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SOLVING LOGISTICS AND TRANSPORTATION PROBLEMS IN A JOB SHOP

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ABSTRACT

A discrete event simulation model was developed to study the flow of material and product in a shop floor. It uses real time data available from a job shop sole dedicated to non-commercial contracts and as such deals with very seasonal demand. The objective of this model is to provide the shop with a decision support tool that will assist in evaluating the movement of products throughout the shop. The simulation will be useful in assessing the length of queues formed at each shop as well as in pointing out bottlenecks. Actual operational and flow data are utilized in developing the model. The simulation is implemented using the Arena software (Kelton 1997). In effect, the model is to be used for a better understanding of operation of the shop floor and better utilization of all the available resources.

1 INTRODUCTION

The unique aspects of this simulation model are in the unique operation of the shop. The shop consists of two floors. Products are categorized into repair categories and depending on which of the four categories they fall under, they may require one or several operations. These operations are scattered throughout the shop on both floors. The workstations may be construed as work cells and modeled following FMC (Farahmand 2000). No specific flow patterns are set. Products are inspected and work schedule is assigned based on the outcome of the inspection.

2 PROCESS FLOW

The process to be modeled consists of 3 distinct stages.

- Part Arrivals
- Processing Stages
- Part Departures.

2.1 Part Arrivals

The product arrives from national inventory location and is sent to the shop.

The product is brought in to the shop loaded on a wagon. The Products are categorized as to whether they are “line support” i.e. disassembled from a helicopter onsite and sent for repairs or sent from the central inventory warehouse packed inside a container or “can”. The products are unloaded, placed on the dolly and brought inside the shop.

2.2 Processing Stages

The processing for each type of product goes through the following stages depending on their work category.

1. *Electrical Inspection*
   This is the stage where electrical inspection is carried out to determine the type of repairs necessary. This stage will essentially categorize the repair.
   - Cat I: means OK. The products in this category need minimal work.
   - Cat II: refers to products that need to be inspected for leaks and might require minor repair work. They require about 2 weeks lead-time.
   - Cat III: refers to products that require full-blown repair. They normally require about 3 weeks lead-time.
   - Cat IV: refers to products that are beyond repair and need to be completely rebuilt.

2. *Pre Shop Analysis (PSA)*
   In this process the products are 100% inspected and are categorized as either CAT I type or CAT IV type. It is here that the routing to various processes throughout the shop is determined.

3. *Non Destructive Testing (NDT)*
This stage is necessary for checking whether there is moisture in the product. This is done by taking an X-ray of the product. On detection, the products are sent to the bonding room for removal and are again brought to the NDT for inspection. This stage is purely inspection. The different types of inspections possible at NDT include
    - X-ray
    - Eddy Current Testing and
    - FPI (Florescent Penetration Inspection).

4. *Red BIM Inspection*
*This inspection is reserved for CAT II and CAT III prod*ucts only. The process includes the use of a detection compound oxygen system to discover leaks in products, normally at the spar or at the OB (outboard) seal.

5. *Sanding*
There are 2 types of sanding process. Laser Paint Stripping is one of them and is preferred more often. The other is manual sanding. The manual sanding is faster and requires less lead-time but the laser generates a better quality and more consistent stripping across the product surface.

6. *Cuff Installation & Repair*
Cuffs help in attaching the products to the rotors and they have bolts that are custom fit to each cuff. The machinists at the product shop use micrometer to determine the dimensions of the cuff holes. Cuffs are replaced after the required hours have expired. Cuffs are also replaced if the cuffs or the bolts are cracked or damaged.

7. *Bonding*
Bonding refers to repair work on the skin surface, honeycomb structure extracting moisture as any other repair to the body of the product. This process includes the following stages.
    - Extract moisture
    - Bonding repairs
    - De-Ice sheath repair
    - Lightning wire mesh repair
    - Skin/plug patch repair
    - Curing process.

8. *Repair tip caps*
In this stage repairs for the tip caps take place. Tip caps are the covers for the far (outside) end of the product. The cap covers the static weights and the outboard seal.

9. *Paint the product*
In this process the products are painted. This includes both the tail and rotor products.

10. *Balance the product*
This is a two-step process.
    - Static
    - Dynamic

    Only when the static balancing has been successfully carried out can the products go for dynamic balancing in a whirl tower.

11. *Can the products*
The finishes NICP products are canned and are kept ready to be sent back to the national inventory.

2.3 Part Departures

1. *DLA:*
This is the final stage where the canned products are sent to when all repairs have been successfully carried out.

2. *SAFER:*
The parts that are defective and cannot be repaired are sent here. These categories of products are normally referred to as CAT IV products. It also includes those products that fail the Red BIM test.

3 BUILDING THE MODEL

This simulation was done using Arena, by Rockwell software limited (formerly Systems Modeling). The whole process has been divided into three steps or modules to allow for easier understanding of the concept. Step I constitute the data modules, step II refer to the logic modules and finally step III refers to the animation.

3.1 Animation Model

The animation model shows the flow of parts and material throughout the shop. For this purpose a 2-D CAD drawing of the shop floor was imported into arena. AutoCAD was used to provide the static background for the animation. A runtime image for the first floor of the shop model is shown in Figure 1. The run time image for the second floor of the blade shop is shown in Figure 2. The output of the simulation was broadly categorized into three major categories-tally variables, discrete change variables, and counters.

4 SIMULATION RESULTS

This section has been divided into three cases based on the probability of arrival for the four blade categories of products viz. Cat I, CAT II, CAT III, and CAT IV. The corre-

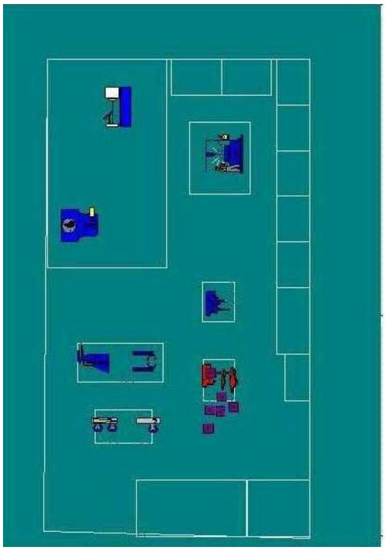

Figure 1: First Floor Layout Of The Shop

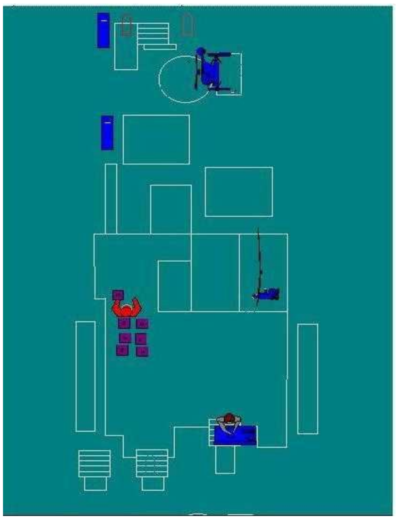

Figure 2: Second Floor Layout Of Shop

sponding values have been entered in the assign node of the Arrive module. They include:

1. Equal distribution of CAT II and CAT III parts i.e., 50% of CAT II and 50% of CAT III.
2. Flooding the Arrive node with 100 % CAT II parts i.e., probability of CAT II equals 1.0 and a probability of zero for the rest.
3. Flooding the Arrive node with 100 % CAT III parts i.e., is probability of CAT III equals 1.0 and a probability of zero for the rest.

The simulation is run for 2 weeks (40 Hours a week) and the following parameters were identified as performance parameters and tabulated for each of the above-mentioned scenarios.

- % Utilization for each Resource
- WIP inventory at the end of each run
- Average Biweekly Throughput.

The bottleneck operations were identified and then eliminated by either increasing the capacity at that operation or reducing cycle time. This process was continued until the first two bottlenecks were eliminated.

4.1 Simulation Run

The simulation is run for a week (2400min). Care was taken by including only steady state period. Output parameters were calculated only after the warm up period was over. The warm up period was determined by running the system for a series of replications and plotting the cycle times for all the four categories as well as the WIP in each of the three above-mentioned cases.

4.1.1 Case I: Simulation of a the Job Shop (50% Cat II & 50% Cat III parts)

Replication ended at time : 4800 min
Statistics were cleared at time : 2100 min
Statistics accumulated for time : 2700 min

Initially all CAT II parts were introduced into the system. The warm-up or the steady state period was determined. Figure 3 shows the plot of The CAT II cycle time against the simulation run time of 42000 minutes. The plot has been shown for only the first 3000 minutes of each replication. From the graph it can be seen that the system stabilizes at around a 1900 minutes.

Figure 4 also shows that the system stabilizes around 2100 minutes for CAT III parts. Figure 3 is a plot of the average WIP against the simulation run time (42000 min). The results are only shown for the first 3000 minutes, even though the model was simulated for 42000 minutes. From this plot, the time at which the system stabilizes is determined to be around 2100 minutes.

Once the warm up period was determined, the model was then run for a period of two weeks with a warm up period of 2100 minutes. The data is tabulated in Tables 1, 2, 3, and 4. Table 1 provides a list of the Tally variables. Tables 2 and 3 show all Discrete-change variables, and finally Table 4 keeps a tab on the counters utilization for the top 3 resources plotted against the simulation run time.

From Table 2 data, the repair process was identified to be the bottleneck with maximum utilization. This is also confirmed from Figure 5, which is a plot of the percent utilization vs run time.

The graph is plotted only for the first 2400 minutes of the simulation, for the sake of clarity. The effect of increasing the capacity could be seen from Figure 6, which shows the percent utilization for the repair blade facility to decrease from its original value. The corresponding changes in cycle times, percent utilization, queue length, and WIP are all recorded in Tables 1, 2, 3, and 4.

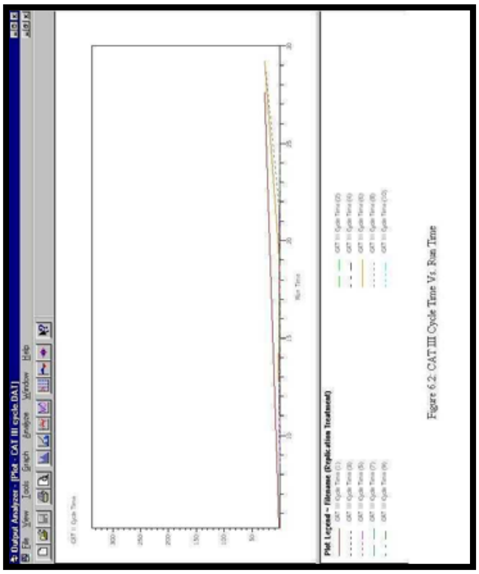

Figure 3: CAT II Cycle Time Vs Run Time

Figure 4: CAT III Cycle Time Vs Run Time

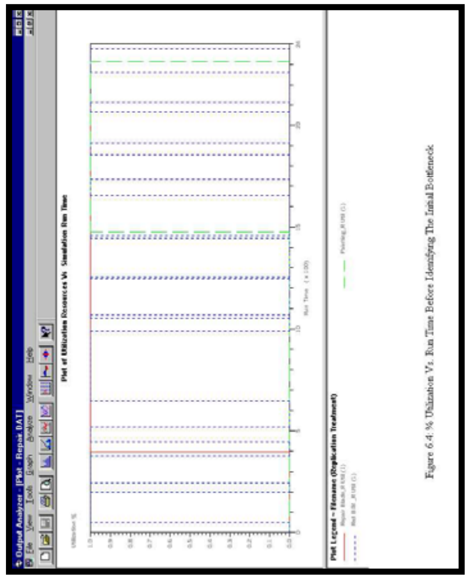

Figure 5: Utilization Vs Run Time

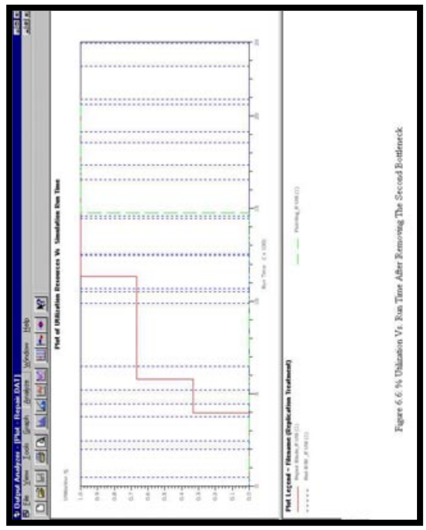

Figure 6: Utilization Vs Run time After Second Bottleneck

Table 1: Cycle Time

Identifier	**Average**		
(Cycle Times)	**Initial Run**	**Bottleneck 1**	**Bottleneck 2**
CAT I	--	--	--
CAT II	.0000	693.18	763.23
CAT III	3565.0	1922.00	1701.60
CAT IV	--	--	--

Table 2: Percentage Utilization

Identifier	Average		
Resource Utilization	**!st run**	**Bottleneck 1**	**Bottleneck II**
PSA	.00000	.00000	.00000
Electrical Inspection	.10860	.10702	.10830
Red BIM	.60003	.34132	.16530
Cuff Test	.13125	.04312	.08670
Laser pain	.24303	.12979	.15042
Sanding	.00000	.00000	.48521
Bonding	.00000	.00000	.00000
Painting	.91359	.88092	1.0000
Repair Blade	1.00000	1.00000	.99168
Tip Cap	.10079	.30530	.19932
Static Balance	.03412	.03109	.08148
Whirl Tower	.17795	.46002	.35432

Table 3: Queue Length

Identifier	Average		
# In Queue	**Initial Run**	**Bottleneck1**	**Bottleneck 2**
PSA	.00000	.00000	.00000
Electrical Inspection	.00000	.00000	.00000
Moisture Inspection	.00000	.00000	.00000
RED BIM	.12314	.00000	.00000
Cuff Test	.00469	.00000	.00000
Laser Paint Strip	.00000	.00000	.00000
Manual Sanding	.00000	.00000	.00000
Sanding	.00000	.00000	.00000
Bonding	.00000	.00000	.00000
Painting	.15419	.72518	2.44370
Repair Blade	8.46200	3.3944	.55427
Tip Cap Shop	.00000	.00000	.00000
Static Balancing	.00000	.00000	.00000
Whirl Tower	.00000	.04249	.03033

Table 4: WIP

Identifier	Count		
	Initial Run	**Bottleneck I**	**Bottleneck II**
WIP	16.762	15.924	15.897
Biweekly Throughput	2	5	4
RED BIM_C_Fail	0	7	6
RED BIM_C_Pass	13	6	7
Cuff Test_C_Fail	2	1	1
DLA_C	2	5	4
SAFER_C	2	11	10
Cuff Test_C_Pass	1	0	1
Whirl Tower_C_Fail	0	0	0

4.1.2 Case II : Simulation of the Job Shop (100% Cat II Parts)

Replication ended at time : 4800 min
Statistics were cleared at time : 2000 min
Statistics accumulated for time : 2800 min

Figure 7 shows the plot of The CAT II cycle time against the simulation run time of 41,800 minutes. Only the first 3000 minutes of each replication is plotted and shown. Figure 7 shows that the model stabilizes around 2000 minutes. Similarly from the data obtained from Figure 8, which is a plot of the Average WIP Vs. The Simulation run time the system was found to stabilize at around 2000 minutes. Once the warm up period was determined, the model

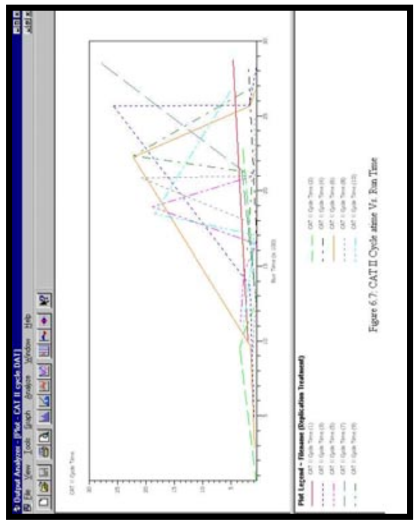

Figure 7: CAT II cycle time Vs Run time

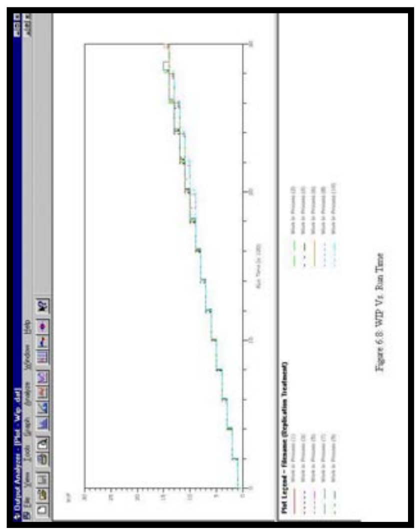

Figure 8: WIP Vs Run time

was then simulated for a period of two weeks with a warm up period of 2000 minutes. The data is tabulated in Tables 5, 6, 7, and 8.

Table 6 shows percent utilization for all the resources. The repair part resource was found to be the process with maximum percent utilization and was identified as the bottleneck. This is confirmed from Figure 9, which is a plot of the percent utilization for the Painting and the Repair Parts resource against the Simulation run Time. The graph is shown to be plotted only for the first 2400 minutes of the simulation, for the sake of clarity.

4.1.3 Case III : Simulation of the Job Shop (100% Cat III Parts)

Replication ended at time : 4800 min
Statistics were cleared at time : 2200 min
Statistics accumulated for time : 2600 min

Considering only CAT III parts, the model was allowed to reach steady state. Figure 9 shows The CAT III cycle time plotted against the total simulation run time of 45,000 minutes. The plot has been shown only for the first 3000 minutes. It is obvious that the system stabilizes at around 2200 minutes. Figure 10 shows the average WIP plotted against the Simulation run time. The data obtained was tabulated in Tables 9, 10, 11, and 12.

Table 5: Cycle Time

Identifier	**Average**		
Cycle times	**Initial Run**	**Bottleneck I**	**Bottleneck II**
CAT I	--	--	--
CAT II	12.669	12.850	14.036
CAT III	--	--	--
CAT IV	--	--	--

Table 6: Percentage Utilization

Identifier	**Average**		
Utilization	**Initial Run**	**Bottleneck I**	**Bottleneck II**
PSA	.00000	.00000	.00000
Elec Insp	.10996	.11282	.11384
Red BIM	.44061	.48712	.33902
Cuff Test	.00000	.00000	.00000
Laser pain	.24719	.17422	.13480
Sanding	.02761	.05723	.05723
Bonding	.00000	.00000	.00000
Painting	1.0000	1.0000	.98058
Repair Blade	1.0000	1.0000	1.0000
Tip Cap	.12747	.19582	.33764
Static Bal	.03584	.16106	.20583
Whirl Tower	.17234	.32238	.47469

Table 7: Queue Length

Identifier	**Average**		
# in Queue	**Initial Run**	**BottleneckI**	**Bottleneck II**
PSA	.00000	.00000	.00000
Electrical Inspection	.00000	.00000	.00000
Moisture Inspection	.00000	.00000	.00000
RED BIM	.07604	.06618	.02556
Cuff Test	. 00000	.00000	.00000
Laser Paint Strip	.00000	.00000	.00000
Manual Sanding	.00000	.00000	.00000
Sanding	.01240	.00334	.00334
Bonding	.00000	.00000	.00000
Painting	1.1807	2.7444	.77419
Repair Blade	6.3852	1.8889	1.3072
Tip Cap Shop	.00000	.00000	.06027
Static Balancing_	.00000	.02582	.00964
Whirl Tower	.00000	.01498	.10641
Elevator1	.00000	.000174	.000174
Elevator2	.00061	.00000	.00000

Table 8: WIP

Identifier	**Count**		
	Initial Run	**Bottleneck I**	**Bottleneck II**
WIP	16.642	16.477	16.003
Biweekly Throughput	2	3	5
RED BIM_C_Fail	4	6	8
RED BIM_C_Pass	11	9	7
Cuff Test_C_Fail	0	0	0
Moisture Inspection	0	0	0
DLA_C	2	3	5
SAFER_C	5	7	9
Cuff Test_C_Pass	0	0	0
Whirl Tower_C_Fail	0	1	1

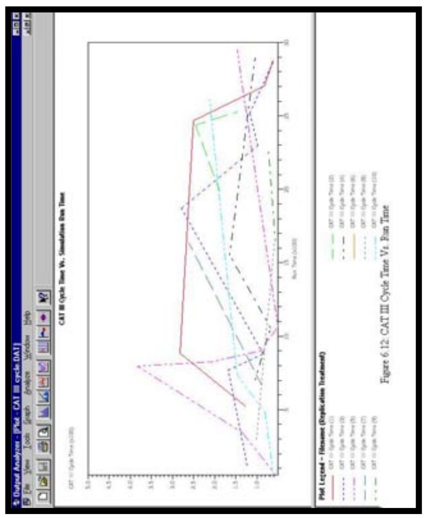

Figure 9: CAT III Cycle time Vs Run Time

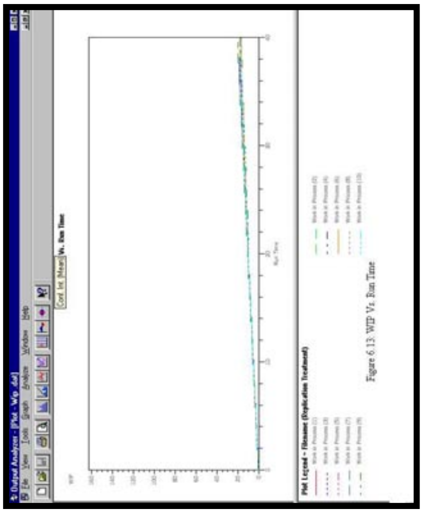

Figure 10: CAT III WIP Vs Run Time

Table 9: Cycle Time

Identifier	Average		
Cycle Times	**Initial Run**	**Bottleneck I**	**Bottleneck II**
CAT I	--	--	--
CAT II	--	--	--
CAT III	764.48	2326.1	1589.2
CAT IV	--	--	--

Table 10: Percentage Utilization

Identifier	**Average**		
Utilization	**Initial Run**	**Bottleneck I**	**Bottleneck II**
PSA	.00000	.00000	.00000
Elec Insp	.11148	.11384	.11354
Red BIM	.33932	.56857	.51056
Cuff Test	.35469	.50826	.40890
Laser pain	.14020	.19248	.15500
Sanding	.00000	.00000	.00000
Bonding	.00000	.00000	.00000
Painting	1.0000	1.0000	.86942
Repair Blade	1.0000	1.0000	1.0000
Tip Cap	.04831	.19540	.34804
Static Bal	.02059	.07415	.12188
Whirl Tower	.08971	.17934	.55703

Table 11: Queue Length

Identifier	**Average**		
# in Queue	**Initial Run**	**Bottleneck I**	**Bottleneck II**
PSA	.00000	.00000	.00000
Electrical Inspection	.00000	.00000	.00000
Moisture Inspection	.00000	.00000	.00000
RED BIM	.01790	.15311	.01694
Cuff Test	.01308	.00034	.01010
Laser Paint Strip	.00000	.00000	.00000
Manual Sanding	.00000	.00000	.00000
Sanding	.00000	.00000	.00000
Bonding	.00000	.00000	.00000
Painting	2.2619	3.4945	.09960
Repair Blade	4.4376	3.3693	2.4644
Tip Cap Shop	.00000	.00000	.01492
Static Balancing_	.00000	.00000	.00000
Whirl Tower	.00000	.13829	.09319
Elevator1	.00000	.00000	.00000
Elevator2	.00000	.00000	.00000

Table 12: WIP

Identifier	**Count**		
	Initial Run	**Bottleneck I**	**Bottleneck II**
WIP	17.851	17.915	15.721
Biweekly Throughput	1	1	6
RED BIM_C_Fail	6	1	5
RED BIM_C_Pass	8	11	9
Cuff Test_C_Fail	1	2	1
Moisture Inspection_C	0	0	0
DLA_C	1	6	5
SAFER_C	8	3	7
Cuff Test_C_Pass	6	9	7
Whirl Tower_C_Fail	0	0	0

The graphical results for the first run with duration of 4800 minutes (2 weeks) are generated using the output analyzer tool. Percent Utilization plotted against the Run time is shown in Figure 11. Resource bottleneck is identified and eliminated.

Percent Utilization data is tabulated in Table 10. The repair part resource has the maximum percent utilization and is therefore determined as the bottleneck. This is also confirmed looking at Figure 11. Next the capacity of the identified bottleneck resource is increased (which in this case is the Repair part facility) by one, thereby taking its total capacity to 3. The graphical output of this simulation run is shown in Figure 12. This graph is similar to Figure 11 with the only difference being that it was plotted after the first bottleneck had been identified.

The capacity of the repair part resource was also increased by one. The Painting resource facility was the next bottleneck that had to be removed. The fact remains that

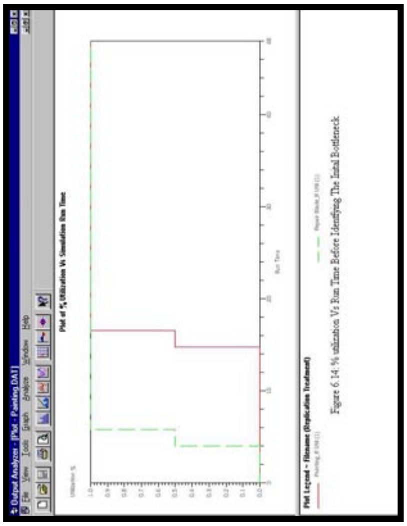

Figure 11: Utilization Vs Run time before bottleneck I

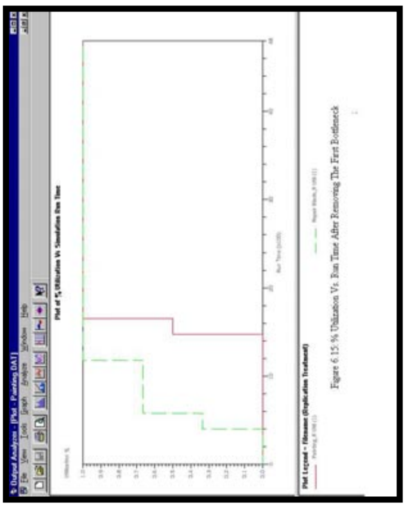

Figure12: Utilization Vs Run time

both painting and the repair part facility had the highest % Utilization. The reason behind it is that the queue length for the painting resource facility was found to be longer than that for the repair part facility and hence was taken as the bottleneck. Thus its capacity was increased by one, which increased the overall capacity to three. The model was run once again to determine the changes in the tally variables and the discrete change variables as well as the final throughput.

5 CONCLUSION

The discrete event simulation model developed was used to assess the length of queues formed at various shop within a job shop. The model was used to identify bottlenecks and help prioritize job orders. This was critical considering the military aspects of the product and the drastic changes in demand and lead times. Actual operational and flow data was utilized in developing the model.

The model was developed using Arena. In effect, the model was used for a better understanding of operation of the shop floor and better utilization of all the available resources. One of the main objectives of the project was to achieve a balance between the various production processes in the shop and try to optimize shop floor operation. Shop bottlenecks were identified at maximum throughput. The entity flow was then reduced at the bottlenecks and cycle times were monitored.

Another unique aspects of this simulation model were the unique operation of the shop. The shop consists of two floors. Products are categorized into repair categories and depending on which of the four categories they fall under, they may require one or several operations. These operations are scattered throughout the shop on both floors. No specific flow patterns are set. Products are inspected and work schedule is assigned based on the outcome of the inspection.

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AUTHOR BIOGRAPHIES

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