and disposed of during the ALSS II simulation. ALSS II can simulate up to 1000 in-process temporary entities. No symbol is defined for the ALSS II temporary entities.

Jobs represent the objects being assembled. All jobs carry a Decision Attribute which can be changed at each Operation Entity. The Decision Attribute can be used to select Transfer Entities and to control job related timing. The throughput time of each job is tracked by ALSS II.

Carriers represent the transporters or special tooling used in the assembly process. The number of carriers in the assembly line system can be restricted to reflect system operating conditions.

4. ALSS II MODEL PERMANENT ENTITIES

ALSS II models the assembly line system using five permanent entities: Assembly Line, Operation, Transfer, Return, and Infinite Capacity Source/Sink. Figures 1 through 5 illustrate the five permanent entity symbols designed by Productive Systems to construct the ALSS II Assembly Line System Network Diagram (Figure 7). After the Network Diagram has been constructed, the model information in entered into the computer using the interactive model development program. ALSS II features context sensitive help screens to guide the user.

4.1 ALSS II Assembly Line Entities

Assembly line system conveyers which run at the same rate or cycle time and do not involve accumulation can be modeled as an ALSS II Assembly Line Entity. The ALSS II Assembly Line Entity is a series of connected Operation Entities. ALSS II supports up to 100 Assembly Line Entities. The general characteristics of the ALSS II Assembly Line Entities are:

Composed of one or more sequentially numbered Operation Entities
Fixed or Variable Cycle Rate
Two Conveyor Types: Linked or Free
Two Conveyor Modes: Cycle or Wait
Three Break Types: None, Halting, or Strip-Out
Break Starting Time Offset
Can be initially filled with Jobs
Can force spaces between Jobs

Figure 1 illustrates the rectangle symbol definer by Productive Systems for the ALSS II Assembly Line Entity. Assembly Line Entity number 7 cycles once each minute or 60 times per hour. The simulated cycle time follows the Normal Distribution with a 10% Coefficient of Variation. The Free Conveyor Type allows a segment of the assembly line to operate even when other segments are blocked. The Wait Conveyor Mode stops cycling whenever no work can take place. The Assembly Line Entity halts for all breaks ten minutes after the rest of the assembly line system.

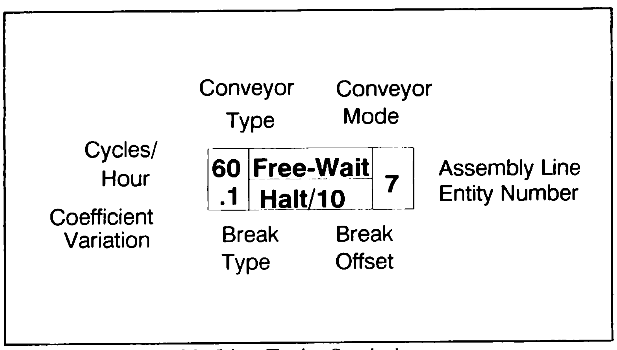

Figure 1. Assembly Line Entity Symbol

4.2 ALSS II Operation Entities

Assembly line system workstations which are subject to machine downtimes and process Jobs and Carriers can be modeled as an ALSS II Operation Entity. ALSS II supports up to 200 Operation Entities. The general characteristics of the ALSS II Operation Entities are:

A sequentially numbered set of Operation Entities form an Assembly Line Entity
The Operation Entity processing time is determined by the Assembly Line Cycle Time
Can contain one or more Jobs
Can be initially filled with Jobs
Can contain any number of Machines subject to downtimes
May be fed Jobs by one or more Transfer Entities
May feed Jobs into one or more Transfer Entities
May be fed Carriers by one Return Entity
May feed Carriers into one Return Entity
Can Batch or Bunch Jobs
Can set or alter the Job Decision Attribute
Can alter the Job Cinema Animation Attribute

Figure 2 illustrates the circle symbol defined by Productive Systems for the Operation Entity. Operation Entity number 4 can hold six jobs and initially contains two jobs. Each entering job generates a batch of three identical jobs. The Operation Entity contains one machine with an uptime probability of 95%. All jobs originating at the Operation Entity are assigned a Decision Attribute of one. Fifty percent of the jobs passing

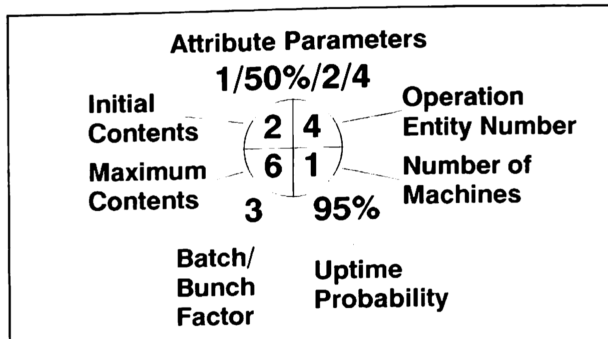

Figure 2. Operation Entity Symbol

through the Operation Entity have their Decision Attribute incremented by two. All jobs passing through the Operation Entity have their Cinema Animation Attribute changed to four.

4.3 ALSS II Transfer Entities

Assembly line system accumulators which hold a variable number of jobs for at least a fixed minimum time can be modeled as an ALSS II Transfer. All job flows between ALSS II Assembly Line Entities must be modeled using ALSS II Transfer Entities. ALSS II supports up to 100 Transfer Entities. The general characteristics of the ALSS II Transfer Entities are:

Connect Assembly Line Entities Via Operation Entities
Can Accumulate Jobs
Minimum Job Travel Time
Job Content Constraints
Minimum and Maximum Total Job Contents
Maximum Available Job Contents
Can be initially filled with Jobs
Supports a variety of Selection Rules
Not subject to downtime or breaks
Can alter the Job Cinema Animation Attribute

Figure 3 illustrates the square symbol defined by Productive Systems for the Transfer Entity. Transfer Entity number 3 can hold up to 25 jobs and initially contains five jobs. Each entering job must spend at least 4.5 minutes traveling through the Transfer Entity. Fifty percent of the jobs in the FROM Operation Entity are selected at random to enter this Transfer Entity. All jobs in the Transfer Entity are placed in the INTO Operation Entity.

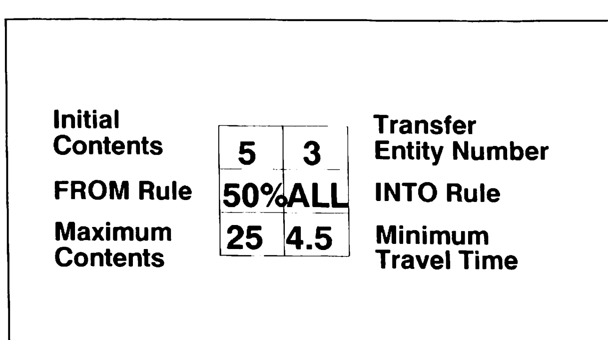

Figure 3. Transfer Entity Symbol

4.4 ALSS II Return Entities

Assembly line system elements which involve a fixed number of tools or carriers can be modeled as an ALSS II Return Entity. The ALSS II Return Entity can also be used to control the number of jobs in a portion of the ALSS II model. ALSS II supports up to 50 Return Entities. The general characteristics of the ALSS II Return Entities are:

- Connect Assembly Line Entities Via Operation Entities
- Can Accumulate Carriers
- Minimum Carrier Travel Time
- Carrier Content Constraints
    - Minimum and Maximum Total Carrier Contents
    - Maximum Available Carrier Contents
- Can be initially filled with Carriers
- Not subject to downtime or breaks
- Can alter the Carrier Cinema Animation Attribute

Figure 4 illustrates the octagon symbol defined by Productive Systems for the Return Entity. Return Entity number 8 can hold up to 30 Carriers and initially contains 15 Carriers. Each entering Carrier must spend at least 9.0 minutes traveling through the Return Entity.

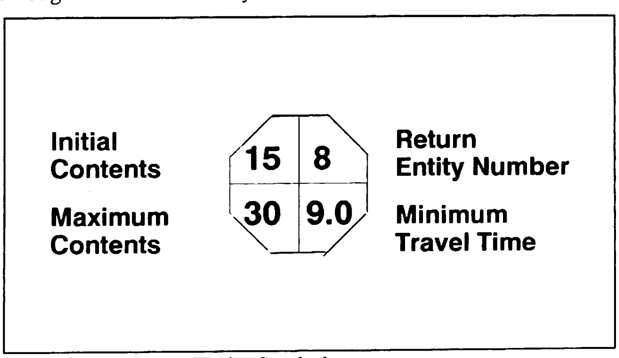

Figure 4. Return Entity Symbol

4.5 ALSS II Infinite Capacity Source/Sink Entities

Figure 5 illustrates the cloud symbol defined by Productive Systems for the Infinite Capacity Source/Sink Entity. No explicit data are required to define the Infinite Capacity Source/Sink Entities. Rather they are automatically included by ALSS II whenever an Assembly Line Entity does not have a feeding Transfer Entity for its first Operation Entity or a removal Transfer Entity for its last Operation Entity. No limit exists for the number of Infinite Capacity Source/Sink Entities.

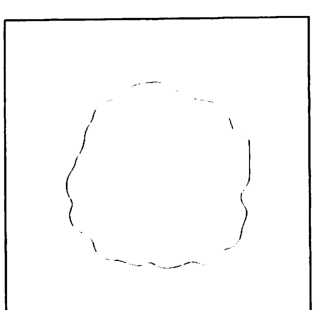

Figure 5. Infinite Capacity Source Sink/Entity Symbol

5. ALSS II EXAMPLE

Figure 6 illustrates the general flow of assemblies or jobs through the example assembly line system. The primary assembly flow starts at the Initial Assembly Line A, continues through either Partial Assembly Line B or C, and concludes with Final Assembly Line D. Shortly after jobs enter Initial Assembly Line A they are loaded onto a carrier. Those carriers are removed near the end of Final Assembly Line D and returned to the Initial Assembly Line A. The total number of carriers in the assembly line system is limited. Subassembly jobs are produced on Subassembly Line E and merged into the primary jobs on Initial Assembly Line A. A portion of the assembly is removed on Initial Assembly Line A, further processed on Process Part Subassembly Line F, and merged back into the primary jobs on Final Assembly Line D. Jobs found to be defective on Final Assembly Line D are routed on to Rework Assembly Line G for rework. The reworked jobs are reintroduced into Final Assembly Line D.

The square boxes in Figure 6 represent accumulators which transfer the jobs between the assembly lines. The hexagon box in Figure 6 represents the return which transports the empty carriers from assembly line D and to assembly line A.

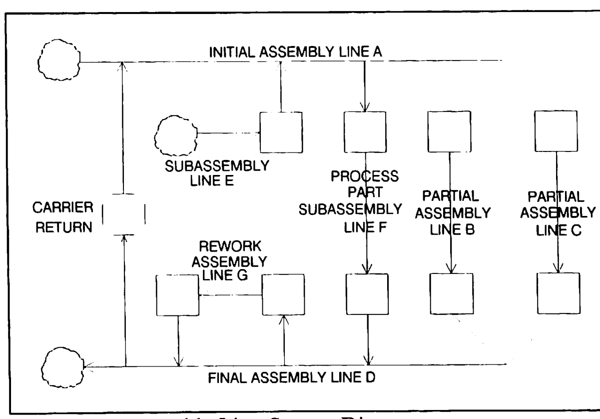

Figure 6. Assembly Line System Diagram

Several assembly line system design options are posed by this example:

1. At what rate should each assembly line operate?
2. What should be the capacities of the accumulators between the assembly lines?
3. How many carriers should be placed in the assembly systems?

If all the workstations or operations in the assembly line system work at a constant rate, questions 1 and 2 can be addressed directly. Because assembly lines A, D, E, and F process all jobs, they should all operate at the same rate. Because assembly lines B and C share the workload from assembly line A, they should operate at one-half the assembly line A rate. Assembly line G should operate at the assembly line D rate times the rework probability. Because the only source of variability in the example assembly line system is the selection of jobs for rework, the only required accumulation is at the beginning of the Rework Assembly Line G. All the other accumulators need only be large enough to allow the jobs to travel through them in an orderly manner.

Determining the number of carriers is a separate problem. Ideally the number of carriers should be as large as the number of possible jobs in the assembly line system. Due to the carrier cost constraints, it is sometimes necessary to operate the assembly line system with fewer carriers.

If the workstations or operations are subject to downtimes, the problem of setting the assembly line rates and accumulator sizes becomes more complex. This is the point at which ALSS II displays its analysis capabilities. For this paper, only some initial starting values will be presented. Several alternatives will be suggested based on the simulation results.

5.1 ALSS II Network Diagram

Figure 7 illustrates the ALSS II Network Diagram for the six assembly lines introduced in Figure 6. Assembly Line Entities A, D, E, and F operate at a fixed rate of 60 cycles per hour. Assembly Line Entities B and C operate at 30 cycles per hour, with the cycle times being sampled from a normal distribution with a mean of 2.0 minutes and standard deviation of 0.2 minutes. Assembly Line Entity G operates at a fixed rate of 15 cycles per hour. Each of the Assembly Line Entity is defined in terms of Operation Entities. Assembly Line Entities A and D are composed of five Operation Entities. Assembly Line Entities E, F, and G are composed of two Operation Entities. Assembly Line Entities B and C are composed of a single Operation Entity.

Seven of the 18 Operation Entities include machines which are subject to downtimes. The expected uptime percent is shown to lower right of the Operation Entity Symbol. The capacity of each ALSS II entity is shown in the lower left corner of each symbol. All ALSS II Operation Entity have a capacity of one job, except for Operation Entity numbers 13 and 14, which have a capacity of 4 and 2 respectively. The ALSS II Transfer Entity capacities and travel times are indicated in Figure 7. Initially all ALSS II Operation and Transfer Entities are empty. The single ALSS II Return Entity began the simulation with 20 carriers. These carriers will be consumed as jobs are processed by Operation Entity number 2 and replenished by Operation Entity number 11.

5.2 ALSS II Results

A variety of output reports and graphs are either automatically or optionally generated by the ALSS II. Only a few of those results can be presented in this paper. The example ALSS II model was executed for a series of 8-hour simulation runs. Statistical data was collected on an hourly basis. Since the assembly line system was initial void of jobs, an 8-hour preliminary simulation was executed to fill the system prior to the start of statistic collection.

Figure 8 illustrates the final screen display generated by the main simulation program. This display indicates that the simulation run terminated itself after six 8-hour runs or 48 hours because the estimated production rate for Key Operation Entity 11-REMOVE CARRIER ASSEMBLY LINE D, had a 95% confidence interval of 38.3 to 45.5 jobs per hour. This confidence interval is

$$\frac{45.5-38.3}{2\times41.9}=8.5\ \%$$

of its estimated mean value of 41.9 jobs per hour. Figure 8 indicates that an additional 12, 8-hour runs would be required to reduce the 95% confidence interval to within 5% of the es-

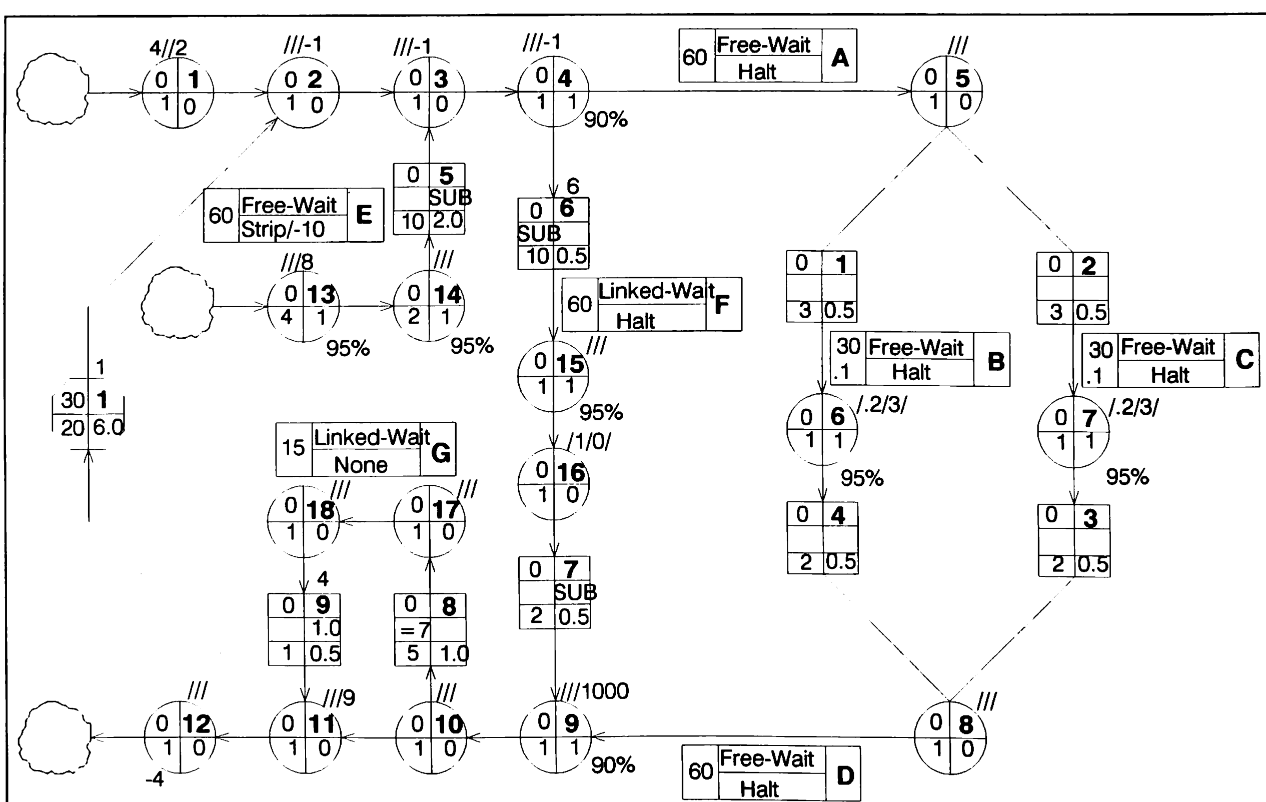

Figure 7. Example ALSS II Network Diagram

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ALSS II Expert System Simulation Termination Analysis predicated on the
 estimated production rate for Key Operation Entity 11-REMOVE CARRIER ASSEMBLY LINE D

        Based on    6 Periods of    8.0 hours each or   48.0 total hours

                                 Jobs per Hour
        Mean                         41.9
        Standard Deviation          3.486          Required Additional Periods
                                                      5%       10%       20%
    90% Confidence Interval      39.1    44.7          5         0         0
    95% Confidence Interval      38.3    45.5         12         0         0
    99% Confidence Interval      36.3    47.5         37         5         0

ALSS II Simulation Terminated at time     48.0 Hours
 Due to sufficient accuracy.
 The hourly production rate for Key Operation Entity 11-REMOVE CARRIER ASSEMBLY LINE D
 Estimated to within plus or minus  8.5% <  10%
 With a 95% Confidence Level
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Figure 8. Final Screen Display Generated by the Main Simulation

timated mean value. An additional 37, 8-hour runs would be required to reduce the 99% confidence interval to within 5% of the estimated mean value. ALSS II automatically generates and prints a summary report at the conclusion of the simulation. That summary report indicates the current status and production statistics for each ALSS II entity.

Figure 9 illustrates the Data Analysis Program System Display for the example model. The upper right portion of the System Display indicates the simulated production by period for each Assembly Line. Assembly Line A INITIAL ASSEMBLY produces 34 jobs the first period, 44 the next, and so on. Data are displayed for 10 periods. Additional periods can be viewed by using the cursor keys. The data can also be grouped by shift or run. The upper left portion of the System Display indicates statistics for the entire simulation run. Assembly Line A INITIAL ASSEMBLY averaged of 41.9 jobs per hour. The hourly production ranged from 19 to 54 jobs.

The lower portion of the System Display indicates statistics related to the highlighted Assembly Line and Analysis Period, in this case Assembly Line A INITIAL ASSEMBLY and Analysis Period 1. Thirty-four of the 60 Assembly Line A INITIAL ASSEMBLY cycles produced a completed job. Thus,

$$\frac{34}{60}=56.7\ \%$$

of the cycles generated a complete job. The number of null cycles is calculated by

$$60-34=26$$

A total of 31 assembly line cycle problems were observed. Four problems were related to a filled Transfers, seven problems were related to a lack of a carrier in the Return, and 20 problems were related to a down machine. Notice that while Assembly Line A INITIAL ASSEMBLY had a total of 31 as-

System Display ALSSPARX WSC 1990 EXAMPLE   Run Date: 7/19/199

		Jobs/Period			** ALSS II Analysis Period 60 Mins *									
ASSEMBLY LINES	CYCLES	MEAN	MIN	MAX	1	2	3	4	5	6	7	8	9	1
1-A INITIAL ASSEMBL	60	41.9	19	54	34	44	41	46	48	28	42	23	39	5
2-B PARTIAL ASSEMBL	19	20.9	9	27	20	20	21	23	24	14	22	10	20	2
3-C PARTIAL ASSEMBL	23	21.0	9	26	20	20	21	23	22	16	22	12	19	2
4-D FINAL ASSEMBLY	60	10.5	4	13	11	8	10	12	11	8	11	6	9	1
5-E MAKE SUBASSEMBL	39	41.9	17	53	34	43	42	46	47	31	41	23	39	5
6-F PROCESS PART AS	42	42.0	18	54	43	39	41	48	44	31	43	24	38	4
7-G REWORK ASSEMBLY	4	8.65	2	14	2	2	9	10	9	8	9	7	5	1

ASSEMBLY LINE: 1-A INITIAL ASSEMBLY LINE   Time 1.00 Hours
Assembly Line Status: Contents 3 of 5 Jobs   1 of 1 Machine(s) Dow
Assembly Line Conveyor Type: Free   Mode: Wait

Number Line Cycles	Number of Jobs	Jobs per Cycle	Number Null Cycles	Total Count	Transfer Filled	Transfer Empty	Return Filled	Return Empty	Mac Dow
				********** ASSEMBLY LINE PROBLEM COUNT **********					
60	34	56.7%	26	31	4	0	0	7	2

F1{Help Display} Esc{Selection Menu} Enter{Detail Display} Threshold = 10%

Figure 9. Data Analysis Program System Display

sembly line cycle problems only 26 cycles failed to produce a job. This was possible because part of the assembly line can function while other parts are blocked by problems.

Figure 10 illustrates a graph of the number of jobs per period produced by Assembly Line A INITIAL ASSEMBLY. Figure 10 illustrates the same information displayed in the fourth row of Figure 9. The number produced ranged from 19 to 54 with an average of 41.9 jobs per hour. The tic marks on the vertical axis of Figure 10 indicate the mean and the 95% confidence interval for the hourly production rate. The 95% confidence interval is 40.0 to 43.8 jobs per hour. These statistics are based observations collected each simulation period or hour.

Figure 11 illustrates the Data Analysis Program Detail Display for Assembly Line A INITIAL ASSEMBLY of the example model. The upper right portion of the Detail Display indicates the simulated production by period for each of the five Operation Entities which comprise Assembly Line A. Operation 2-LOAD CARRIER produced 32 jobs the first period, 46 the next, and so on. The upper left portion of the Detail Display indicates statistics for the entire simulation run. All Operations on Assembly Line A INITIAL ASSEMBLY produced an average of 41.9 jobs per hour.

The lower portion of the Detail Display indicates statistics related to the highlighted Operation and Analysis Period, here Operation 2-LOAD CARRIER and Analysis Period 1. This Operation currently contains one job and had an average contents of 0.860 jobs. Operation 2-LOAD CARRIER is fed carriers by Return Entity number 1. At simulation time 1.00 hours, the Return Entity contained 15 available and 3 enroute carriers. Over the one-hour period it had a mean available content of 3.00 carriers and is empty 63% of the time. The return was

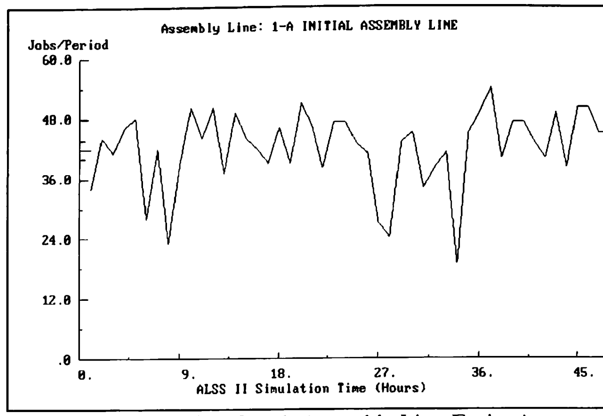

Figure 10. Production Graph Assembly Line Entity A

never filled to its capacity of 30 carriers. The return never forced an assembly line to wait for a carrier. However, as seen in Figure 9 Assembly Line A INITIAL ASSEMBLY lacked a carrier 20 during the one hour period. That lack would not prevent the assembly line from cycling, but would prevent a job from entering Operation Entity number 2. This causes blank spaces to be moved along the assembly line.

Figure 12 graphically illustrates the contents of the Return over the 48-hour simulation period. The three curves are normally displayed in three different colors to differentiate between them. The top curve represents Maximum Total Return contents observed each simulation period. The Maximum Total Return contents varied from 7 to 18 with a mean of about 10. The middle curve represents Mean Available Return contents, which varied from 0 to 9 with a mean of about 1.5. The bottom

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Detail Display  ASSEMBLY LINE: 1-A INITIAL ASSEMBLY LINE    Run Date:  7/19/1991
                        MEAN  Jobs/Period   ** ALSS II Analysis Period    60 Mins *
OPERATION ENTITY      UPTIME MEAN MIN MAX      1   2   3   4   5   6   7   8   9  1
1-START ASSEMBLY L           41.9  16  54  :  32  46  39  48  45  31  41  23  39  5
2-LOAD CARRIER ASS           41.9  17  54  :  32  46  39  48  46  30  41  23  40  5
3-PROCESS ASSEMBLY           41.9  17  54  :  32  46  40  47  47  29  41  23  40  5
4-REMOVE SUBASSEMB  87.6%    41.9  18  54  :  33  45  41  46  47  29  41  23  40  5
5-UNLOAD ASSEMBLY            41.9  19  54  :  34  44  41  46  48  28  42  23  39  5







OPERATION:  2-LOAD CARRIER ASSEMBLY   ALSS II Simulation Time    1.00 Hours
Operation Entity Current Job Contents:     1 of  1  Mean Job Contents:    .860
                    Operation Machines Not Subject to Downtimes
            **Rule*** **Other** Cap- Current  Mean Min Max Out Empt Full Lines
RESOURCE   #  FROM INTO Oper Line city Avl Enr  Avl  Avl Tot put Time Time Wait
Leave Tran NONE for this Operation Entity
Enter Tran NONE for this Operation Entity
Leave Retn  1           11   4   30  15   3  3.00   0  18  32  63%   0%  .000
Enter Retn NONE for this Operation Entity
  {Help Display}     {Selection Menu}      {System Display}                  10%
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Figure 11. Data Analysis Program Detail Display Assembly Line Entity A INITIAL ASSEMBLY LINE

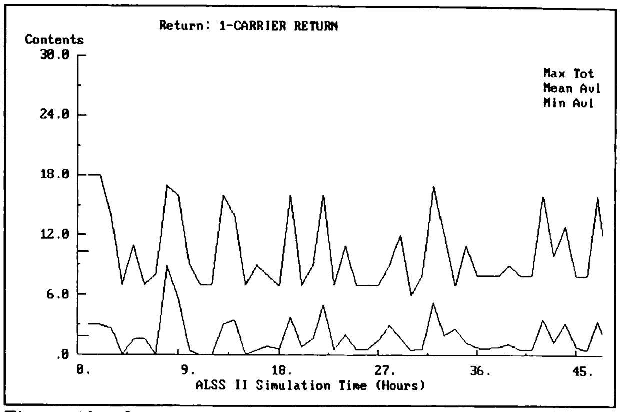

Figure 12. Contents Graph Carrier Return Entity

curve, which in Figure 12 corresponds to the X axis, represents Minimum Available Return contents and is always zero. This last curve indicates that additional carriers might improve the performance of the assembly system.

6. ALSS II AS A DESIGN TOOL

The purpose of ALSS II is to determine how to improve the performance of the assembly line system. One critical element in the example model is the number of Return carriers. Initially the assembly line system is loaded with 20 carriers. Figure 11 indicated that the Return Entity is empty for 63% of the first one-hour period. Figure 9 indicated that during period one, Assembly Line A INITIAL ASSEMBLY lack a carrier on 20 occasions. It appears the increasing the number of carriers should improve the system performance. This hypothesis was test by repeating the original example after increasing the number of carriers from 20 to 25 and 30. Table 1 indicates the result of the ALSS II experimentation.

Table 1. ALSS II Experimentation results

Number of Carriers in Return Entity	Assembly Line A INITIAL ASSEMBLY Production	Mean Available Return Contents	Return Time Empty
20	41.9	1.83	41%
25	42.7	3.35	31%
30	43.3	7.59	0%

ALSS II uses the Student t test to determine if the results of the alternative runs produce statistically significant production estimates. As the number of carriers increased from 20 to 25 the hourly production rate for Assembly Line A INITIAL ASSEMBLY is found to be to be significantly different at the 95% confidence level. As the number of carriers increased from 20 to 30 the hourly production rate is found to be to be significantly different at the 99% confidence level. As the number of carriers increased from 25 to 30 the hourly production rate is found to be to be significantly different at the 90% confidence level. Because the return entity was never empty in the 30 carrier case, it is not likely that 30 carriers would be required. A complete cost analysis and additional ALSS II simulation runs would be required to determine the most cost effective number of carriers in the return entity. The influence of machine downtime, transfer sizes, and assembly line cycle time should also be tested using ALSS II.

7. CONCLUDING REMARKS

ALSS II has proven to be an effective tool for rapidly analyzing complex assembly line systems. Being SIMAN IV based, if a particular system cannot adequately modeled using ALSS II, a more detailed model can be developed in SIMAN IV. ALSS II is made available by Productive Systems at no additional charge to its consulting clients. Productive Systems provides extensive training in the use of ALSS II.

REFERENCES

Pegden, C.D. (1982), *Introduction to SIMAN*, Systems Modeling Corporation, State College, PA.

Systems Modeling Corporation (1989), *SIMAN IV Reference Guide*, Systems Modeling Corporation, Sewickley, PA.