Prototype Build Optimization

by

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ABSTRACT

The Design Operations Team has the capability of eliminating human capital overreduction and increasing production by becoming more efficient. It is customary within the Design Operations Team to exhaust its over-time allocation. A consequence of this inefficiency is headcount overreduction.

Implementation of a simulation-based change management tool fosters a low risk solution to experiment with continuous improvement projects. Simulations help uncover opportunities through evidence-based outcomes that support and guide strategic restructuring decisions.

The existing operation was analyzed. The workorder system data was collected and aggregated. The data failed to provide adequate input for a simulation due to data inconsistencies. Milling machine data was collected and aggregated. The forecasted milling schedule did not match real time data and proved impractical for simulating.

An interview process was conducted with workers from the Design Operations Team. Sequential elemental process steps and their estimated times were gathered during the interviews. The time it took to walk between each of the shops was calculated. Process elemental times and walk times were added to the simulation and the results were analyzed.

The simulation results prove that quality inputs have a direct impact on the results produced from the simulation. The inputs must be refined to strengthen evidence-based simulation results for confidence in strategic choice. The workorder system plays an instrumental role for improving efficiency in data mining, process control, operational transparency and seamless communication.

CHAPTER 1 INTRODUCTION

1.1 Objective

The objective of this thesis paper is to demonstrate how to improve efficiency, reduce cost, maintain headcount and increase production within the Design Operations Team (DOT). A virtual representation of the operation is constructed within a simulation software program. Empirical data is collected as input into the simulation program. The results of the simulation provide insight into operational issues, people, resources and timing.

1.2 Problem Description

It is customary within DOT to exhaust their allocated over-time. A consequence of this inefficiency is headcount overreduction. Due to the organizations constant fluctuation and changing complexity programs may follow a generic process and timeline, more often, project uniqueness leads to amendments.

DOT maintains the opinion, disparities between prototype projects are too great to standardize. Tribal knowledge is essential to depict current state.

1.3 Initiating the Prototype Build

DOT builds numerous types of prototype properties for vehicle appearance evaluation prior to approving a program to go to market. A portion of these prototype properties are built for research clinics. There are multiple research clinics conducted prior to a program being approved to go to market. This analysis will focus on DOT's process to build a prototype property, for the last research clinic, prior to approving a program to enter the market.

A considerable amount of work and funding, inside and outside of DOT, is involved in developing any research clinic event. Thus, the research clinic date is a critical deadline that multiple work groups work towards.

Prior to the research event, DOT is given a timeline and a statement of work for the prototype requested. DOT evaluates the statement of work, current queue length, and establishes if the time allocated is sufficient to complete the prototype. If DOT agrees to build the prototype, the data set frozen at milestone I is sent to DOT. If DOT does not agree, the prototype is outsourced, and the data set is sent to the outsourcing group.

Meanwhile data continues to shift after milestone I. The final marketed product is built from milestone III data. When the prototype is completed it will closely resemble but not entirely reflect final product assumptions.

The disparity between the marketed product and the product researched poses a challenge for the Design and the Marketing Teams. If the Design Team or the Marketing Team insist on updating the prototype to better reflect the marketed product and the request is after the cutoff of milestone I, then DOT must provide a response for production feasibility within the timeframe requirement.

If DOT agrees to alter the prototype, complexity is added to the operation. Although complicated, DOT is familiar with deviation and is able to contain minor fluctuations. However, when multiple product-line teams deviate, stack-up develops within DOT, man-hours increase, supplier lead times are affected and production becomes less manageable (Zarrella et al., 2004).

If DOT is unable to meet demand, production feasibility is reassessed with the outsourcing team.

1.4 Strategy

Regardless of opinion and irrespective of project variation, there are repeatable processes. The method in this paper, will demonstrate how to improve the operation through the utilization of empirical evidence.

Data is gathered from the workorder system. Historical CNC programming language is downloaded from CNC milling machines and workorder times are extracted. Supplementary data is developed through documenting sequential process steps and assigning average completion times to each step. The data is added to a simulation software, Simlu8.

Simlu8 is used to build a virtual representation of the stations, locations, location distances and resources. The software utilizes the code visual logic to route work sequences to stations and to obtain resources. Resource utilization, activity utilization and queue utilization results are attained after the simulation is ran. Utilization results are analyzed to gain insight into system behavior and segregate value-added work. Non-value-added work is highlighted from the analyzation, then narrowed further to target key areas needing improvement.

1.5 Expected Results

The created data set is built off of hypothetical data. It is expected that the data set will need to be refined. Large variations between programs influence elemental averages. To maximize optimization, elements should be written in smaller increments and optionality should be built into the process.

CHAPTER 2 PROBLEM ASSESSMENT

"Most organizational researchers agree that cultures are inherently fuzzy, they incorporate contradictions, paradoxes, ambiguities, and confusion" (National Research Council, 1997, p. 69).

There are many hypotheses explicating the inefficiencies within DOT. Perhaps timelines are not respected, or data delivery is late. Possibly, work is stopped and restarted, maybe parts are over manufactured, or workorders are not entered. The uncertainty prevents the provision of a clearly structured process.

It is known that the system is overloaded at times and underutilized at times. Overtime serves as a mask for these operational inefficiencies. When the allocation of overtime is exhausted headcount overreduction arises.

2.1 Symptom Network

Diagnosing the root cause within this highly complex system was difficult because of the conflicting and sometimes irrelevant information gathered. A focused system examination was conducted to obtain root cause, illustrated in the Symptom Network Chart (see Figure 1), (Opar, 2002).

The salient problem is headcount overreduction. Level one of the symptom network denotes the salient problem occurs because overtime allocation is exhausted.

Level two establishes that overtime allocation is exhausted because of DOT stack up.

Level three clarifies why there is stack up in DOT. Those causes are, inaccurate mill scheduling, an uncontrolled work order system, late data delivery, required data not delivered, change requests not entered in the workorder system and project requirements change after the deadline.

Level four demonstrates an uncontrolled work order system, late data delivery, required data not delivered, change requests not entered in the workorder system and project requirements changed after the deadline occur because of breaking process protocol and complexity changes.

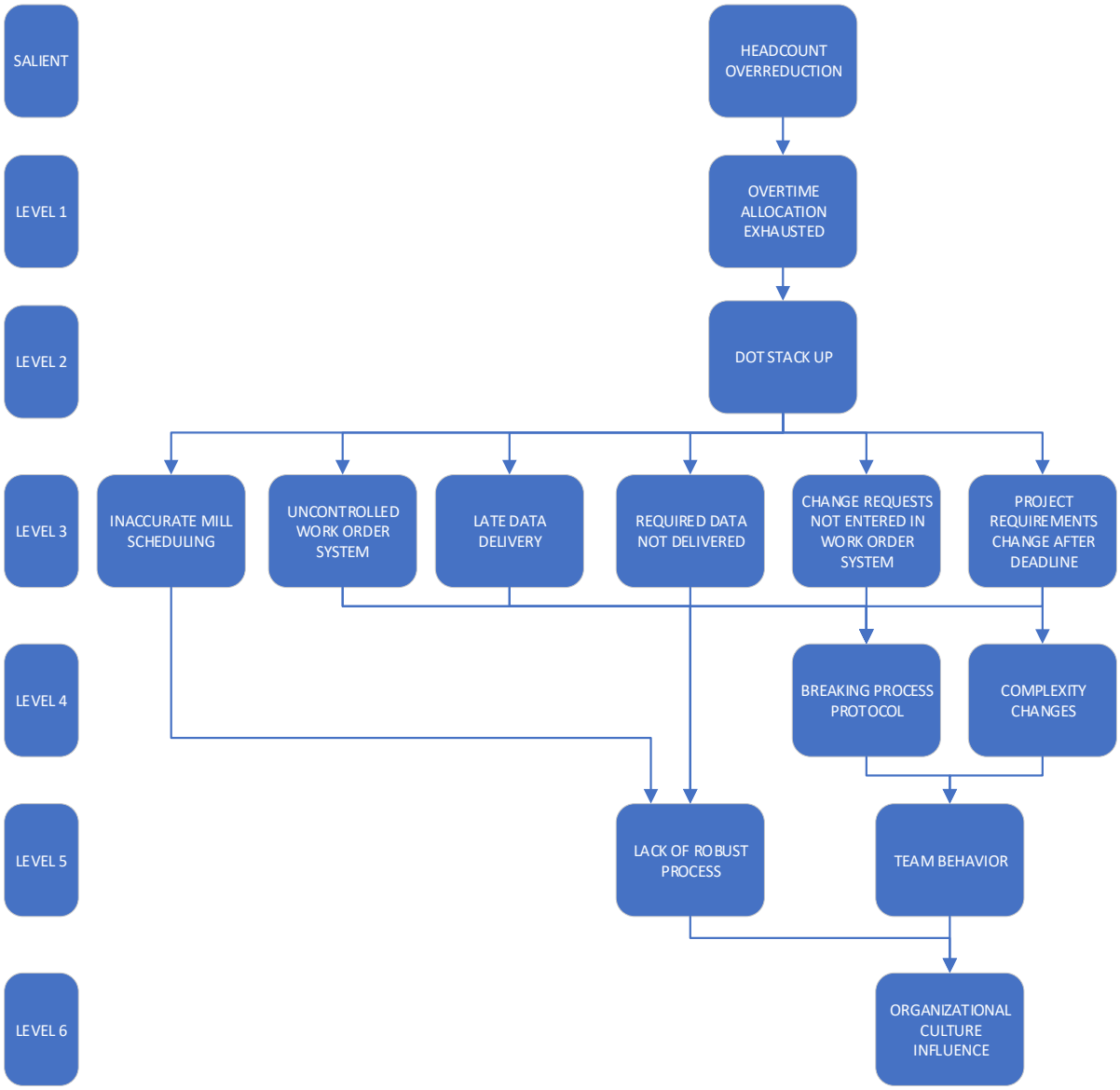

Figure 1 Symptom Network

Level five illustrates inaccurate mill scheduling, an uncontrolled work order system, late data delivery, required data not delivered, change requests not entered in the workorder system and project requirements changed after the deadline are caused from lacking a robust process.

Level five also states that breaking process protocol and complexity changes are caused by team behavior.

Level six describes, lack of a robust process and team behavior are caused by the influence of organizational culture.

The root cause can be found in level six, the influence of organizational culture. Root cause can be solved by attacking issues found in level five, lack of a robust process and team behavior.

2.2 Goal Symptom Network

The salient problem to be solved is robust process implementation and improved team behavior. If a robust process is implemented, it will not affect production capability if team behavior does not complement the process (see Figure 2).

Level one outlines how the implementation of a robust process and improved team behavior will provide enhanced forecast accuracy, better part visibility and seamless communications.

Level two suggests organizational obstacles will be removed when forecast accuracy, part visibility, and communications are improved.

Level three shows when organizational obstacles are removed, costs decrease.

Level four clarifies that when costs decrease, headcount can be justified.

Level five implies when headcount is justified then production can increase. The intent is to reach level five and increase production volume. For production to increase, headcount must

be justified, cost must decrease, and organizational obstacles must be removed. Addressing causes outlined in level one will lead to reaching goals in levels two, three and four.

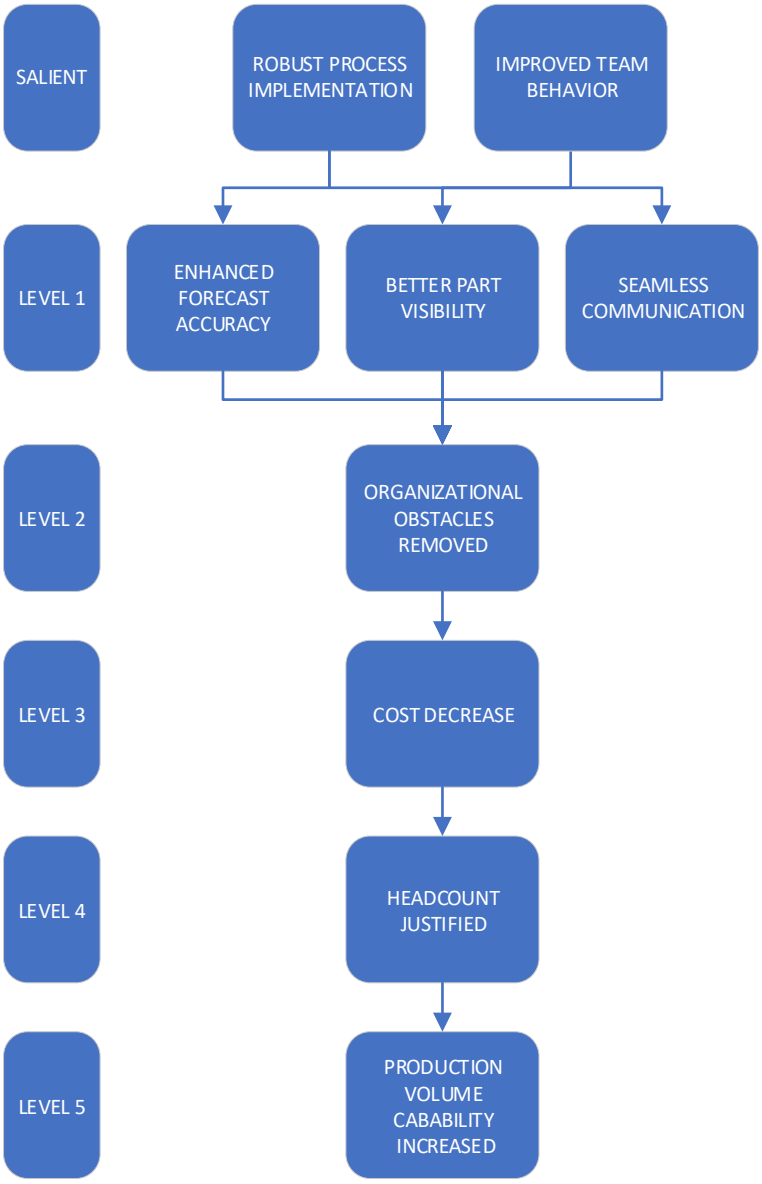

Figure 2 Goal Symptom Network

"Great communication requires vulnerability on both sides, which is scary for most people. Put aside the fear and remember—and remind—that the rewards far outweigh the perceived potential danger" (Hassell, 2019).

2.3 Root Cause Symptom Network

Root cause is established by looking further into the sources outlined in the goal symptom network; enhanced forecast accuracy, better part visibility and seamless communications.

The salient issue becomes seamless communication. Level one indicates to attain seamless communication the forecast needs to improve. Level two suggests improving the accuracy of the forecast requires better part visibility. Level three reveals to attain better part visibility there needs to be clean data. Level four confirms that clean data requires process control (see Figure 3).

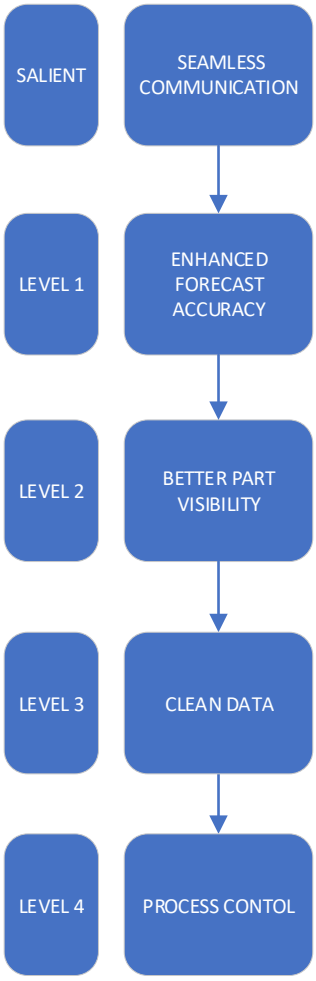

Figure 3 Root Cause Symptom Network

CHAPTER 3 DATA EVALUATION

Available data was collected and reviewed. The first set of data examined was from the workorder system. The next set of data was downloaded from the 6 mill machines within shop B. The data sets were aggregated, and results were found.

Process times were assumed. Generic names were given to milling machines, resource groups, stations, locations and shops.

3.1 Workorder Process

The process for work entering into the operation is initiated by a workorder. A workorder is a statement of work and is created in the workorder system. The details of the workorder are typed into the workorder system via unconstrained text. When created, a workorder is issued an automated workorder number.

Upon submission, the workorder is sent to station 24, at physical location 14. An employee from resource group 16, plans the breakup and route of the workorder. He/she divides the workorder into subcomponent parts. He/she then assigns each subcomponent of the workorder a route and a forecasted duration for each stop in the route.

Routing determinations are influenced by workorder subcomponents currently in the system, unless a specified manufacturing process is required. The resource at station 24, must balance the new workorder subcomponent with the existing queue. Once routed, each of the newly created workorder subcomponents are added to the queue of the first stop or shop in the route.

When the workorder subcomponent arrives to the queue of any stop assigned in the route, the group leader will check the workorder subcomponent into the workorder system through a scanning process or through manual entry. If a subcomponent of a workorder contains multiple

pieces, the leader divides the work amongst the resources and stations. The physical work of each piece of the workorder subcomponent could start at different times and may arrive to the next shop at any given time.

When the entire workorder subcomponent is completed, the leader enters the number of hours the workorder subcomponent took to complete. The workorder subcomponent is sent to the queue of the next shop assigned in the route. This cycle continues until each workorder subcomponent has finished the assigned route and the entire workorder is complete.

3.2 Workorder System Data Evaluation

Workorders from the workorder system were downloaded. A section consisting of 8 sequential months were analyzed. Systemic issues were immediately evident. The workorders were not written prescriptively, combing through the data took time. The information within each workorder varied greatly making it challenging to commonize effectively.

The workorders were consolidated into programs per shop, yet it was difficult to devise the duration of time a component stayed in the system. The data in the workorder system is collected by date, not hour. The summation of hours is manually entered. The system does not consider the number of workers it took to build a subcomponent. If a subcomponent contains multiple pieces and worked on by multiple workers, the hours entered to complete the subcomponent are not accurately reflected.

The time tracked within the workorder system, per workorder subcomponent is equal to the overall duration of time it is in each group of stations collectively. Not the time it takes to build each piece of the sub-component. Non-value-added wait time is part of the overall duration.

3.3 Shop B Process

The lead in shop B checks the workorder system for the next workorder subcomponent in the queue for shop B and checks it into shop B. The lead then manually adds the checked in workorder subcomponent onto a separate tracking document.

The separate tracking document is a scheduling document used for organizing machine availability and worker assignment. The tracking document for shop B is tracked in days, and because shop B carries 2 shifts, one day is equal to 14 hours, or two eight-hour shifts, minus two one-hour breaks.

3.4 Shop B Data Evaluation

Shop B has 6 CNC machines, the mills are able to hold 6 months of past data. Historical CNC programming data was downloaded from each of the 6 mills. To account for overlap from the scheduling document and machine time, 8 months of scheduled workorder data was compiled. These two data sets were compared.

The first analysis was the assessment of Mill 1. Data mining the CNC machining logic from the log reports found on Mill 1 was time consuming. Once completed, the start and stop times of each workorder subcomponent were extracted from the code logic.

Shop B's tracking document was filtered for workorder subcomponents matching the 6 months of workorders pulled from the mills. The extracted workorder subcomponent start and stop times from Mill 1 were cross referenced with the start and stop times of workorder subcomponents found on the shop B tracking document (see Table 1 and Figure 4).

Over the 8-month duration, the sum of machine time on Mill 1 was 11,112.76 minutes, or 185.21 hours. According to the shop B tracking document, the sum of time assigned to mill 1 was 603,300 minutes, or 10,055 hours. A discrepancy of 9,869.79 hours.

MONTH	Machine Time for Mill 1	Assigned Shop Time for Mill1
Month 1	584.12	27,180
Month 2	3,654.96	176,100
Month 3	1,931.66	83,940
Month 4	765.75	131,880
Month 5	932.12	30,660
Month 6	467.70	3,660
Month 7	1,774.67	131,940
Month 8	1,011.78	17,940
Grand Total	11,122.76	603,300

Table 1 Shop B Mill 1 vs Mill 1 Machining

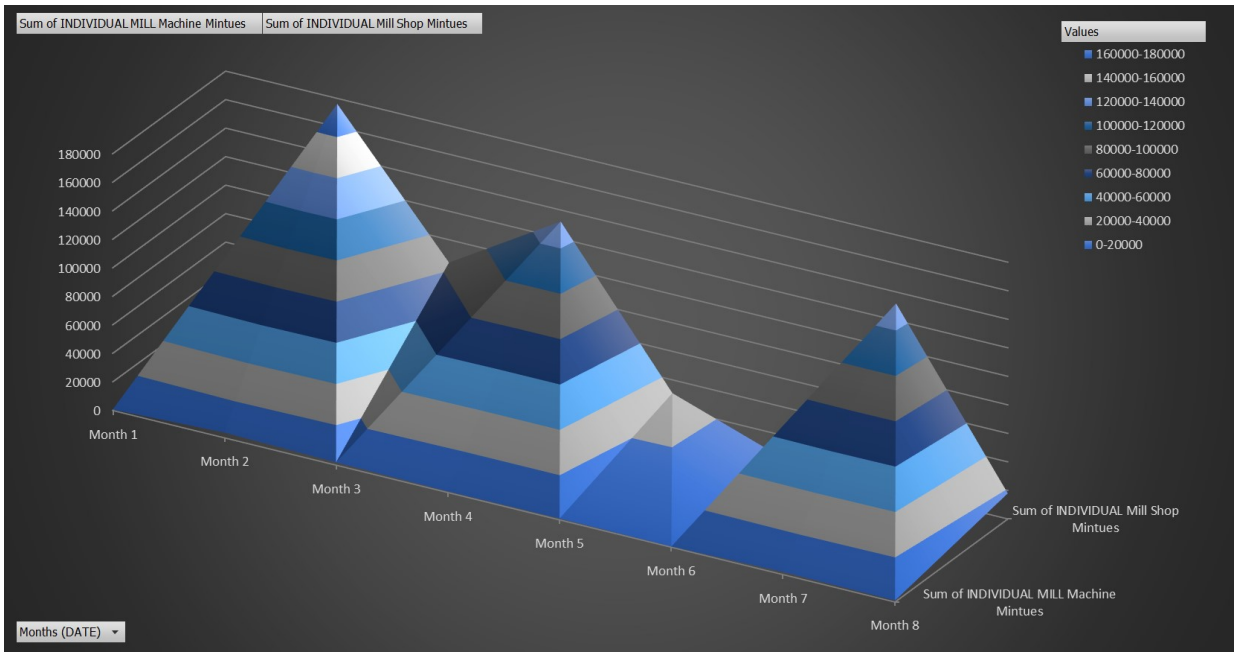

Figure 4 Mill 1 Workorder Subcomponent Times

The shop B tracking document contained workorder subcomponent numbers not assigned to Mill 1 but found loaded onto Mill 1. The analysis in Table 2 contains the number of workorder subcomponents from the shop B tracking document that match workorder subcomponents downloaded from Mill 1, regardless of the machine it was assigned to in the shop B tracking document.

There were 848 workorder subcomponent numbers downloaded from Mill 1 matching workorder subcomponent numbers within the shop B tracking document. The shop B tracking

document showed 185 of those workorder subcomponents were assigned to Mill 1, 83 to Mill 4, 356 between Mill 2 and Mill 3, 119 to Mill 5, 103 to Mill 6, and 2 unassigned.

MILL	WO
1	185
2/3	356
4	83
5	119
6	103
(blank)	2
Total	848

Table 2 Mill 1 Workorder Subcomponent Assignment

Of the 848 workorder subcomponents, 185 or 22% were assigned correctly. The sum of time shown in the shop B tracking document for workorder subcomponents far outweigh the machine times of the matching subcomponent workorders and requires further investigation.

3.5 Shop B Month D Data Evaluation

Since workorder subcomponents loaded on Mill 1 were not clearly matched to workorder subcomponents assigned to Mill 1, data from Mill 2, Mill 3, Mill 4, Mill 5 and Mill 6 were aggregated for one month, Month D. Workorder subcomponents from shop B's tracking document falling within Month D were compared to machining data in Month D.

213 workorder subcomponents, were tracked in shop B for Month D (see Table 3). Of the 213 workorder subcomponents tracked in shop B, 64 workorder subcomponents were assigned to Mill 1.

76 workorder subcomponents were assigned to Mill 2 and/or Mill 3. Mill 2 and Mill 3 are scheduled as one entity within the shop B tracking document. It does not clarify which of these 2 mills the work is completed on.

There were no workorder subcomponents tracked for Mill 4 or loaded to Mill 4 for Month D.

There were 45 workorder subcomponents assigned to Mill 5.

There were 27 workorder subcomponents assigned to Mill 6. However, there was no data loaded onto Mill 6, leaving 12% incorrectly assigned to Mill 6.

There was one workorder subcomponent not assigned in the mill tracking document.

MILL	WORK ORDERS
1	64
2/3	76
5	45
6	27
(blank)	1
Grand Total	213

Table 3 Month D Workorder Subcomponent Assignment

Table 4 shows a comparison of subcomponent workorder minutes in Month D. The first column shows machine minutes per mill. The second column shows shop minutes assigned per mill, according to the shop B tracking document. The third column shows the minutes of matching machine time minutes to assigned minutes per mill.

The fourth column shows the gap of minutes per mill between minutes assigned and machine minutes loaded on each mill. The Month D comparison shows 283 hours of scheduled subcomponent workorders on the shop B tracking document matched to those found loaded on the mills. The Month D comparison shows a gap of 4,785 hours of matched subcomponent workorders between machine time and shop time.

If a workorder subcomponent was scheduled on Mill 2 and/or Mill 3 and a matching workorder subcomponent was loaded to Mill 2 and/or Mill 3, then the scheduling data was changed to reflect Mill 2 or Mill 3 respectively. If a workorder subcomponent was scheduled on

Mill 2 and/or Mill 3 and the work was not performed on Mill 2 and/or Mill 3, then it is not a match (see Row 2/3 of Table 4 and Figure 5).

MILL	Sum of Machine Mintues	Sum of Shop B Mintues	Sum of MATCH MINTUES	Sum of TIME GAP IF MATCH
1	2,663.15	61,380.00	2,601.47	57,938.53
2	1,268.89	45,480.00	1,268.89	44,211.11
2 / 3	339.24	13,860.00	-	-
3	1,630.46	80,220.00	1,630.46	78,589.54
5	11,774.42	72,000.00	11,458.28	42,061.72
6	227.59	66,420.00	-	64,320.00
Grand Total	17,903.75	339,360.00	16,959.11	287,120.89
Hours	298.40	5,656.00	282.65	4,785.35

Table 4 Time Gap of Shop B vs Machining

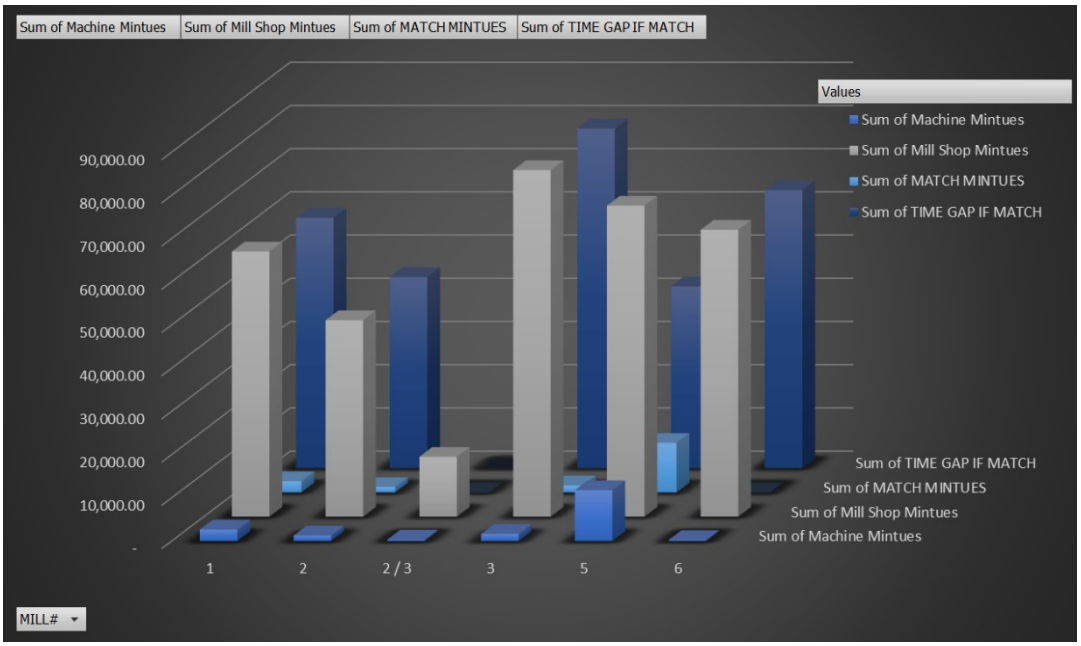

Figure 5 Time Gap of Shop B vs Machining

Mill 2 and/or Mill 3 was assigned 339.24 minutes but those workorders were found loaded onto either Mill 1 or Mill 5 (see Table 5). Of those same subcomponent workorders 13,860 minutes were accounted for within the mill tracking document.

MILL ASSIGNED	Mill Shop Mintues	Loaded From	Machine Mintues
2/3	3,360	5	64.59
2/3	1,260	5	61.09
2/3	1,260	5	60.25
2/3	1,680	1	70.76
2/3	5,040	5	20.75
2/3	1,260	5	61.80
	13,860		339.24

Table 5 Mill 2//3 Unmatched Minutes

Table 6 illustrates the shop B tracking document designations of workorder subcomponents compared to the actual mill machining time. Mill 1 was assigned 61.68 minutes of work actually completed on Mill 3.

Of the 3,238.59 minutes assigned Mill 2 and/or Mill 3, 70.76 minutes were completed on Mill 1. 1,268.89 minutes were completed on Mill 2. 1,630.46 minutes were completed on Mill 3. 268.48 minutes were completed on Mill 5. Together Mill 2 and Mill 3 ran a total of 3,271.56 minutes in contrast to the scheduled 3,238.59 minutes.

11,458.28 minutes were assigned to Mill 5 and machined on Mill 5. 97.83 minutes of work assigned to Mill 5 was performed on Mill 1. 157.19 hours of work assigned to Mill 5 was performed on Mill 2, 61.11 minutes of work assigned to Mill 5 was performed on Mill 3.

Of the 227.59 minutes scheduled on Mill 6, zero minutes were found loaded to Mill 6. 67.41 minutes of work assigned to Mill 6 was performed on Mill 1. 92.22 minutes of work assigned to Mill 6 was performed on Mill 2. 67.96 minutes of work assigned to Mill 6 was performed on Mill 5.

Mill	1	2/3	5	6	Total
1	2,601.47	70.76	97.83	67.41	2,837.47
2		1,268.89	157.19	92.22	1,518.31
3	61.68	1,630.46	61.11		1,753.25
5		268.48	11,458.28	67.96	11,794.73
6				-	-
Total	2,663.15	3,238.59	11,774.42	227.59	17,903.75

Table 6 Month D Scheduled vs Actual

3.6 Shop B Month D Data Evaluation Less Mill 2/3

Workorder subcomponent minutes contained in the shop B tracking document were compared to the mill machining minutes loaded from each respective mill. Only subcomponent workorders matching the shop B tracking document to those loaded from the mills are reflected in this analysis.

Workorder subcomponents scheduled on Mill 2 and/or Mill 3 and not performed on Mill 2 and/or Mill 3, are not included in this analysis. The sum of machine time in comparison to shop time is drastically different. Machining data matching data on the shop B document still leaves extreme unallocated time between machine time and shop time (see Figure 6).

Mill 1 shows 2,601.47 machine minutes compared to 57,938.53 from the shop B tracking document. Mill 2 shows 1,268.89 machine minutes compared to 44,211.11 from the shop B tracking document. Mill 3 shows 1,630.46 machine minutes compared to 78,589.54 from the shop B tracking document. Mill 5 shows 11,458.28 machine minutes compared to 42,901.72 from the shop B tracking document. Mill 6 shows zero machine minutes compared to 63,480 from the shop B tracking document. Discrepancy for Mill 1 is 96%, 97.1% for Mill 2, 98% for Mill 3, 73% for Mill 5, and 100% for Mill 6.

This assessment proves the need for additional data to clarify part life in the fabrication area.

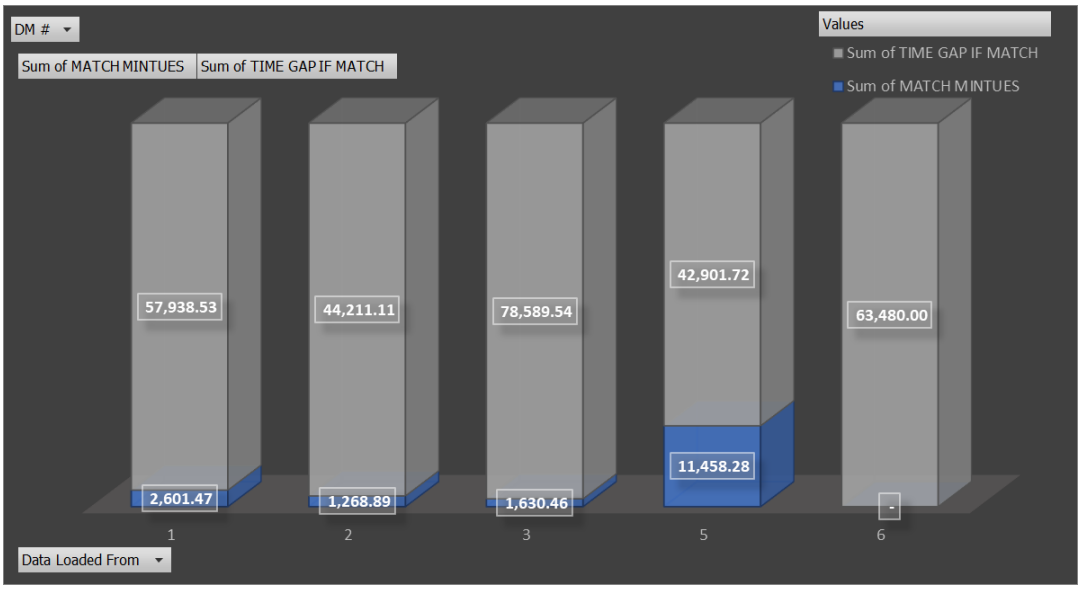

Figure 6 Time Gap of Shop B vs Machining Less Mill 2/3

CHAPTER 4 CURRENT STATE EVALUATION

The data available from the workorder system and from the milling machines did not fully characterize the length of time it takes to build a prototype property. Foundational elements are missing and must be added for complete representation. A fully documented procedure of DOT will help diagnose missing links and aid to crafting future state (Edgett & Cooper, 2012).

According to Cooper (2009), smart companies have removed waste from their new product development process by applying the value-stream analysis concept. Value stream mapping links all processes together with the aim of maximizing customer value.

4.1 Process Design

To glean insight into actual fabrication work, personal interviews were conducted with each shop supervisor and their respective leads over the duration of a year. Elemental process steps were documented and written in sequential order per component. Each process step, or job, was assigned a station and a resource.

Each of the process elements were assigned an average hourly time, the time assigned equates to the amount of time it would take one worker to finish that job. See the example in Table 7. Steps end when a component is set aside, exits a shop, is left to cure, is left to dry, travels to a different location, or changes employee hands.

The process elements are written for in-house manufacturing capabilities, not all components are produced in house. Outsourced components are accounted for within the process according to their lead time averages and up to when the part arrives at the dock for installation.

STEP	COMPONENT	ACTIVITY	SEND TO	RESOURCE	PATH	QUANTITY	HOURS
1	Component 5	Station 4	Station 5	Resource 2	1	1	8.0
2	Component 5	Station 5	Station 10	Resource 3	1	1	2.0
3	Component 5	Station 10	Station 36	Resource 3	1	1	0.5
4	Component 5	Station 36	Station 5	Resource 3	1	1	4.0
5	Component 5	Station 5	Station 6	Resource 3	1	1	0.3
6	Component 5	Station 6	Station 5	Resource 8	1	1	1.0
7	Component 5	Station 5	Station 18	Resource 3	1	1	0.2
8	Component 5	Station 18	Station 12	Resource 12	1	1	1.0
9	Component 5	Station 12	Station 18	Resource 7	1	1	2.0
10	Component 5	Station 18	Station 1	Resource 12	1	1	1.0
11	Component 5	Station 1	Station 18	Resource 7	1	1	1.0
12	Component 5	Station 18	Station 16	Resource 12	1	1	1.0
13	Component 5	Station 16	Station 7	Resource 11	1	1	1.0
14	Component 5	Station 7	Station 9	Resource 8	1	1	8.0
15	Component 5	Station 9	Station 8	Resource 5	1	1	1.0

Table 7 Jobs Example-Path 1

Each component process follows a sequence of events and a sequential path. It is possible for a component to have more than one fabrication method or path. All components are assigned to path one (see Table 7). If there is a second path option, then the jobs for completing the second path are added to the process flow and assigned to path 2 (see Table 8). If there is a third path all elements are added and assigned to path 3. If there is a fourth path all elements are added and assigned to path 4.

Table 13 - Table 35 are located in APPENDIX I. There are 12 components that have more than one path option (see Table 13). There are 10 path options available, no component has more than 4 path options (see Table 14).

STEP	COMPONENT	ACTIVITY	SEND TO	RESOURCE	PATH	QUANTITY	HOURS
1	Component 5	Station 4	Station 21	Resource 2	2	1	8.0
2	Component 5	Station 21	Station 22	Resource 14	2	1	4.0
3	Component 5	Station 22	Station 21	Resource 14	2	1	1.0
4	Component 5	Station 21	Station 22	Resource 14	2	1	1.0
5	Component 5	Station 22	Station 1	Resource 14	2	1	1.0
6	Component 5	Station 1	Station 16	Resource 7	2	1	1.0
7	Component 5	Station 16	Station 7	Resource 11	2	1	1.0
8	Component 5	Station 7	Station 9	Resource 8	2	1	8.0
9	Component 5	Station 9	Station 8	Resource 5	2	1	1.0

Table 8 Jobs Example-Path 2

4.2 Resources

Resources are divided into groups; each resource group is allocated a number of heads. Each of the 19 resource groups are assigned to a station, not to a location (see Table 15). 18 of the 19 resource groups work first shift. Resource group 4 works second shift. Resource groups 3 and 4 do the same job, but on different shifts. Data for resource groups 3 and 4 will be shown in resource group 3.

Resource 2 is assigned to location 14 because it is a desk job.

Resource 5 is a vital resource group needed to force constraints into the system. Resource group 5 pulls resources from both resource groups 7 and 12 to work at station 5. Resource group 5 will not show results, utilization results will be accumulated within the resource groups 7 and 12. It is important to allocate a different resource group to station 5, in order to pull resources from both groups at any time.

Resource group 8 is assigned to an activity that does not require work, such as paint drying, curing time for a fiber glass component or machine time for milling a part.

Resource group 9 is analogous to resource group 8. Resource 9 captures the point in time when a component exits the internal system and the point that it reenters the system. The amount of resources in resource 9 is unknown, therefore the group resource 9 will not show accurate

results. In order to not be constrained to resource heads, 100 heads are allocated to resource group 9.

There is no elemental data accounted for resource group 11 or 17. These are place holders for future development and will not produce results at this time.

4.3 Stations and Locations

The operation consists of 48 stations and are numbered from 1 to 48. Each station is assigned to 1 of 15 locations, pertaining to its' physical location in the building. Locations may contain multiple stations. Table 16 shows a list of locations. Stations are listed and assigned to the location of where the station is physically located.

Stations 1, 5, 6, 9-13, 16-23 and 25 are assembly stations. Stations 26 – 48 are sub-assembly stations. The purpose of sub-assembly stations is to introduce constraints into the simulation. Jobs assigned to sub-assembly stations must be completed as a sub-component prior to install. When complete the sub-component travels as one component for installation.

Station 8 is the exit activity and is used as the last activity in a component process (see line 15 under column SEND TO within Table 7, and line 9 under column SEND TO within Table 8).

The imaginary location 14 was added to the process flow for work not requiring walking. A station is assigned to location 14 because work occurs in the same location or because the work is a desk job. Stations where work occurs in the same location are stations 2 and 7, these are assigned to location 14. Stations 3, 4 and 24 are desk jobs and are assigned to location 14.

Station 14 is not used.

Station 15 is used for components that are outsourced and are assigned to location 14. Process steps for Station 15 are assigned lead times. The lead time is accumulated from the time data is sent outside to the time the component arrives at the dock.

Station 25 is used for when a product is physically shipped out of the building. Station 25 is also assigned to location 14 but should be changed to a dock location in the future.

4.4 Operation Layout

A shop is an area consisting of multiple stations and locations, and possibly multiple resource groups. There are 6 shops, shop A, shop B, shop C, shop D, shop E and shop F. The shop area is managed by a shop supervisor. Supervisors are responsible for resource groups allocated to them. Each resource group is assigned a group leader.

Table 9 shows the locations supervised by supervisors 1-6. Supervisor 1 is responsible for 15 stations at location 9 and 1 station at location 14. Supervisor 2 is responsible for 3 stations at location 2, 1 station at location 3, 2 stations at location 10 and 1 station at location 15. Supervisor 3 is responsible for 1 station at location 8, 2 stations at location 13 and 2 stations at location 14. Supervisor 4 is responsible for 1 station at location 1, 4, 5, 6, 11, 12, and 1 station at location 14. Supervisor 5 is responsible for 1 station at location 14. Supervisor 6 is responsible for 3 stations at location 7 and 8 stations at location 8.

Table 17 - Table 27 show resource groups, stations, locations and supervisor allocations per shop.

Supervisor Allocations	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9	Location 10	Location 11	Location 12	Location 13	Location 14	Location 15	Total
Supervisor 1									15					1		16
Supervisor 2		3	1							2					1	7
Supervisor 3								1					2	2		5
Supervisor 4	1			1	1	1					1	1		1		7
Supervisor 5														1		1
Supervisor 6							3	8								11
Grand Total	1	3	1	1	1	1	3	9	15	2	1	1	2	5	1	47

Table 9 Supervisors 1-6

All of the process information collected is organized into worksheets to be loaded into the simulation.

CHAPTER 5 SIMULATION MODEL AND PROCEDURE

The discrete event simulation program, Simul8 (Simul8, n.d.), is the software used to design and run the simulation. It is a time-based computer model used to mimic a real or proposed operation. It has the capability of introducing randomness into the system by adding resources, constraints and studying their interactions (Simul8, n.d.).

5.1 Worksheet Logic

Data is loaded into the simulation by six worksheets. Those worksheets are, Station to Resource Mapping (Table 15), Station to Location Mapping (Table 16), Time Matrix Between Locations (Table 28), Component Batching Worksheet (Table 29), Job Matrix Worksheet (Table 30) and Job Path Worksheet (Table 31). These worksheets contain resources, number of heads, stations, locations, work types, components, jobs, timing, batch quantities, and path qualifiers.

Resources are divided into groups and assigned a number of heads.

The stations share the same station name for, the travel activity, station activity, queue and exit queue. Except for the final station which shares the station name with the travel activity and the queue, but the final station does not have an exit queue.

Stations are assigned to locations.

The work type is a numerical number given to the work item, also referred to as a component. There are 328 different work types in this simulation.

A job is a numerical number incremented until the number of process steps are completed for a work type.

Timing is the number of hours it takes for a job to be completed.

Batch quantity is the number of the work type needed.

A path qualifier determines a jobs' path.

The Resource to Station Mapping Worksheet contains resource group assignment according to station designations. The resource group is referenced to find a value for the number of heads allocated to the resource group and checks for resource availability. That data is shown in Table 15.

The resources are added to a station by looking to the resource worksheet and finding the station number in column E. The stations corresponding resource group code is found in column F. The code from column F is matched to its equivalent in column A. The value assigned to the code is the name of the resource group, found in column B. The value found in column C is the number of heads assigned to that resource group.

The Station to Location Mapping Worksheet is shown in Table 16. Column A is a list of code numbers set to equal a physical location name, shown in column B. Column D is a list of stations with its' corresponding code in column E. The code from column E is matched to its equivalent in column A. Column B is the location the station is assigned to.

The Time Matrix between Locations Worksheet contains a matrix, displayed in Table 28. This matrix holds time values for the time it takes to travel from one physical location to another. The current location name is found in column A. The travel to location name is found in row 1. The intersection of the row and column is the variable used for travel time.

The Component Batching Worksheet contains a list of unique components, work type, batch quantity and job (see Table 29). This sheet is used to generate all components in the simulation. It matches batch size to the component and then generates unique jobs to dictate batch size.

The Job Matrix Worksheet is a table of information that controls complex routings and timings. This worksheet informs the system of each line item in the process. It consists of the work type, the job number, the station, and the number of hours (see Table 30). This worksheet has 3,000-line items, the exhaustive list is not included.

The Job Path Worksheet is a table of information that controls pathway options within the simulation. It consists of a path qualifier, a work type, a job and an activity (see Table 31). This worksheet also has 3,000-line items, the exhaustive list is not included.

The path qualifier is found in column A for job 1 of a work type within the Job Path Worksheet. The path qualifier is the inverse of the number of path options for a work type. The remainder of jobs of a work type contain a 0 in the path qualifier column.

Instead of displaying each line item in the Job Matrix Worksheet and the Job Path Worksheet, the summation of hours per resource group at each station are shown in Table 32 - Table 35.

5.2 Interaction with Objects

Along with loading worksheets into the simulation, objects must also be added. Figure 7 illustrates the flow for the simulation within the software application. Objects control work within the simulation using visual logic. There are, 19 resources, one start point, 99 queues, 100 activities and one end point object, added to the simulation.

Prior to running the simulation, the reset command clears the objects in the simulation. Visual logic uses the Location Worksheet to rebuild the process and name the activities, queues and resources.

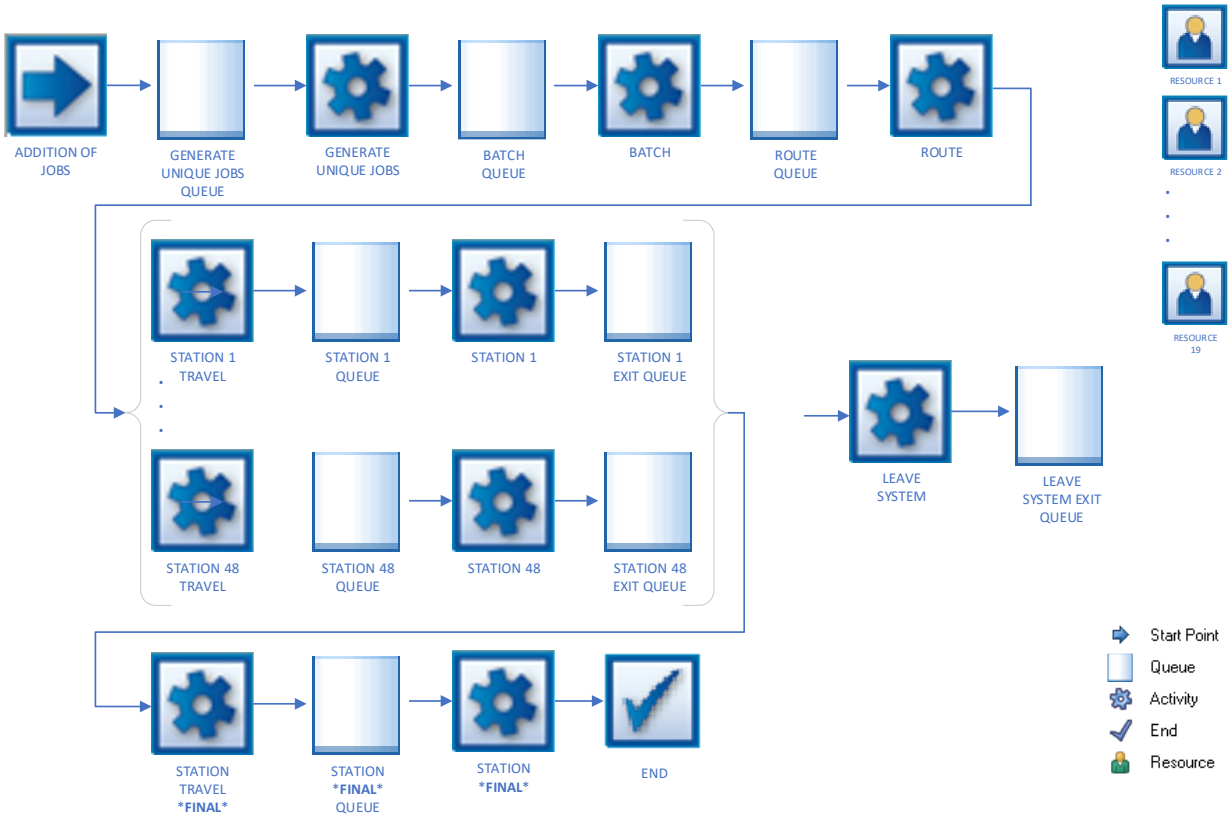

Figure 7 Simul8 Object Flow (Simul8, n. d.)

Visual logic determines resources at the onset of a simulation by looking into the Station to Resource Mapping Worksheet. This worksheet is used to match resources to activities automatically without the need to manually interact with the simulation. The activity is set to a replication number equaling the number of resources allocated to the group assigned to the station activity.

The work item is sent to the queue of the station of the next incremented job the work item is assigned to. The queue looks into the simulation for resources available for that station. If there is a resource available, the item will enter the station and begin to process. If no resource is available, the work item remains in the queue until the station is able to accept the work item.

Visual logic also uses attributes to control work by assigning labels to objects. When a job exits an object, visual logic finds where the object is and where it is going by referencing the Job Matrix Worksheet. The value is stored in a label, labels are attached to objects. Objects contain a list of jobs that have entered the object.

The start point addition of jobs, is a processor and does not have resources assigned to it. The interarrival time and distribution can be adjusted here. Addition of Jobs, routes out by priority to the Generate Unique Jobs queue (see Figure 8).

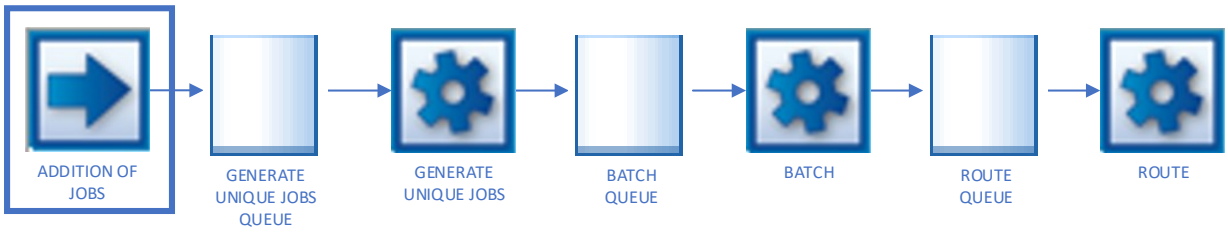

Figure 8 Simul8 Object Addition of Jobs (Simul8, n. d.)

The Generate Unique Jobs queue, Batch queue, Route queue, all of the station queues, all of the station exit queues and the Leave System exit queue are set to an infinite capacity with zero shelf life. All jobs sit in a queue until the activity is free to accept the job from the queue and a resource is available at the activity. Queues do not have resources assigned to them (see Figure 9). Visual logic runs on entry of every queue activity to ensure the part follows the selected job path for the remainder of the work type.

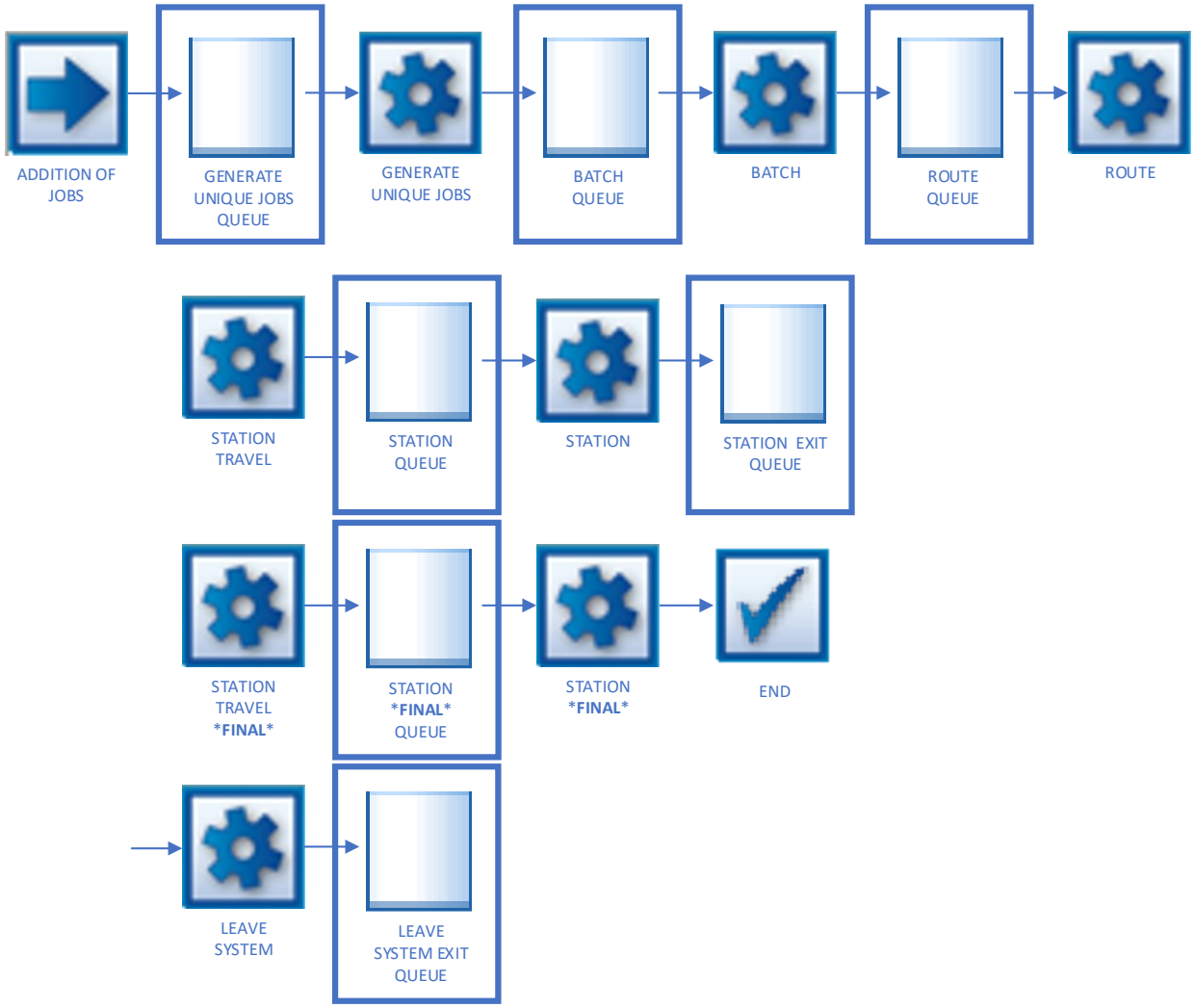

Figure 9 Simul8 Object Queues (Simul8, n. d.)

The simulation contains invisible activities that process information and station activities that process information but are visible in the physical environment. There are 52 activities that process information that do not have resources assigned to them. Those activities are, Generate Unique Jobs, Batch, Route, 48 Travel activities and Leave System.

The activity, Generate Unique Jobs, pulls jobs from the Generate Unique Jobs Queue by priority. It looks into the Component Batching Worksheet to set batch size and match it to the station. It counts the number of parts that need to be created for each job in the Component Worksheet and stores the batch value in the Batch label. The count will show 328 components, it is assumed all 328 components are needed.

Generate Unique Jobs circulates jobs out to the batch queue, ignoring blocked routes, then the count starts over (see Figure 10).

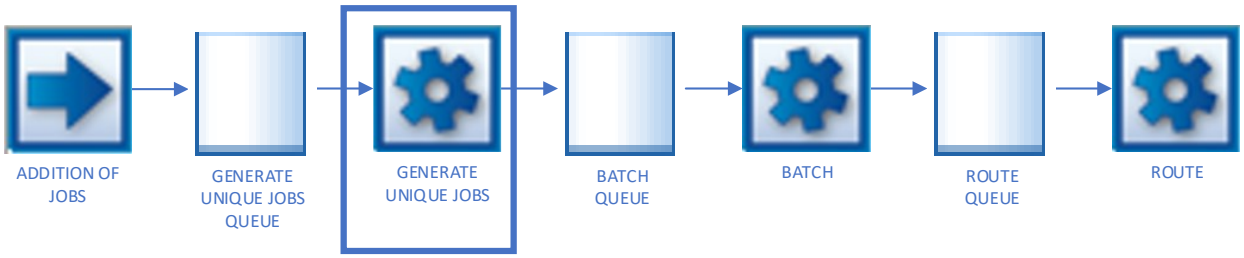

Figure 10 Simul8 Object Generate Unique Jobs Activity (Simul8, n. d.)

The Batch activity pulls jobs from the Batch queue by priority. The batching value found in the Batch label is looked up in the component worksheet. The job increases incrementally until the batch quantity shown in the Batch label matches the quantity in the worksheet, The Batch activity circulates jobs out to the route queue and ignores blocked routes (see Figure 11).

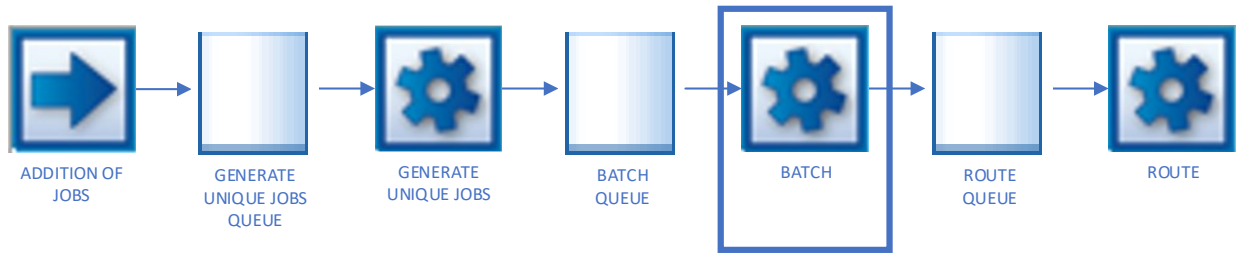

Figure 11 Simul8 Object Batch Activity (Simul8, n. d.)

The Route activity pulls jobs in from the Route queue by priority. It looks up the next station in the Job Path Worksheet matrix for routing out (see Figure 12).

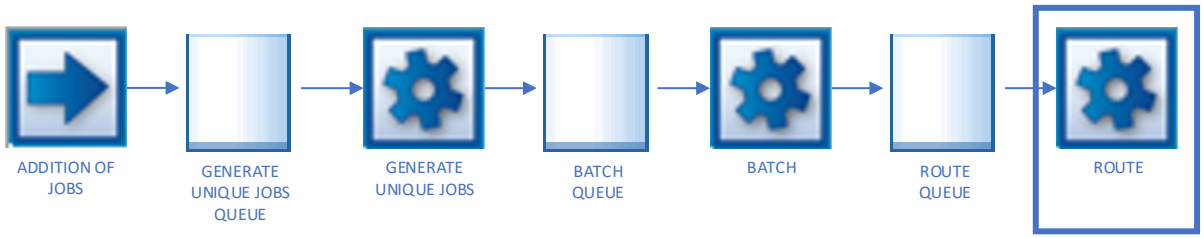

Figure 12 Simul8 Object Route Activity (Simul8, n. d.)

All travel activities pull jobs in by priority. Travel time is added at the Travel stations. Travel time is controlled using visual logic and points to the correct cell in the Time Matrix between Locations to dictate travel time (see Figure 13). If the station is different than the station in the previous step than the system will add the value to the wait time queue otherwise it will enter a 0. Visual logic code directs stations to delete travel time attached to it and then add the new travel time. The travel activities circulate jobs out to the next station queue, ignoring blocked routes.

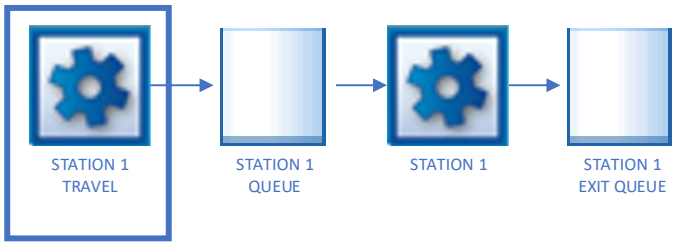

Figure 13 Simul8 Object Travel Station Activity (Simul8, n. d.)

The remaining 48 activities are stations with resources assigned. Visual logic is run at each station activity upon entry from the preceding queue. The station looks to the Job Matrix Worksheet for the next incremented job of the work item, returns the process time assigned and adds the travel time variable to the process time for the job (see Figure 14).

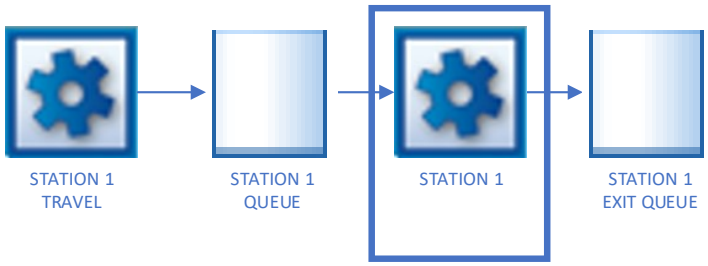

Figure 14 Simul8 Object Station Activity (Simul8, n. d.)

The activity, Leave System pulls jobs in by priority. Some parts will leave the system prior to reaching the final station. These jobs exit the system at the Leave System activity according to the Jobs Matrix Worksheet. Parts that leave the system early are smaller parts that marry to another job. The parts become one and exit to the next station as one job. These

combined parts are referred to as sub-assemblies. The smaller part enters the Leave System activity and then routes to the Leave System Queue (see Figure 15).

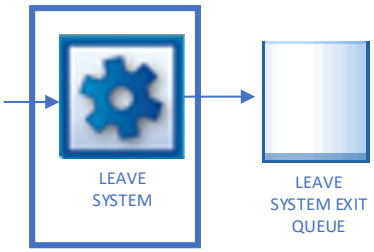

Figure 15 Simul8 Object Leave System Activity (Simul8, n. d.)

The Station *FINAL* is the final assembly station for all parts assembled. When all jobs for each of the 328 components have accumulated at the End object, the workorder is considered complete (see Figure 16).

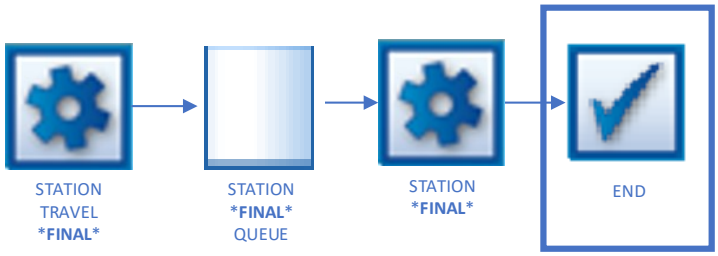

Figure 16 Simul8 Object End (Simul8, n. d.)

CHAPTER 6 SIMULATION RESULTS

Experimenting with different simulation scenarios produce results that can help influence operational improvements. Animating operational interactions bring unnoticed problems to light (Markgraf, n.d.).

6.1 Example Simulation

This example provides a framework for what the simulation results will look like. This example simulation will focus on one work item, component 127. There are 18 jobs for completing component 127. The interarrival rate for the example simulation was set with a fixed value of 1.

The Job Matrix Worksheet (Table 30) and the Job Path Worksheet (Table 31) are loaded to include only component 127. The Station to Resource Mapping (Table 15), Station to Location Mapping (Table 16), Time Matrix between Locations (Table 28), Component Batching (Table 29) are loaded the same as explained in 5.1 Worksheet Logic.

The results for the resources with the largest utilization is resource 15 utilizing 1 employee at 49.99%, followed by resource 3 utilizing 2 employees at 12.26% (see Table 10).

RESOURCE	UTILIZATION%	AVG USAGE	MAX USAGE
RESOURCE 2	4.99	1	1
RESOURCE 3	12.26	0.61	2
RESOURCE 7	0.61	0.08	1
RESOURCE 11	3.02	0.12	1
RESOURCE 12	7.76	1.01	2
RESOURCE 15	49.99	1	1

Table 10 Example Simulation Resource Results (Simul8, n.d.)

The activity results are displayed in Table 11. The location with the largest amount of completed jobs is station 24 with 11,661 jobs. Followed by station 4 with 482 jobs, station 2, station 5, station 7 and station 9 each with 481.

The stations with the largest percentage of jobs waiting are, station 1 at 98.24%, station 13 at 97.39% and station 9 at 93.77%. The largest percentage of activity locations working are stations 4 and 24 at 99.99%.

ACTIVITY	COMPLETED JOBS	AVG USAGE	% WAITING	% WORKING
Station 1	52	0.018	98.24	1.76
Station 2	481	0.13	87.37	12.63
Station 4	482	1	0.01	99.99
Station 5	481	0.24	75.58	24.42
Station 6	0	0	3.05	0
Station 7	481	0.18	81.96	18.04
Station 9	481	0.06	93.77	6.23
Station 13	52	0.03	97.39	2.32
Station 16	52	0.12	87.93	12.07
Station 18	209	0.341	65.90	34.1
Station 24	11,661	1	0.002	99.99

Table 11 Example Simulation Activity Results (Simul8, n.d.)

The results of queues with the largest number of items entered is station 24 with 23,508 items. Followed by station 4 with 11,661 items, station 5 with 1,444 items and station 18 with 690 items.

The standard deviation of the queues with the longest wait times are, station 4 with wait time of 64,967.73, station 18 with wait time of 53,850.51 and the station 24 with wait time of 34,528.17 (see Table 12).

QUEUE	CURRENT CONTENTS	ITEMS ENTERED	SIZE AVG	SIZE MAX	TIME MIN	TIME AVG	TIME MAX	TIME SD DEV
Station 1		156		2		0		
Station 2		481		1				
Station 4	11,178	11,661	5,586.81	11,178	583.69	112,776.83	224,319.38	64,967.73
Station 5		1444		2	4.971	0.01	4.971	
Station 7	52	52	25.19	52				
Station 9		481		1				
Station 13		52		1				
Station 16		52		1				
Station 18	480	690	237.45	430	2156.229	93,798.67	186,037.04	53,850.51
Station 24	11,846	23,508	5,992.45	11846	23.301	59,535.01	119,023.71	34,528.17

Table 12 Example Simulation Queue Results Queues (Simul8, n.d.)

6.2 Simulation I

The interarrival rate for the simulated prototype process was set with an Average distribution with a value of 1. This distribution was chosen because the data is built off of estimated averages and actual arrival times are unknown.

6.2.1 Resource Results

Resource utilizations are displayed in Table 38. The most efficient resource groups are 1, 3, 7 and 13.

Resource 1 is utilized on average 99.23% using 5 of 5 employees, maximum used is used is 5. Resource 3 is utilized on average, 99.63% using 5 of 5 employees. Resource 7 is utilized on average 99.46% using 10 of 10 employees. Resource 13 is utilized on average 99.46% using 13 of 13 employees.

Resources groups with more than an adequate number of employees are 2, 8, 9, 11, 12 and 16. Resource 2 is utilized on average 99.46% using 10 of 20 employees.

Resource 8 is utilized on average 95.73% using 4 of 100 nonexistent employees, maximum used is 4. On average, 1 employee per 4-hours is utilized. Resource 8 is built into the system for work that does not require a resource. Parts that must cure, dry or be machined are

constrained to sequencing but should not absorb a resource. There is no constraint to the number of parts that can be set aside at a time.

Resource 9 is utilized on average 2.98% using 3 of 100 employees. The elemental data for resource 11 was not completely captured and is why the results show this resource utilizes less than 1 of 2 employees at 0.14%.

Resource 12 is utilized on average 99.39% using 2 of 13 employees, maximum used is 2. Shop E utilizes resource group 12. Resource 12 lays up fiber glass parts from a mold and waits for parts to cure. Cure time for a fiber glass part is 16 hours. This operation should be investigated further to better understand why resource group 12 is underutilized. A logical reason could be that resource 12 spends a portion of time laying up parts and large portion of time waiting for those parts to cure. Station 9 pulls resources from resource group and 12 and 7. It is possible that resource group 12 is underutilized because station 9 is pulling resources from resource group 7 before it pulls from resource group 12.

Resource 16 is utilized on average 99.46% using 1 of 2 employees.

The resources groups without an adequate number of employees assigned are 6, 14, 15, 18 and 19. These resource groups should be considered bottlenecks.

Resource 6 is utilized on average 49.73% using 5 of 4 employees. The resources in group 6 need to work 125% to complete the work.

Resource 14 is utilized on average 42.39% using 5 to 8 of 5 employees. The resources in group 14, on average, need to work 100%. At maximum the resources in group 14 need to work 160% to complete the work.

Resource 15 is utilized on average 39.37% using 2 of 1 employee. The resources in group 15 need to work 200% to complete the work.

Resource 18 is utilized on average 7.59% using 8 to 10 of 5 employees. The resources in group 18, on average, need to work 160%. At maximum the resources in group 18 need to work 200% to complete the work.

Resource 19 is utilized on average 99.46% using 5 of 4 employees. The resources in group 19 need to work 125% to complete the work.

Resource group 5 is a pooled resource group and will not have results. Resource groups 10 and 17 does not have work assigned and will not have results.

6.2.2 Activity and Queue Results

Activity utilizations are displayed in Table 39 and queue results are shown in Table 40.

Resource 1 works at station 3 with a queue of 319 and 10 completed jobs.

Resource 2 works at station 4 with a queue of 26,336 and 207 completed jobs.

Resource 3 works at stations 5, 6, 10 and 36. Station 5 has a queue of 526 and 276 completed jobs. Station 6 has a queue of 91 and 185 completed jobs. Station 10 has a queue of 63 and 275 completed jobs. Station 36 has a queue of 3 and 271 completed jobs.

Resource 5 works at station 9 with a queue of 4,686 and no completed jobs.

Resource 6 works at station 13 with a queue of 46,985 and 716 completed jobs.

Resource 7 works at stations 1 with a queue of 280 and 18 completed jobs.

Resource 7 works at station 12 with a queue of 8,142 and 37 completed jobs.

Resource 8 works at stations 2, 7 and 14. Station 2 has a queue of 1 and 6 completed jobs. Station 7 has a queue of 2 and 23 completed jobs. Station 14 has no queue or completed jobs.

Resource 9 works at station 15 with a queue of 2,335 and no completed jobs.

Resource 11 works at stations 16 and 17 with a queue of 1 and 25 completed jobs. Station 17 has no queue and no completed jobs.

Resource 12 works at stations 11, 18, 26, 28, 35, 37, 39 and 44. Station 18 has a queue of 142 and 113 completed jobs. Station 26 has no queue and 175 completed jobs. Station 28 has a queue of 1 and 3 completed jobs. Station 37 has a queue of 4 and 73 completed jobs. Stations 11, 35, 39 and 44 have no queues or completed jobs.

Resource 13 works at station 19, 27, 29, 30, 31, 32, 33, 34, 38, 41, 42, 43 and 46. Station 19 has a queue of 7,967 and 63 completed jobs. Stations 27, 30, 33, 34 and 45 have no queues or

completed jobs. Station 29 has a queue of 1 and 1 completed job. Station 31 has no queue and 69 completed jobs. Station 32 has a queue of 154 and no completed jobs. Station 38 has a queue of 1 and 1 completed job. Station 41 has a queue of

2 and 4 completed jobs. Station 42 has a queue of 463 and 69 completed jobs. Station 43 has no queue and 1completed job. Station 46 has a queue of 596 and 2 completed jobs.

Resource 14 works at stations 21 and 22. Station 21 has a queue of 303 and 163 completed jobs. Station 22 has a queue of 351 and 41 completed jobs.

Resource 15 works at stations 20 and 23. Station 20 has a queue of 7 and 15 completed jobs. Station 23 has a queue of 1 and 18 completed jobs.

Resource 16 works at station 24. Station 24 has a queue of 64 and 41 completed jobs.

Resource 17 works at station 25. Station 25 has a queue of 125 and no completed jobs.

Resource 18 works at station 40 and 47. Station 40 has a queue of 987 and 163 completed jobs. Station 47 has a queue of 596 and 70 completed jobs.

Resource 19 works at station 48. Station 48 has a queue of 596 and 340 completed jobs.

6.3 Simulation II

The interarrival rate was set with an Average distribution with a value of 1. The simulation was loaded to run with a different allocation of resources for resource groups. This is done by changing the numeric digit in column C of the resource spreadsheet and then running the visual logic code (see Table 15).

Resource 18 was changed to 10. Resource 19 was changed to 5. Resource 6 was changed to 5. Resource 14 was changed to 7. Resource 15 was changed to 2. Resource 9 was changed to 2. Resource 8 was changed to 20.

The results did not show much fluctuation to the results seen previously in simulation I (see Table 41).

6.4 Simulation III

The interarrival rate was set with an average distribution with a value of 1. The allocation of resources was returned to the original numbers and station 2 was altered to pull resources from resource 12, instead of resource 8. The simulation is set up to change large amounts of data by adjusting one simple data point. This is done by changing the cell F3 in the resource spreadsheet from 8 to 12 and then running the visual logic code (see Table 15).

The results from that simulation do not vary much from simulation I, (see Table 42),

6.5 Simulation IV

The interarrival rate was set with an average distribution with a value of 1. The simulation was kept with station 2 pulling resources from resource group 12. Station 9 was adjusted to pull resources only from resource 12 and not from resource 7, by changing the cell F10 in the resources spreadsheet from 5 to 12 and then running the visual logic code (see Table 15).

6.5.1 Resource Results

When station 9 utilizes only resource group 12, the results change for resource groups 6, 8, 12, 14, 15, 16, 18 and 19 (see Table 43).

The resource results illustrated that resource group 6 decreased from utilizing 5 employees at 49.73% or 125% per employee, to 4 employees at 98.93%.

The resource results illustrated that resource group 8 increased from utilizing 4 employees at 95.73% to a maximum of 5 employees at 1.6%. Resource 8 is a placeholder for work that does not require a resource.

In this simulation, station 5 is assigned resources from group 12, instead of both groups 7 and 12. The utilization in resource group 12 became more efficient utilizing 2 to 10 of 13

resources 51.34%, compared to starving 11 employees. Although, the utilization in resource group 7 stayed the same.

The resource results illustrated resource group 14 utilized 1 to 4 of 5 employees 31.33%, compared to 5 to 8 employees at 42.93% or 160% per operator.

The utilization in resource group 15 became more efficient using 1 resource 97.14% of the time, compared to 2 resources at 39.37% or 200% per operator.

The utilization in resource group 16 became more efficient using both resources 98.63% of the time, compared to 1 resource at 99.46%.

The utilization in resource group 18 became more efficient using 5 of 5 resources 98.93% of the time, compared to utilizing 8 to 10 of 4 resources 7.59% of the time or 200%per operator.

This alleviates the bottlenecks at station 6, 14, 15 and 18 but not at station 19. The utilization in resource group 19 became less efficient using 8 of 4 resources 79.14% of the time, compared to utilizing 5 of 5 resources 99.46% of the time or 125% per operator.

6.5.2 Activity and Queue Results

When station 9 utilizes only resource group 12, the results change for stations 6, 13, 18, 22, 24, 25, 32, 46, 47, and 48 (see Table 44 and Table 45).

Resource 1 works at station 3 with a queue of 319 and 10 completed items.

Resource 2 works at station 4 with a queue of 26,336 and 207 completed items.

Resource 3 works at stations 5, 6, 10 and 36. Station 5 has a queue of 551 and 279 completed items. Station 6 has a queue of 1 and 89 completed items, compared to a queue of 91 and 185 completed jobs. Station 10 has a queue of 56 and 278 completed items. Station 36 has a queue of 3 and 225 completed items.

Resource 5 works at station 9 with no queue or completed items.

Resource 6 works at station 13 with a queue of 47,144 and 548 completed items. Compared to a queue of 46,985 and 716 completed jobs

Resource 7 works at station 1 and 12. Station 1 has a queue of 435 and 20 completed items. Station 12 has a queue of 8,146 and 37 completed items.

Resource 8 works at station 2, 7, 8 and 14. Station 2 has a queue of 1 and 17 completed items. Station 7 has a queue of 1 and 20 completed items. Station 8 and 14 has no queue or completed items.

Resource 9 works at station 15. Station 15 has a queue of 2,335 and no completed items.

Resource 11 works at station 16 and 17. Station 16 has a queue of 1 and 21 completed items. Station 17 has no queue or completed items.

Resource 12 works at station 11, 18, 26, 28, 35, 37, 39 and 44. Stations 11, 27, 35, 39 and 44 have no queues or completed items. Station 18 has a queue of 1 and 360 completed items, compared to a queue of 142 and 113 completed jobs. Station 26 has a queue of 43 and 126 completed items. Station 28 has no queue and 3 completed items. Station 37 has a queue of 1 and 73 completed items. Station 44 has no queue and no completed items.

Resource 13 works at station 19, 27, 29, 30, 31, 32, 33, 34, 38, 41, 42, 43, 45 and 46. Station 19 has a queue of 7,957 and 64 completed items. Stations 27, 30, 31, 33 and 34 have no queues or completed items. In comparison, station 31 has 69 completed jobs in simulation I. Station 29 has no queue and 1 completed item. Station 32 has a queue of 153 and 70 completed items, compared to a queue of 154 and no completed jobs. Station 34 has no queue and no completed items. Station 38 has no queue and 1 completed item. Station 41 has a queue of 2 and 4 completed items. Station 42 has a queue of 477 and 71 completed items. Station 43 has a queue of 1 and 1 completed item. Station 45 has no queue and 2 completed items. Station 46 has a queue of 594 and 72 completed items, compared to a queue of 596 and 2 completed jobs.

Resource 14 works at stations 21 and 22. Station 21 has a queue of 303 and 163 completed jobs. Station 22 has a queue of 351 and 41 completed jobs, compared to a queue of 77 and 41 completed items.

Resource 15 works at stations 20 and 23. Station 20 has a queue of 7 and 15 completed jobs. Station 23 has a queue of 1 and 18 completed jobs.

Resource 16 works at station 24 with a queue of 83 and 82 completed items, compared to a queue of 64 and 41 completed jobs.

Resource 17 works at station 25 with no queue and no completed items, compared to a queue of 125.

Resource 18 works at stations 40 and 47. Station 40 has a queue of 992 and 128 completed items. Station 47 has a queue of 212 and 126 completed items, compared to a queue of 596 and 70 completed jobs.

Resource 19 works at station 48 with a queue of 3,933 and 90 completed items, compared to a queue of 596 and 340 completed jobs.

Resource 3 changed because of station 6. Resource 6 changed because of station 13. Resource 12 changed because of station 18. Resource 13 changed because of station 32 and 46. Resource 14 changed because of station 22. Resource 16 changed because of station 24. Resource 17 changed because of station 25. Resource 18 changed because of station 47. Resource 19 changed because of station 48.

6.6 Simulation V

The simulation was reverted to its original state and the interarrival times were changed to an Exponential distribution with an average of 1. The Exponential distribution was chosen because it is similar to the way the operation behaves for order arrival. This distribution represents time between random occurrences independent of each other. Orders arrive in clusters instead of timed arrivals with this distribution.

6.6.1 Resource Results

Resource utilizations improve for resource groups 6, 8, 12, 14, 15, 16 and 18. (see Table 46). Resource 6 is more efficient using 4 of 4 employees compared to 5. Resource 8 is more efficient using 9 of 100 employees compared to 4. Resource 12 is more efficient using 11 of 13 employees compared to 2. Resource 14 is more efficient using 5 of 5 employees compared to 8. Resource 15 is more efficient using 1 of 1 employee compared to 2. Resource 16 is more efficient using 2 of 2 employees compared to 1. Resource 18 is more efficient using 5 of 5 employees compared to 10.

Resource 19 is less efficient using 8 of 4 employees compared to 5.

6.7 Simulation VI

The simulation was reverted to its original state and the interarrival times adjusted to a Normal distribution with an average of 1 and a standard deviation of 6. The Normal distribution was chosen to avoid the likelihood of extreme high or low values due to variability, so that 95% of samples fall within +/-6 standard deviations within the mean.

6.7.1 Resource Results

Resource utilizations improve for resource groups 6, 8, 12, 14, 15, 16, 18 and 19 (see Table 46). Resource 6 is more efficient using 4 of 4 employees compared to 5. Resource 8 is more efficient using 17 of 100 employees compared to 4. Resource 12 is more efficient using 12 of 13 employees compared to 2. Resource 14 is more efficient using 5 of 5 employees compared to 8. Resource 15 is more efficient using 1 of 1 employee compared to 2. Resource 18 is more efficient using 5 of 5 employees compared to 10.

Resource 19 is less efficient using 8 of 4 employees compared to 5.

6.8 Simulation VII

The simulation was reverted to its original state and the interarrival times were opened to allow for more variability. The Weibull distribution was chosen because it allows for more versatility when dealing with multiple data sets. The distribution was set to an alpha of 1, a beta of 1 and min of 1.

6.8.1 Resource Results

Resource utilizations improve for resource groups 6, 8, 12, 14, 15, 16 and 18 (see Table 46). Resource 6 is more efficient using 4 of 4 employees compared to 5. Resource 8 is more efficient using 16 of 100 employees compared to 4. Resource 11 is more efficient using 3 of 5 employees compared to 2. Resource 12 is more efficient using 11 of 13 employees compared to 2. Resource 14 is more efficient using 5 of 5 employees compared to 8. Resource 15 is more efficient using 1 of 1 employee compared to 2. Resource 16 is more efficient using 2 of 2 employees compared to 1. Resource 18 is more efficient using 5 of 5 employees compared to 10.

Resource 19 is less efficient using 8 of 4 employees compared to 5.

6.8.2 Activity and Queue Results

The Weibull distribution activity results are shown in Table 47 and the queue results are shown in Table 48.

Resource 1 works at station 3 with a queue of 162 and 10 completed items.

Resource 2 works at station 4 with a queue of 13,776 and 206 completed items.

Resource 3 works at station 5, 6, 10 and 36. Station 5 has a queue of 317 and 367 completed items. Station 6 has a queue of 1 and 133 completed items. Station 10 has a queue of 6 and 255 completed items.

Resource 5 works at station 9 with a queue of 2,410 and 0 completed items.

Resource 6 works at station 13 with a queue of 24,637 and 540 completed items.

Resource 7 works at station 1 and 12. Station 1 has a queue of 275 and 23 completed items. Station 12 has a queue of 4,297 and 38 completed items.

Resource 8 works at stations 2, 7, 8 and 14. Station 2 has no queue and 49 completed items. Station 7 has a queue of 12 and 22 completed items. Station 8 has no queue or completed items. Station 14 has no queue or completed items.

Resource 9 works at station 15 with a queue of 1,229 and 0 completed items.

Resource 11 works at station 16 and 17. Station 16 has a queue of 1 and 24 completed items. Station 17 has no queue or completed items.

Resource 12 works at stations 11, 18, 26, 28 35, 37, 39 ad 44. Station 11 has no queue or completed items. Station 18 has a queue of 1 and 290 completed items. Station 26 has no queue and 97 completed items. Station 28 has no queue and 6 completed items. Station 35 has no queue or completed items. Station 37 has no queue and 73 completed items. Station 39 has no queue or completed items. Station 44 has no queue or completed items.

Resource 13 works at stations 19, 27, 29, 30, 31, 32, 33, 34, 38, 41, 42, 43, 45 and 46. Station 19 has a queue of 4,165 and 63 completed items. Stations 27, 31, 34, 43 and 41 has no queue or completed items. Station 29 has no queue and 4 completed items Stations 30, 33 and 38 have no queue and 1 completed items. Station 32 has no queue and 71 completed items. Stations 42 and 46 have no queue and 72 completed items. Station 45 has no queue and 2 completed items.

Resource 14 works at stations 21 and 22. Station 21 has a queue of 200 and 118 completed items. Station 22 has a queue of 4 and 36 completed items.

Resource 15 works at stations 20 and 23. Station 20 has a queue of 8 and 8 completed items. Station 23 has a queue of 80 and 8 completed items.

Resource 16 works at station 24 with a queue of 8 and 78 completed items.

Resource 17 works at station 25 with no queue or completed items.

Resource 18 works at stations 40 and 47. Station 40 has no queue or completed items. Station 47 has a queue of 67 and 118 completed items.

Resource 19 works at station 48 with a queue of 2,037 and 90 completed items.

6.9 Simulation Results

The simulation providing the best throughput for all groups was the Weibull distribution (see 6.8 Simulation VII). The results proved a bottleneck at station 48, resource group 19. Resource 19 needs to work at 200% using 8 of 4 allocated employees. Station 48 carries a queue of 2,037 and completes only 90 items. Station 48 is at the beginning of the process and feeds station 1. There are 15 components that enter into station 48, these components should be considered the longest lead items (see Table 37).

CHAPTER 7 CONCLUSION

The Design Operations Team has the capability of eliminating human capital overreduction and increasing production by becoming more efficient. The workflow stack-up within Design Operations was analyzed. Data from the workorder system was reviewed, the results were not optimal. Milling data was gathered and aggregated but proved unrewarding. Process steps and associated time values were written and added to a simulation program. The simulation results prove that quality inputs have a direct impact on the results produced from the simulation.

The workorder system plays an instrumental role in the functions of data mining, process control, operational transparency and seamless communications. Robust process implementation and enriched team behavior enhance; part visibility, forecasts, cost reduction, headcount justification and volume growth.

7.1 Recommendations

The current workorder system is a valuable tracking system for workorders. Enhancing the capabilities of the workorder system will eliminate cumbersome data mining, simplify tracking workorders and provide cleaner data. Controls should be added to the workorder system to decrease the time spent mining data.

When a work order is initiated, the ID and title fields should be automatically complied. The ID should be a numeric number reflecting the exact date and time of when the user pushes the submit button. This ID will stay with the workorder and the workorder subcomponents through the duration of the work order.

There should be additional fields with predetermined lists consisting of the program, model year, supporting milestone topic, property (prototype) requested, action, model size and theme (see Figure 17).

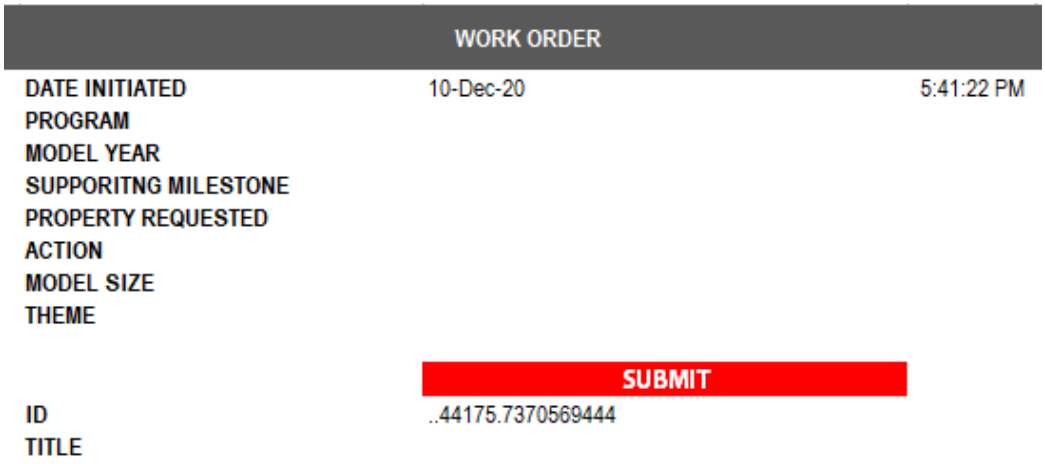

Figure 17 Work Order

As new programs are introduced, the list for the program field will need to be loaded with new program codes (see Figure 18).

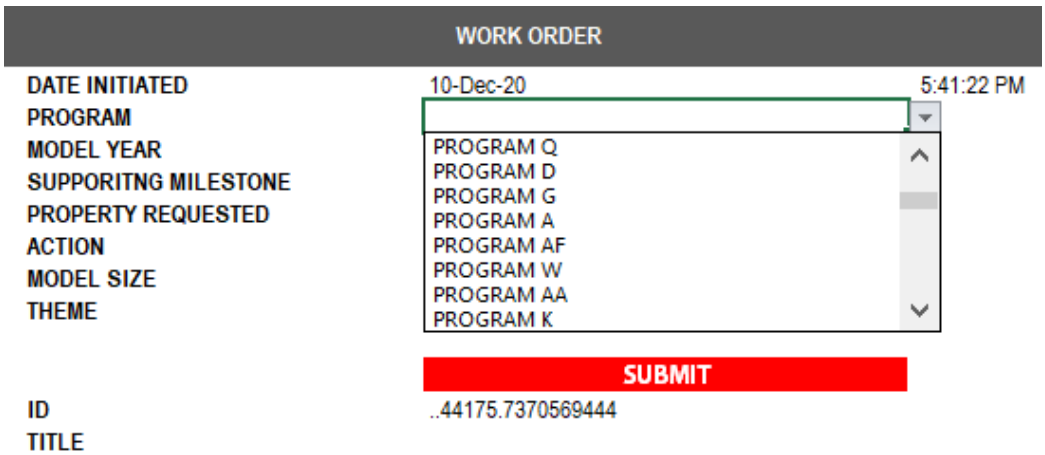

Figure 18 Work Order Program

After the user chooses a program, the ID and the title should update to reflect the program. The model year is chosen next (see Figure 19).

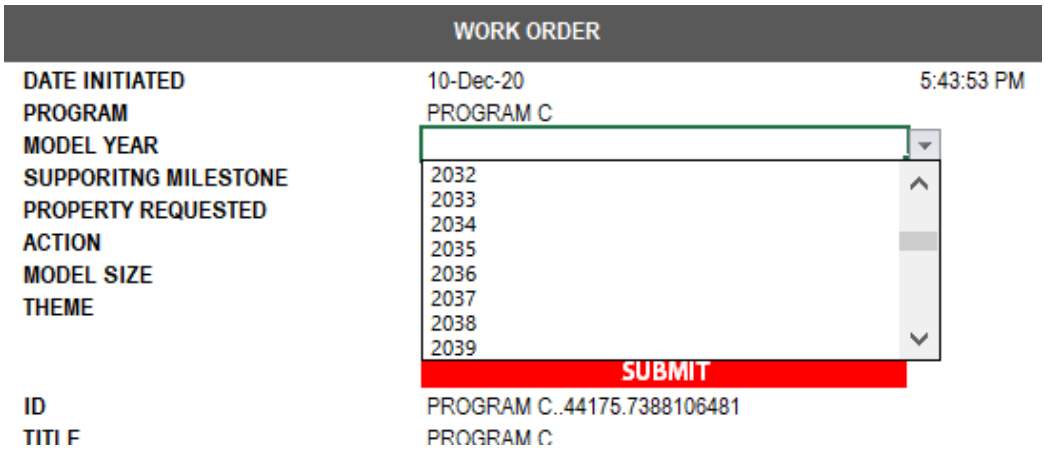

Figure 19 Work Order Model Year

After the user chooses a model year, the ID should update to reflect the model year. The supporting milestone topic is chosen next (see Figure 20).

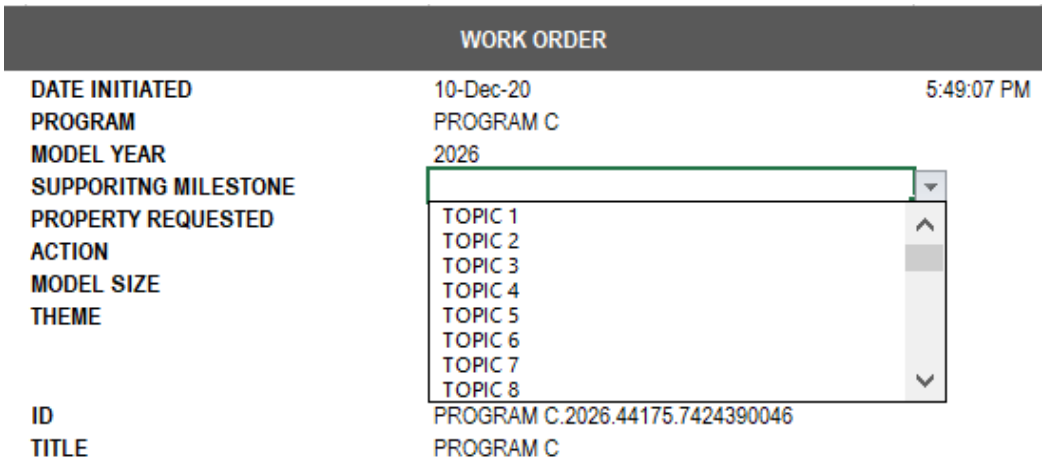

Figure 20 Work Order Topic

After the user chooses a milestone topic, the title should update to reflect the milestone topic. The property type requested is chosen next (see Figure 21).

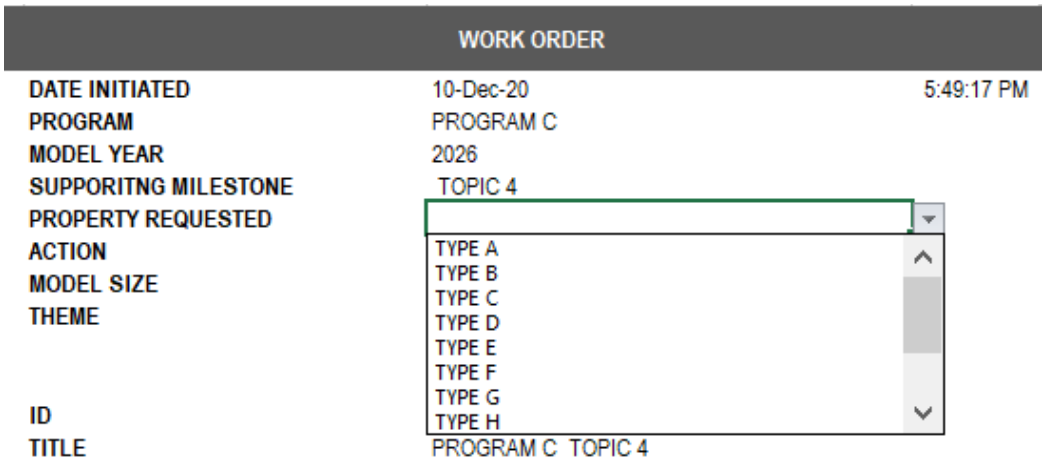

Figure 21 Work Order Property Type

After the user chooses a property type, the title should update to reflect the property type. The action field is chosen next. The action field distinguishes whether the work will be carried out in the shops or outsourced (see Figure 22).

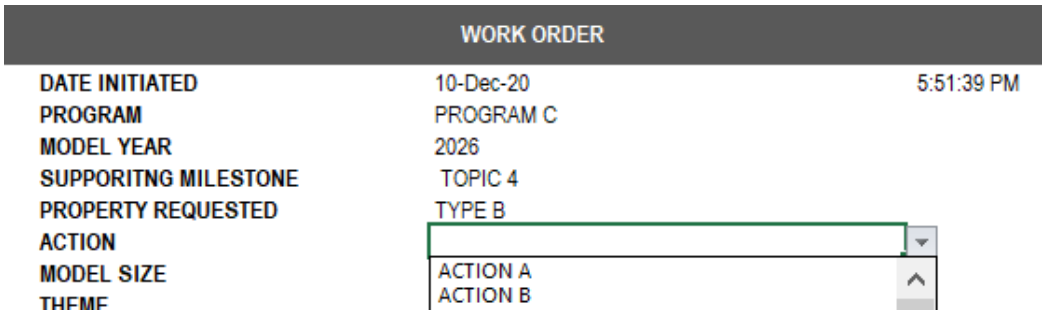

Figure 22 Work Order Action

The remaining fields consist of the model size (see Figure 23) and theme (see Figure 24).

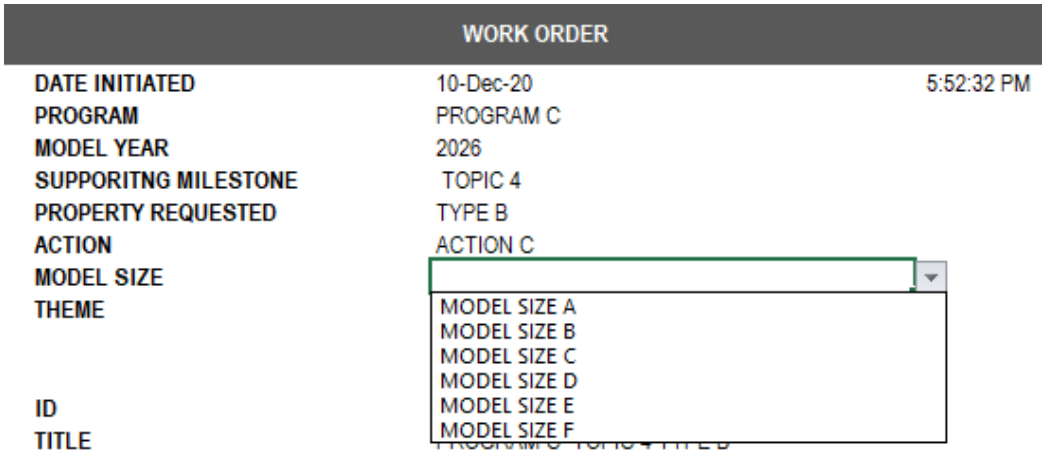

Figure 23 Work Order Model Size

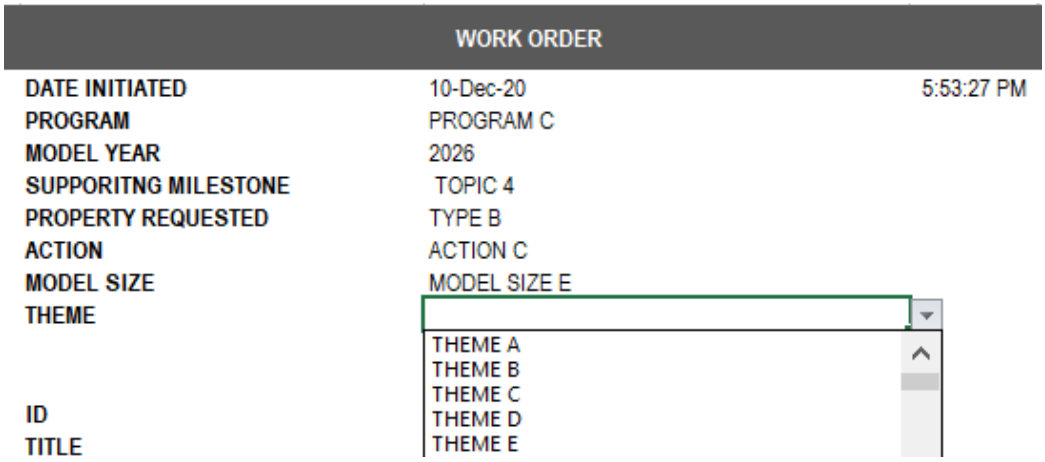

Figure 24 Work Order Theme

Figure 25 illustrates a completed work order ready for submission. Once the work order is submitted a list of components should be compiled as the workorder BOM.

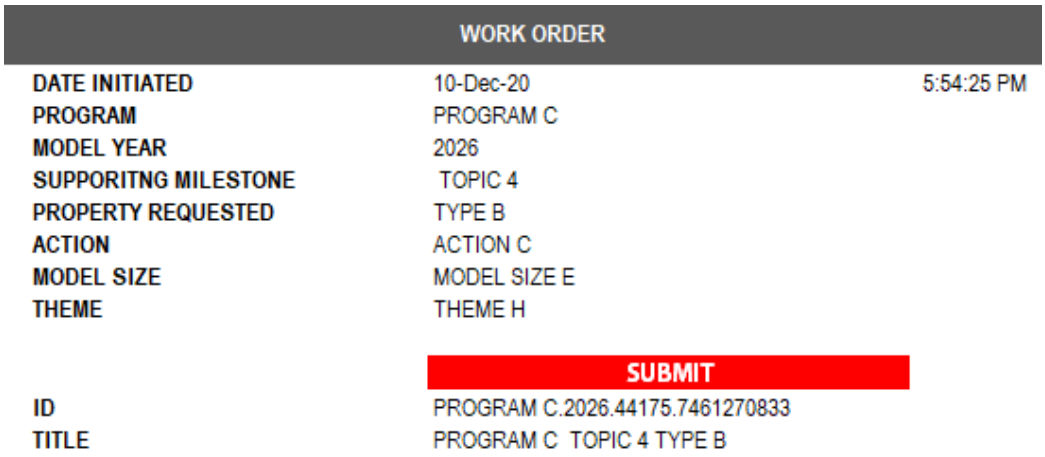

Figure 25 Work Order Submit

A standardized BOM for each prototype model and model size will need to be built and added to the work order system. The codes for the model type and model size should pull the generic components list and output a BOM.

The next step is to adjust the generic BOM to reflect the distinct prototype. There should be an option to remove components that are not built in the shops by labeling those components as outsourced, purchased or not needed. For components built in the shops, if there are multiple manufacturing methods available for a component, there should be an option if a particular manufacturing method is preferred (see Figure 26).

WORK ORDER BOM BUILDER

ID	Program C.2026.44175.7461270833
TITLE	PROGRAM C TOPIC 4 TYPE B

	COMPONENT	BOM	MANUFACTURING PROCESS
1	COMPONENT 1	SHOP BUILD	B
2	COMPONENT 2	CARRY OVER	NA
3	COMPONENT 3	SHOP BUILD	ANY
4	COMPONENT 4	NOT NEEEDED	NA
5	COMPONENT 5	OUTSOURCE	E
6	COMPONENT 6	PURCHASED PART	NA

SUBMIT

Figure 26 Work Order BOM Builder

When all components are labeled appropriately and the manufacturing preference is decided, the BOM should be complete. Submitting the work order BOM should create a work order shop schedule for each component (see Figure 27).

WORK ORDER SHOP SCHEDULER

		START	END
ID	Program C.2026.44175.7461270833	12/11/2020	EXIT DAY
TITLE	Program C Topic 4 Type B	3:50:30 PM	EXIT Scan 6
COMPONENT	COMPONENT 4		

JOB	STATION	ACTION	QUANTITY	START TIME	END TIME	EMPLOYEE
1	STATION 22	JOB C	1	BEGIN Scan 1	EXIT Scan 1	EMPLOYEE 1
2	STATION 16	JOB K	1	BEGIN Scan 2	EXIT Scan 2	EMPLOYEE 2
3	STATION 3B	JOB F	1	BEGIN Scan 3	EXIT Scan 3	EMPLOYEE 3
4	STATION 15	JOB D	1	BEGIN Scan 4	EXIT Scan 4	EMPLOYEE 4
5	STATION 23	JOB J	1	BEGIN Scan 5	EXIT Scan 5	EMPLOYEE 5
6	STATION 3B	JOB G	1	BEGIN Scan 6	EXIT Scan 6	EMPLOYEE 6

Figure 27 Work Order Shop Scheduler

A more disciplined approach to the scanning process should be implemented. Work should be initiated by the employee working on a component. Their employee number should be retained for the job worked in the employee column within the component workorder shop schedule. Scan times should be retained in the start time and exit time columns, within the component workorder shop schedule.

7.2 Future System

Further investigation is required to answer if the studios are producing at their best. The lack of complete elemental data weakens the assessments' accuracy, impacting system behavior negatively. Firm data collection must continue to ensure process times are accurate.

Distinguishing if there is adequate head count cannot be answered in complete confidence until all aspects are gathered and added to the simulation. All prototypes produced in the studios need to be evaluated and added to the simulation. When all work within DOT has been accurately measured, then the data derived from the simulation can be utilized to establish the heartbeat or Takt time of the system (iSixSigma.com, n.d.).

The simulation should encompass more than the physical build elements. Program meeting cadences and adjacent functions that effect deadlines should be incorporated.

Forecasts should be compared to actual program budgets and examined for absent data. When the forecast proves true to actual data, then fact-based statements surrounding whether work is value added can be supported.

APPENDICES

APPENDIX I SIMULATION DATA INPUTS

MANUFACTURING PROCESS		COMPONENT	PATH OPTION			
			1	2	3	4
A	1	Component 1	G	B		
B	2	Component 5	B	G		
C	3	Component 48	B	E	G	
D	4	Component 54	B	E	G	
E	5	Component 61	E	G		
F	6	Component 74	B	G		
G	7	Component 169	G	B		
H	8	Component 177	F	A		
I	9	Component 216	I	J		
J	10	Component 228	E	B		
	11	Component 276	C	D	H	I
	12	Component 223	E	B		

Table 13 Component Path Options

PATH ROUTES PER MANUFACTURING PROCESS									
A	B	C	D	E	F	G	H	I	J
Station4	Station4	Station5	Station4	Station9	Station4	Station4	Station4	Station4	Station4
Station5	Station5	Station10	Station5	Station26	Station5	Station5	Station5	Station13	Station21
Station10	Station10	Station36	Station10	Station4	Station10	Station10	Station10	Station12	Station22
Station36	Station36	Station5	Station36	Station21	Station36	Station36	Station36	Station16	Station16
Station5	Station5	Station6	Station5	Station21	Station5	Station5	Station5	Station7	Station7
Station6	Station6	Station42	Station6	Station22	Station6	Station6	Station6	Station9	Station13
Station5	Station5	Station18	Station42	Station1	Station5	Station5	Station42	Station8	Station9
Station18	Station18	Station12	Station18	Station16	Station18	Station12	Station18		
Station12	Station18	Station12	Station12	Station7	Station12	Station18	Station12		
Station18	Station2	Station18	Station12	Station26	Station18	Station1	Station12		
Station37	Station18	Station42	Station18	Station8	Station37	Station18	Station18		
Station47	Station12	Station42	Station42		Station47	Station16	Station42		
Station37	Station18	Station16	Station42		Station37	Station7	Station42		
Station8	Station12	Station7	Station16		Station8	Station9	Station16		
	Station26	Station42	Station7			Station8	Station7		
	Station18	Station8	Station42				Station42		
	Station16		Station8				Station8		

Table 14 Path Routes per Manufacturing Process

	A	B	C	D	E	F
1	Resource CODE	Resource	HEADS		STATION	STATION CODE
2	1	Resource 1	5		Station 1	7
3	2	Resource 2	20		Station 2	8
4	3	Resource 3	5		Station 3	1
5	4	Resource 4	4		Station 4	2
6	5	Resource 5	23		Station 5	3
7	6	Resource 6	4		Station 6	3
8	7	Resource 7	10		Station 7	8
9	8	Resource 8	100		Station 8	8
10	9	Resource 9	100		Station 9	5
11	10	Resource 10	5		Station 10	3
12	11	Resource 11	2		Station 11	12
13	12	Resource 12	13		Station 12	7
14	13	Resource 13	13		Station 13	6
15	14	Resource 14	5		Station 14	8
16	15	Resource 15	1		Station 15	9
17	16	Resource 16	2		Station 16	11
18	17	Resource 17	100		Station 17	11
19	18	Resource 18	5		Station 18	12
20	19	Resource 19	4		Station 19	13
21					Station 20	15
22	POOL Resources from				Station 21	14
23	Resources Groups 7 and 12				Station 22	14
24					Station 23	15
25					Station 24	16
26					Station 25	17
27					Station 26	12
28					Station 27	13
29					Station 28	12
30					Station 29	13
31					Station 30	13
32					Station 31	13
33					Station 32	13
34					Station 33	13
35					Station 34	13
36					Station 35	12
37					Station 36	3
38					Station 37	12
39					Station 38	13
40					Station 39	12
41					Station 40	18
42					Station 41	13
43					Station 42	13
44					Station 43	13
45					Station 44	12
46					Station 45	13
47					Station 46	13
48					Station 47	18
49					Station 48	19

Table 15 Station to Resource Mapping

	A	B	C	D	E
1	Location CODE	Locations		Station	Station CODE
2	1	Location 1		Station 1	1
3	2	Location 2		Station 2	8
4	3	Location 3		Station 3	14
5	4	Location 4		Station 4	14
6	5	Location 5		Station 5	2
7	6	Location 6		Station 6	2
8	7	Location 7		Station 7	7
9	8	Location 8		Station 8	14
10	9	Location 9		Station 9	5
11	10	Location 10		Station 10	3
12	11	Location 11		Station 11	8
13	12	Location 12		Station 12	4
14	13	Location 13		Station 13	6
15	14	Location 14		Station 14	14
16	15	Location 15		Station 15	14
17				Station 16	7
18				Station 17	7
19				Station 18	8
20				Station 19	9
21				Station 20	10
22				Station 21	11
23				Station 22	12
24				Station 23	10
25				Station 24	14
26				Station 25	14
27				Station 26	8
28				Station 27	9
29				Station 28	9
30				Station 29	9
31				Station 30	9
32				Station 31	9
33				Station 32	9
34				Station 33	9
35				Station 34	9
36				Station 35	8
37				Station 36	2
38				Station 37	8
39				Station 38	9
40				Station 39	8
41				Station 40	13
42				Station 41	9
43				Station 42	9
44				Station 43	9
45				Station 44	8
46				Station 45	9
47				Station 46	9
48				Station 47	13
49				Station 48	15

Table 16 Station to Location Mapping

Shop A	Supervisor 2	TOTAL
Shop A	2	2
Location 2	2	2
Resource 3	2	2
Station 5	1	1
Station 6	1	1
Grand Total	2	2

Table 17 Shop A Allocations

Shop B	Supervisor 4	TOTAL
Shop B	4	4
Location 1	1	1
Resource 7	1	1
Station 1	1	1
Location 4	1	1
Resource 7	1	1
Station 12	1	1
Location 5	1	1
Resource 5	1	1
Station 9	1	1
Location 6	1	1
Resource 6	1	1
Station 13	1	1
Grand Total	4	4

Table 18 Shop B Allocations

Shop C	NONE	Supervisor 2	TOTAL
Shop C	1	1	2
Location 14	1		1
Resource 8	1		1
Station 14	1		1
Location 3		1	1
Resource 3		1	1
Station 10		1	1
Grand Total	1	1	2

Table 19 Shop C Allocations

Shop D	Supervisor 6	TOTAL
Shop D	2	2
Location 7	2	2
Resource 11	2	2
Station 16	1	1
Station 17	1	1
Grand Total	2	2

Table 20 Shop D Allocations

SHOP E	Supervisor 2	Supervisor 3	Supervisor 4	Supervisor 6	TOTAL
Shop E	1	1	2	8	12
Location 11			1		1
Resource 14			1		1
Station 21			1		1
Location 12			1		1
Resource 14			1		1
Station 22			1		1
Location 2	1				1
Resource 3	1				1
Station 36	1				1
Location 7				1	1
Resource 8				1	1
Station 7				1	1
Location 8		1		7	8
Resource 12		1		6	7
Station 11				1	1
Station 18				1	1
Station 26		1			1
Station 35				1	1
Station 37				1	1
Station 39				1	1
Station 44				1	1
Resource 8				1	1
Station 2				1	1
Grand Total	1	1	2	8	12

Table 21 Shop E Allocations

Shop F	Supervisor 1	TOTAL
Shop F	15	15
Location 9	15	15
Resource 12	1	1
Station 28	1	1
Resource 13	14	14
Station 19	1	1
Station 27	1	1
Station 29	1	1
Station 30	1	1
Station 31	1	1
Station 32	1	1
Station 33	1	1
Station 34	1	1
Station 38	1	1
Station 41	1	1
Station 42	1	1
Station 43	1	1
Station 45	1	1
Station 46	1	1
Grand Total	15	15

Table 22 Shop F Allocations

Shop G	Supervisor 2	TOTAL
Shop G	2	2
Location 10	2	2
Resource 15	2	2
Station 20	1	1
Station 23	1	1
Grand Total	2	2

Table 23 Shop G Allocations

Shop H	Supervisor 5	TOTAL
Shop H	1	1
Location 14	1	1
Resource 17	1	1
Station 25	1	1
Grand Total	1	1

Table 24 Shop H Allocations

Shop I	Supervisor 3	TOTAL
Shop I	2	2
Location 13	2	2
Resource 18	2	2
Station 40	1	1
Station 47	1	1
Grand Total	2	2

Table 25 Shop I Allocations

Shop J	NONE	Supervisor 1	Supervisor 3	Supervisor 4	TOTAL
Shop J	1	1	2	1	5
Location 14	1	1	2	1	5
Resource 1				1	1
Station 3				1	1
Resource 16			1		1
Station 24			1		1
Resource 2		1			1
Station 4		1			1
Resource 8	1				1
Station 8	1				1
Resource 9			1		1
Station 15			1		1
Grand Total	1	1	2	1	5

Table 26 Shop J Allocations

Shop K	Supervisor 2	TOTAL
Shop K	1	1
Location 15	1	1
Resource 19	1	1
Station 48	1	1
Grand Total	1	1

Table 27 Shop K Allocations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	TIME **WALK**	Location 1	Location 2	Location 3	Location 4	Location 5	Location 6	Location 7	Location 8	Location 9	Location 10	Location 11	Location 12	Location 13	Location 14	Location 15
2	Location 1		6.92	5.04	0.78	0.30	1.04	4.44	1.16	5.78	3.18	0.82	0.92	3.02	0.00	2.10
3	Location 2	7.08		9.28	6.94	6.90	7.50	4.44	8.38	10.44	7.14	8.30	8.30	8.42	0.00	7.04
4	Location 3	5.04	9.28		4.20	4.16	4.76	9.28	5.40	7.26	5.20	5.40	5.40	5.44	0.00	3.82
5	Location 4	0.62	7.44	4.20		0.46	0.42	5.26	1.62	6.46	4.60	1.14	1.26	5.48	0.00	2.66
6	Location 5	0.36	6.98	4.16	0.04		0.60	4.80	1.16	4.78	3.54	0.68	0.80	5.02	0.00	2.20
7	Location 6	1.04	7.62	4.76	0.54	0.64		5.44	2.44	4.62	4.18	1.04	2.20	4.94	0.00	2.84
8	Location 7	4.44	4.42	5.84	4.90	4.86	5.46		4.98	6.42	4.66	3.18	3.18	4.98	0.00	4.34
9	Location 8	1.02	8.56	5.40	2.34	1.02	2.32	5.02		6.04	4.26	0.84	0.76	4.28	0.00	2.36
10	Location 9	5.78	10.44	7.26	5.16	5.26	4.62	6.18	6.04		4.00	5.00	5.00	4.32	0.00	4.74
11	Location 10	3.18	7.14	5.20	4.60	3.54	4.18	4.66	4.26	4.00		3.30	3.30	1.16	0.00	4.06
12	Location 11	0.82	2.36	5.40	0.62	0.58	1.18	4.70	0.82	6.20	3.30		0.42	4.20	0.00	2.50
13	Location 12	0.92	2.36	5.40	0.86	0.82	2.48	4.70	0.54	6.20	3.30	0.40		4.20	0.00	2.50
14	Location 13	3.02	0.62	5.44	3.80	3.32	4.06	5.00	4.74	1.16	1.16	4.26	4.26		0.00	4.08
15	Location 14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
16	Location 15	2.26	7.04	3.82	0.10	0.06	0.66	4.34	2.58	4.98	4.06	2.40	2.40	3.14	0.00	

Table 28 Time Matrix Between Locations

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
2	Component 1	1	2	26
3	Component 2	2	2	2
4	Component 3	3	1	18
5	Component 4	4	4	1
6	Component 5	5	1	24
7	Component 6	6	2	1
8	Component 7	7	1	18
9	Component 8	8	4	1
10	Component 9	9	1	18
11	Component 10	10	4	1
12	Component 11	11	1	3
13	Component 12	12	1	31
14	Component 13	13	1	18
15	Component 14	14	1	2
16	Component 15	15	1	8
17	Component 16	16	8	1
18	Component 17	17	1	18
19	Component 18	18	1	2
20	Component 19	19	1	18
21	Component 20	20	4	1
22	Component 21	21	1	18
23	Component 22	22	6	1
24	Component 23	23	1	18
25	Component 24	24	1	2
26	Component 25	25	1	18
27	Component 26	26	6	1
28	Component 27	27	1	18
29	Component 28	28	1	2
30	Component 29	29	1	18
31	Component 30	30	6	1
32	Component 31	31	1	4
33	Component 32	32	1	18
34	Component 33	33	4	1
35	Component 34	34	1	18
36	Component 35	35	4	1
37	Component 36	36	1	3
38	Component 37	37	1	2
39	Component 38	38	1	8
40	Component 39	39	1	1
41	Component 40	40	1	11
42	Component 41	41	2	12
43	Component 42	42	1	4
44	Component 43	43	2	12
45	Component 44	44	1	19
46	Component 45	45	2	1
47	Component 46	46	1	19
48	Component 47	47	1	1
49	Component 48	48	1	47
50	Component 49	49	1	3
51	Component 50	50	1	16
52	Component 51	51	1	1
53	Component 52	52	1	6
54	Component 53	53	1	12

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
55	Component 54	54	1	47
56	Component 55	55	1	3
57	Component 56	56	1	8
58	Component 57	57	1	11
59	Component 58	58	1	9
60	Component 59	59	1	4
61	Component 60	60	2	1
62	Component 61	61	1	27
63	Component 62	62	4	2
64	Component 63	63	1	16
65	Component 64	64	1	1
66	Component 65	65	1	4
67	Component 66	66	1	11
68	Component 67	67	2	1
69	Component 68	68	1	11
70	Component 69	69	1	10
71	Component 70	70	1	11
72	Component 71	71	1	12
73	Component 72	72	1	6
74	Component 73	73	1	11
75	Component 74	74	1	26
76	Component 75	75	2	2
77	Component 76	76	1	16
78	Component 77	77	6	1
79	Component 78	78	1	8
80	Component 79	79	1	2
81	Component 80	80	2	8
82	Component 81	81	1	6
83	Component 82	82	1	4
84	Component 83	83	1	12
85	Component 84	84	1	6
86	Component 85	85	1	5
87	Component 86	86	1	12
88	Component 87	87	2	1
89	Component 88	88	1	18
90	Component 89	89	4	1
91	Component 90	90	1	4
92	Component 91	91	1	10
93	Component 92	92	1	6
94	Component 93	93	2	1
95	Component 94	94	4	4
96	Component 95	95	1	12
97	Component 96	96	1	20
98	Component 97	97	2	1
99	Component 98	98	1	11
100	Component 99	99	1	1
101	Component 100	100	4	6
102	Component 101	101	1	12
103	Component 102	102	1	18
104	Component 103	103	2	1
105	Component 104	104	1	18
106	Component 105	105	2	1
107	Component 106	106	2	2
108	Component 107	107	1	18
109	Component 108	108	2	1

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
110	Component 109	109	1	18
111	Component 110	110	2	1
112	Component 111	111	2	2
113	Component 112	112	1	1
114	Component 113	113	1	4
115	Component 114	114	1	8
116	Component 115	115	4	1
117	Component 116	116	4	8
118	Component 117	117	4	1
119	Component 118	118	4	15
120	Component 119	119	4	1
121	Component 120	120	1	4
122	Component 121	121	1	12
123	Component 122	122	4	18
124	Component 123	123	4	2
125	Component 124	124	4	8
126	Component 125	125	4	1
127	Component 126	126	8	2
128	Component 127	127	1	18
129	Component 128	128	2	2
130	Component 129	129	1	6
131	Component 130	130	1	12
132	Component 131	131	4	15
133	Component 132	132	4	1
134	Component 133	133	4	1
135	Component 134	134	1	6
136	Component 135	135	4	18
137	Component 136	136	4	1
138	Component 137	137	4	1
139	Component 138	138	4	1
140	Component 139	139	1	9
141	Component 140	140	4	1
142	Component 141	141	1	15
143	Component 142	142	1	2
144	Component 143	143	1	13
145	Component 144	144	4	1
146	Component 145	145	1	18
147	Component 146	146	1	2
148	Component 147	147	1	4
149	Component 148	148	2	5
150	Component 149	149	1	6
151	Component 150	150	2	6
152	Component 151	151	2	1
153	Component 152	152	1	2
154	Component 153	153	1	18
155	Component 154	154	1	2
156	Component 155	155	1	2
157	Component 156	156	1	9
158	Component 157	157	2	1
159	Component 158	158	1	3
160	Component 159	159	1	8
161	Component 160	160	6	1
162	Component 161	161	2	4
163	Component 162	162	2	6
164	Component 163	163	1	6

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
165	Component 164	164	2	1
166	Component 165	165	1	18
167	Component 166	166	1	8
168	Component 167	167	1	8
169	Component 168	168	2	2
170	Component 169	169	1	23
171	Component 170	170	1	18
172	Component 171	171	2	2
173	Component 172	172	1	18
174	Component 173	173	2	2
175	Component 174	174	4	1
176	Component 175	175	1	15
177	Component 176	176	4	1
178	Component 177	177	1	28
179	Component 178	178	6	2
180	Component 179	179	1	15
181	Component 180	180	4	1
182	Component 181	181	1	8
183	Component 182	182	2	1
184	Component 183	183	1	15
185	Component 184	184	4	1
186	Component 185	185	1	18
187	Component 186	186	4	1
188	Component 187	187	1	15
189	Component 188	188	4	1
190	Component 189	189	1	18
191	Component 190	190	4	1
192	Component 191	191	1	18
193	Component 192	192	2	1
194	Component 193	193	1	4
195	Component 194	194	1	12
196	Component 195	195	1	18
197	Component 196	196	1	2
198	Component 197	197	1	8
199	Component 198	198	2	1
200	Component 199	199	2	2
201	Component 200	200	1	18
202	Component 201	201	4	1
203	Component 202	202	1	18
204	Component 203	203	4	1
205	Component 204	204	2	2
206	Component 205	205	1	6
207	Component 206	206	1	12
208	Component 207	207	1	1
209	Component 208	208	1	2
210	Component 209	209	1	2
211	Component 210	210	1	9
212	Component 211	211	1	9
213	Component 212	212	1	1
214	Component 213	213	1	9
215	Component 214	214	1	9
216	Component 215	215	1	1
217	Component 216	216	1	11
218	Component 217	217	12	1
219	Component 218	218	1	18

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
220	Component 219	219	1	2
221	Component 220	220	1	1
222	Component 221	221	2	1
223	Component 222	222	1	2
224	Component 223	223	1	2
225	Component 224	224	1	33
226	Component 225	225	4	2
227	Component 226	226	1	4
228	Component 227	227	4	1
229	Component 228	228	1	33
230	Component 229	229	2	2
231	Component 230	230	1	2
232	Component 231	231	1	18
233	Component 232	232	1	2
234	Component 233	233	1	2
235	Component 234	234	1	18
236	Component 235	235	2	1
237	Component 236	236	1	18
238	Component 237	237	1	18
239	Component 238	238	1	18
240	Component 239	239	3	1
241	Component 240	240	3	1
242	Component 241	241	1	18
243	Component 242	242	8	1
244	Component 243	243	6	1
245	Component 244	244	1	18
246	Component 245	245	1	2
247	Component 246	246	1	18
248	Component 247	247	4	1
249	Component 248	248	2	10
250	Component 249	249	4	6
251	Component 250	250	2	18
252	Component 251	251	2	18
253	Component 252	252	2	21
254	Component 253	253	2	7
255	Component 254	254	2	24
256	Component 255	255	2	32
257	Component 256	256	2	19
258	Component 257	257	4	22
259	Component 258	258	4	12
260	Component 259	259	1	24
261	Component 260	260	2	4
262	Component 261	261	2	30
263	Component 262	262	2	6
264	Component 263	263	1	8
265	Component 264	264	2	1
266	Component 265	265	1	8
267	Component 266	266	6	1
268	Component 267	267	1	18
269	Component 268	268	4	1
270	Component 269	269	1	3
271	Component 270	270	1	11
272	Component 271	271	1	1
273	Component 272	272	1	10
274	Component 273	273	1	1

	A	B	C	D
1	COMPONENT	Work Type	Batch	Job
275	Component 274	274	1	8
276	Component 275	275	1	24
277	Component 276	276	1	47
278	Component 277	277	1	4
279	Component 278	278	1	12
280	Component 279	279	1	20
281	Component 280	280	1	8
282	Component 281	281	1	1
283	Component 282	282	1	4
284	Component 283	283	1	12
285	Component 284	284	1	18
286	Component 285	285	1	2
287	Component 286	286	2	2
288	Component 287	287	1	18
289	Component 288	288	2	1
290	Component 289	289	1	18
291	Component 290	290	2	1
292	Component 291	291	2	2
293	Component 292	292	1	6
294	Component 293	293	1	12
295	Component 294	294	4	1
296	Component 295	295	4	1
297	Component 296	296	4	1
298	Component 297	297	1	4
299	Component 298	298	1	12
300	Component 299	299	1	18
301	Component 300	300	1	2
302	Component 301	301	2	2
303	Component 302	302	1	18
304	Component 303	305	2	1
305	Component 304	303	1	6
306	Component 305	304	1	12
307	Component 306	306	1	10
308	Component 307	307	1	5
309	Component 308	308	2	1
310	Component 309	309	4	1
311	Component 310	310	1	8
312	Component 311	311	2	1
313	Component 312	312	1	8
314	Component 313	313	6	1
315	Component 314	314	1	18
316	Component 315	315	6	1
317	Component 316	316	4	3
318	Component 317	317	1	18
319	Component 318	318	4	1
320	Component 319	319	1	8
321	Component 320	320	1	25
322	Component 321	321	4	1
323	Component 322	322	4	4
324	Component 323	323	1	10
325	Component 324	324	4	5
326	Component 325	325	1	12
327	Component 326	326	1	2
328	Component 327	327	1	5
329	Component 328	328	1	1

Table 29 Component Batching

	A	B	C	D
1	JOB MATRIX WORKSHEET			
2	Work Type	Job	Activity	AVG Hours
3	127	1	Station 4	8
4	127	2	Station 5	2
5	127	3	Station 10	0.5
6	127	4	Station 36	1
7	127	5	Station 5	0.25
8	127	6	Station 6	1
9	127	7	Station 5	0.2
10	127	8	Station 18	1
11	127	9	Station 18	16
12	127	10	Station 2	16
13	127	11	Station 18	4
14	127	12	Station 12	2
15	127	13	Station 12	2
16	127	14	Station 1	1
17	127	15	Station 18	1
18	127	16	Station 16	1
19	127	17	Station 7	8
20	127	18	Station 9	1

Table 30 Job Matrix Worksheet for Component 127

	A	B	C	D
1	JOB PATH WORKSHEET			
2	Path Qualifier	Work Type	Job	Activity
3	1	127	1	Station 4
4	0	127	2	Station 5
5	0	127	3	Station 10
6	0	127	4	Station 36
7	0	127	5	Station 5
8	0	127	6	Station 6
9	0	127	7	Station 5
10	0	127	8	Station 18
11	0	127	9	Station 18
12	0	127	10	Station 2
13	0	127	11	Station 18
14	0	127	12	Station 12
15	0	127	13	Station 12
16	0	127	14	Station 1
17	0	127	15	Station 18
18	0	127	16	Station 16
19	0	127	17	Station 7
20	0	127	18	Station 9

Table 31 Job Path Worksheet for Component 127

PATH 1	Resource 1	Resource 2	Resource 3	Resource 4	Resource 5	Resource 6	Resource 7	Resource 8	Resource 9	Total
Station 1							648.85			648.85
Station 2								1,153.00		1,153.00
Station 3	160.00									160.00
Station 4		979.00								979.00
Station 5			223.45							223.45
Station 6								128.00		128.00
Station 7								1,016.00		1,016.00
Station 9					333.50					333.50
Station 10			49.50							49.50
Station 12							1,045.20			1,045.20
Station 13						291.00		10.00		301.00
Station 15									14,816.50	14,816.50
Station 36			138.00							138.00
Total	160.00	979.00	410.95	0.00	333.50	291.00	1,694.05	2,307.00	14,816.50	25,470.60

PATH 1	Resource 11	Resource 12	Resource 13	Resource 14	Resource 15	Resource 16	Resource 17	Resource 18	Resource 19	Total
Station 16	347.50									347.50
Station 18		1,439.00								1,439.00
Station 19			397.50							397.50
Station 20					64.00					64.00
Station 21				523.00						523.00
Station 22				157.20						157.20
Station 24						4.00				4.00
Station 25							5.00			5.00
Station 26			0.50					34.90		35.40
Station 27			2.00							2.00
Station 28			23.60							23.60
Station 29			25.00							25.00
Station 30			8.00							8.00
Station 31			25.00							25.00
Station 32			32.00							32.00
Station 33			11.50							11.50
Station 34			21.00							21.00
Station 35		9.00								9.00
Station 37		17.50								17.50
Station 38			22.20							22.20
Station 39		3.00								3.00
Station 40								487.40		487.40
Station 41			20.00							20.00
Station 42			108.60							108.60
Station 43			21.00							21.00
Station 44		2.00								2.00
Station 45			22.00							22.00
Station 46			25.00							25.00
Station 47								26.20		26.20
Station 48									594.00	594.00
Total	347.50	1,470.50	764.90	680.20	64.00	4.00	5.00	548.50	594.00	25,470.60

Table 32 Resource Hours per Station - Path 1

PATH 2	Resource 2	Resource 3	Resource 5	Resource 6	Resource 7	Resource 8	Resource 9	Resource 11	Resource 12	Resource 13	Resource 14	Resource 15	Resource 18	Total
Station 1					6.00									6.00
Station 2						240.00								240.00
Station 4	194.00													194.00
Station 5		46.80												46.80
Station 6						21.00								21.00
Station 7						168.00								168.00
Station 9			9.50											9.50
Station 10		10.00												10.00
Station 12					18.00									18.00
Station 13				92.00		4.00								96.00
Station 15							0.50							0.50
Station 16								63.00						63.00
Station 18									142.00					142.00
Station 19										322.25				322.25
Station 21											65.00			65.00
Station 22											54.00			54.00
Station 23												62.00		62.00
Station 26													9.20	9.20
Station 27										21.00				21.00
Station 28										3.70				3.70
Station 29										42.75				42.75
Station 31										17.00				17.00
Station 32										16.00				16.00
Station 33										13.00				13.00
Station 34										8.00				8.00
Station 35									2.00					2.00
Station 36		20.00												20.00
Station 37									2.00					2.00
Station 38										27.00				27.00
Station 40													2.00	2.00
Station 41										52.00				52.00
Station 42										52.20				52.20
Station 43										27.00				27.00
Station 44									1.00					1.00
Station 45										28.00				28.00
Station 46										42.00				42.00
Station 47													1.00	1.00
Grand	194.00	76.80	9.50	92.00	24.00	433.00	0.50	63.00	147.00	671.90	119.00	62.00	12.20	1,904.90

Table 33 Resource Hours per Station - Path 2

PATH 3	Resource 2	Resource 6	Resource 8	Resource 11	Resource 13	Resource 14	Resource 18	Total
Station 4	24.00							24.00
Station 7			16.00					16.00
Station 13		3.00						3.00
Station 16				2.00				2.00
Station 21						15.00		15.00
Station 22						4.00		4.00
Station 26							6.00	6.00
Station 42					2.00			2.00
Station 47							3.00	3.00
Total	24.00	3.00	16.00	2.00	2.00	19.00	9.00	75.00

Table 34 Resource Hours per Station - Path 3

PATH 4	Resource 2	Resource 6	Resource 13	Resource 14	Resource 18	Total
Station 4	8.00					8.00
Station 13		1.00				1.00
Station 21				5.00		5.00
Station 22				2.00		2.00
Station 42			2.00			2.00
Station 47					1.00	1.00
Total	8.00	1.00	2.00	7.00	1.00	19.00

Table 35 Resource Hours per Station - Path 4

STEP	COMPONENT	ACTIVITY	SEND TO	RESOURCE	PATH	QUANTITY	HOURS
1	Component 127	Station 4	Station 5	Resource 2	1	1	8.0
2	Component 127	Station 5	Station 10	Resource 3	1	1	2.0
3	Component 127	Station 10	Station 36	Resource 3	1	1	0.5
4	Component 127	Station 36	Station 5	Resource 3	1	1	1.0
5	Component 127	Station 5	Station 6	Resource 3	1	1	0.3
6	Component 127	Station 6	Station 5	Resource 8	1	1	1.0
7	Component 127	Station 5	Station 18	Resource 3	1	1	0.2
8	Component 127	Station 18	Station 18	Resource 12	1	1	1.0
9	Component 127	Station 18	Station 2	Resource 12	1	1	16.0
10	Component 127	Station 2	Station 18	Resource 8	1	1	16.0
11	Component 127	Station 18	Station 12	Resource 12	1	1	4.0
12	Component 127	Station 12	Station 18	Resource 7	1	1	2.0
13	Component 127	Station 18	Station 1	Resource 12	1	1	2.0
14	Component 127	Station 1	Station 18	Resource 7	1	1	1.0
15	Component 127	Station 18	Station 16	Resource 12	1	1	1.0
16	Component 127	Station 16	Station 7	Resource 11	1	1	1.0
17	Component 127	Station 7	Station 9	Resource 8	1	1	8.0
18	Component 127	Station 9	Station 8	Resource 5	1	1	1.0

Table 36 Component 127 Process Steps

	STEP	COMPONENT	STATION	SEND TO	RESOURCE
1	1	Component 14	STATION 48	STATION 1	Resource 19
	2	Component 14	STATION 1	STATION 8	Resource 7
2	1	Component 18	STATION 48	STATION 1	Resource 19
	2	Component 18	STATION 1	STATION 8	Resource 7
3	1	Component 24	STATION 48	STATION 1	Resource 19
	2	Component 24	STATION 1	STATION 8	Resource 7
4	1	Component 28	STATION 48	STATION 1	Resource 19
	2	Component 28	STATION 1	STATION 8	Resource 7
5	1	Component 79	STATION 48	STATION 1	Resource 19
	2	Component 79	STATION 1	STATION 8	Resource 7
6	1	Component 123	STATION 48	STATION 1	Resource 19
	2	Component 123	STATION 1	STATION 8	Resource 7
7	1	Component 142	STATION 48	STATION 1	Resource 19
	2	Component 142	STATION 1	STATION 8	Resource 7
8	1	Component 146	STATION 48	STATION 1	Resource 19
	2	Component 146	STATION 1	STATION 8	Resource 7
9	1	Component 154	STATION 48	STATION 1	Resource 19
	2	Component 154	STATION 1	STATION 8	Resource 7
10	1	Component 196	STATION 48	STATION 1	Resource 19
	2	Component 196	STATION 1	STATION 8	Resource 7
11	1	Component 219	STATION 48	STATION 1	Resource 19
	2	Component 219	STATION 1	STATION 8	Resource 7
12	1	Component 232	STATION 48	STATION 1	Resource 19
	2	Component 232	STATION 1	STATION 8	Resource 7
13	1	Component 245	STATION 48	STATION 1	Resource 19
	2	Component 245	STATION 1	STATION 8	Resource 7
14	1	Component 285	STATION 48	STATION 1	Resource 19
	2	Component 285	STATION 1	STATION 8	Resource 7
15	1	Component 300	STATION 48	STATION 1	Resource 19
	2	Component 300	STATION 1	STATION 8	Resource 7

Table 37 Bottleneck Components

APPENDIX II SIMULATION DATA OUTPUTS

RESOURCE SIM I	% UTILIZATION	CURRENT USE	AVERAGE USE	MAXIMUM USE	ALLOCATED
Resource 1	99.23	5	4.96	5	5
Resource 2	99.46	10	9.95	10	20
Resource 3	99.63	5	4.96	5	5
Resource 5	0	0	0	0	23
Resource 6	49.73	5	4.97	5	4
Resource 7	99.46	10	9.95	10	10
Resource 8	95.73	4	3.82	4	100
Resource 9	2.98	3	2.98	3	100
Resource 10	0	0	0	0	5
Resource 11	0.14	0	0.14	2	2
Resource 12	99.39	2	1.99	2	13
Resource 13	99.46	13	12.93	13	13
Resource 14	42.93	5	5.58	8	5
Resource 15	39.37	2	1.97	2	1
Resource 16	99.46	1	1.00	1	2
Resource 17	0	0	0	0	100
Resource 18	7.59	8	7.59	10	5
Resource 19	99.46	5	4.97	5	4

Table 38 Simulation I Resource Results (Simul8, n.d.)

ACTVITY SIM I	WAITING %	WORKING %	COMPLETED JOBS	AVERAGE USE	MAXIMUM USE	CURREN I CONTENTS	RESOURCE STARVED %
ROUTE	100		105,377.00		1		
EXIT GENERATE JOBS	100		167		1		
LEAVE SYSTEM							
STATION 1	100		18	1.08	2	1	
STATION 2			6	0.63	2		
STATION 3			10	4.85	5	5	
STATION 4			207	9.70	10	10	
STATION 5			276	2.09	4	2	
STATION 6			185	2.05	4	2	
STATION 7			23	0.97	3	2	
STATION 8	100						
STATION 9	1.07						98.928
STATION 10			275	0.88	2	1	
STATION 11							
STATION 12			37	8.63	10	9	
STATION 13			716	4.85	5	5	
STATION 14							
STATION 15				2.91	3	3	
STATION 16			25	0.15			
STATION 17							
STATION 18			113	1.55	2	2	
STATION 19			63	6.16	8	7	
STATION 20	1.67	98.33	15	0.97	1	1	
STATION 21			163	3.88	4	4	
STATION 22			41	1.57	4	1	
STATION 23	4.64	95.36	18	0.94	1	1	
STATION 24			41	0.97	1	1	
STATION 25							
STATION 26			175	1.03	2	1	
STATION 28			3		1		
STATION 29			1	0.15	1		
STATION 33			69	0.24	3	1	
STATION 36			271	1.58	3	2	
STATION 37			73	0.39	1		
STATION 38			1	0.03	1		
STATION 40			163	4.85	5	5	
STATION 41			4	0.06	2		
STATION 42			69	3.45	5	3	
STATION 43			1	0.03	1		
STATION 45			2	0.06	2		
STATION 46			70	2.51	5	2	
STATION 47			340	2.06	4	2	
STATION 48			62	4.85	5	5	

Table 39 Simulation I Activity Results (Simul8, n.d.)

QUEUE SIM I	AVERAGE QUEUE SIZE	MAXIMUM QUEUE SIZE	MINIMUM Q UEUEING TIME	MINIMUM (NON-ZERO) QUEUEING TIME	AVERAGE QUEUEING TIME	AVERAGE (NON-ZERO) QUEUEING TIME	MAXIMUM QUEUEING TIME	NUMBER OF NON-ZERO QUEUEING TIMES	% QUEUED LESS THAN TIME LIMIT	ST DEV OF QUEING TIME	QUEUE CURRENT CONTENTS	QUEUE ITEMS ENTERED
BATCH		327							100.00			54,776
LEAVE SYSTEM	31.14											
Station 1	135.64	280	1.00	1.00	88.66	88.66	152.00	19	5.26	43.53	280	299
Station 1 EXIT	6.04	15									15	15
Station 2	0.03	1		0.50	1.33	1.60	3.00	5	100.00	1.08		6
Station 3	153.68	319		77.00	77.53	116.30	155.00	10	33.33	65.50	319	334
Station 4	12,698.89	26,336		8.00	80.53	84.42	165.00	207	9.68	48.77	26,336	26,553
Station 5	246.21	526		0.50	52.24	58.82	105.65	275	11.15	31.03	526	804
Station 6	47.27	91		1.00	32.14	34.15	59.50	176	13.37	17.25	86	273
Station 6 EXIT	51.68	126									126	126
Station 7	0.30	2		0.75	1.44	1.57	4.80	23	100.00	1.03		25
Station 7 EXIT	6.37	16										
Station 9	2,257.15	4,686									4,686	4,686
Station 10	32.39	63		0.25	16.67	16.73	30.45	275	28.99	8.55	63	339
Station 12	3,921.42	8,142		1.00	67.04	85.66	164.00	36	23.91	50.73	8,142	8,188
Station 12 EXIT	3.74	6										
Station 13	22,660.39	46,985		1.00	82.77	83.58	164.00	714	7.21	49.52	46,985	47,706
Station 13 EXIT	228.64	479									479	479
Station 15	1,124.70	2,335							100.00		2,335	2,338
Station 16		1							100.00			25
Station 18	68.39	142		1.00	45.81	46.62	91.00	113	13.04	27.99	142	257
Station 19	3,838.28	7,967		6.50	72.43	81.77	156.70	62	17.14	50.08	7,967	8,037
Station 20	4.02	7		11.50	34.13	36.40	60.00	15	6.25	16.97	5	21
Station 21		303							100.00			105,377
Station 22	167.69	351		2.00	52.97	54.94	113.00	161	13.17	34.09	351	518
Station 23		1		2.00	0.05	2.00	2.00	1	100.00			42
Station 24	31.14	64		2.00	65.80	69.46	130.25	18	10.53	41.45	64	83
Station 25	60.05	125		3.00	61.50	63.00	123.00	41	9.52	36.80	125	167
Station 25 EXIT	19.52	41									41	41
Station 47		1							100.00			342
Station 48	1,905.39	3,958		8.00	80.05	86.50	164.00	62	14.93	55.17	3,958	4,025
Station 32	73.11	154		3.50	54.17	54.96	110.75	69	15.71	33.19	154	224
Station 28	0.06	1	1.50	1.50	2.67	2.67	3.75	3	100.00			
Station 29		1	1.25	1.25	1.25	1.25	1.25	1	100.00			
Station 36	1.55	3		0.20	0.98	0.98	2.00	272	100.00	0.33	2	275
Station 37	1.12	4		0.25	2.60	2.63	5.50	72			20	20
Station 38		1	2.00	2.00	2.00	2.00	2.00	1	100.00			
Station 40	472.55	987		0.50	66.22	68.68	142.50	162	11.31	42.54	987	1,155
Station 41	0.06	2	1.50	1.50	2.19	2.19	3.00	4	100.00	0.63		4
Station 43			1.00	2.50	2.50	2.50	2.50	1	100.00			1
Station 42	221.50	463		0.50	65.48	68.33	141.25	69	13.89	43.28	463	535
Station 42 EXIT	11.29	22									22	22
Station 46	284.85	596		0.50	68.14	69.10	145.75	71	12.50	44.23	596	668

Table 40 Simulation I Queue Results (Simul8, n.d.)

RESOURCE SIM II	% UTILIZATION	CURRENT USE	AVERAGE USE	MAXIMUM USE	ALLOCATED
Resource 1	99.23	5	4.96	5	5
Resource 2	99.46	10	9.95	10	20
Resource 3	99.63	5	4.96	5	5
Resource 5	0	0	0	0	23
Resource 6	49.73	5	4.97	5	5
Resource 7	99.46	10	9.95	10	10
Resource 8	95.73	4	3.82	4	20
Resource 9	95.41	3	2.98	3	3
Resource 10	0	0	0	0	5
Resource 11	2.98	0	0.14	2	2
Resource 12	99.39	2	1.99	2	13
Resource 13	99.46	13	12.93	13	13
Resource 14	42.93	5	5.6	8	7
Resource 15	39.37	2	2.0	2	2
Resource 16	99.46	1	1.0	1	2
Resource 17	0.00	0	0	0	100
Resource 18	7.59	8	7.59	10	10
Resource 19	99.46	5	4.97	5	5

Table 41 Simulation II Resource Results (Simul8, n.d.)

RESOURCE SIM III	% UTILIZATION	CURRENT USE	AVERAGE USE	MAXIMUM USE	ALLOCATED
Resource 1	98.45	5	4.92	5	5
Resource 2	98.93	10	9.89	10	20
Resource 3	99.06	5	4.67	5	5
Resource 5	0	0	0	0	23
Resource 6	49.46	5	4.95	5	4
Resource 7	98.93	10	9.89	10	10
Resource 8	90.82	4	3.63	4	100
Resource 9	2.97	3	2.97	3	100
Resource 10	0	0	0	0	5
Resource 11	0.13	0	0.14	2	2
Resource 12	98.78	2	1.98	2	13
Resource 13	98.93	13	12.86	13	13
Resource 14	42.40	5	5.51	8	5
Resource 15	38.74	2	1.94	2	1
Resource 16	98.09	1	0.99	1	2
Resource 17	0	0	0	0	100
Resource 18	7.58	8	7.59	10	5
Resource 19	98.93	5	4.95	5	4

Table 42 Simulation III Resource Results (Simul8, n.d.)

RESOURCE SIM IV	% UTILIZATION	CURRENT USE	AVERAGE USE	MAXIMUM USE	ALLOCATED
Resource 1	98.45	5	4.92	5	5
Resource 2	98.93	10	9.89	10	20
Resource 3	99.08	5	4.67	5	5
Resource 5	0	0	0	0	23
Resource 6	98.93	4	4.95	4	4
Resource 7	98.93	10	9.89	10	10
Resource 8	1.60	2	3.63	5	100
Resource 9	2.97	3	2.97	3	100
Resource 10	0	0	0	0	5
Resource 11	2.50	0	0.14	2	2
Resource 12	51.34	8	1.98	10	13
Resource 13	98.93	13	12.86	13	13
Resource 14	31.33	1	5.51	4	5
Resource 15	97.14	1	1.94	1	1
Resource 16	98.63	2	0.99	2	2
Resource 17	0	0	0	0	100
Resource 18	98.93	5	7.59	5	5
Resource 19	79.14	8	4.95	8	4

Table 43 Simulation IV Resource Results (Simul8, n.d.)

ACTIVITY SIM IV	% WAITING	% WORKING	# COMPLETED JOBS	AVERAGE USE	MAXIMUM USE	CURRENT CONTENTS	% RESOURCE STARVED
GENERATE JOBS	100		167		1		
BATCH	100		54,779		1		
ROUTE	100		105,377		1		
Station 1			20	0.83	2	0	
Station 2			17	1.72	4	3	
Station 3			10	4.85	5	5	
Station 4			207	9.70	10	10	
Station 5			279	2.15	4	2	
Station 6			89	0.45	4	1	
Station 7			20	1.06	3	1	
Station 8	100						
Station 9	1.072						98.93
Station 10			278	0.85	2	1	
Station 12			37	8.87	10	10	
Station 13			548	3.88	4	4	
Station 15				2.91	3	3	
Station 16			21	1.12	2		
Station 18			360	4.63	7	4	
Station 19			64	6.21	8	7	
Station 20	2.86	54.28	8	0.55	1	1	42.86
Station 21			163	3.88	4	4	
Station 22			41	1.57	4	1	
Station 23	4.64	42.86	8	0.42	1	0	52.50
Station 24			82	1.94	2	2	
Station 26			126	0.41	2	0	
Station 28			3	0.03	1		
Station 29			1	0.15	1		
Station 32			70	0.26	3	1	
Station 36			225	1.55	3	2	
Station 37			73	0.33	3	1	
Station 38			1	0.03	1		
Station 40			128	3.64	5	4	
Station 41			4	0.06	2		
Station 42			71	3.42	5	3	
Station 43			1	0.03	1		
Station 45			2	0.06	2		
Station 46			72	2.58	5	2	
Station 47			126	0.80	2	1	
Station 48			90	7.76	8	8	

Table 44 Simulation IV Activity Results (Simul8, n.d.)

QUEUE													
SIM IV	AVERAGE QUEUE SIZE	MAXIMUM QUEUE SIZE	MINIMUM QUEUEING TIME	MINIMUM (NON-ZERO) QUEUEING TIME	AVERAGE QUEUEING TIME	AVERAGE (NON-ZERO) QUEUEING TIME	MAXIMUM QUEUEING TIME	NUMBER OF NON-ZERO QUEUEING TIMES	% QUEUED LESS THAN TIME LIMIT	QUEUED LESS THAN TIME LIMIT	ST DEV OF QUEING TIME	QUEUE CURRENT CONTENTS	QUEUE CURRENT CONTENTS
BATCH		327							100	10			54,776
ROUTE		303							100	10			105,377
Station 1	210.66	435	1.00	1.00	89.25	89.25	153.75	20	5.00	10	43.77	435	455
Station 2	0.03	1		0.50	1.33	1.60	3.00	5	100.00	10	1.08		20
Station 3	153.68	319		77.00	77.53	116.30	155.00	10	33.33	10	65.50	319	334
Station 4	12,698.89	26,336		8.00	80.53	84.42	165.00	207	9.68	10	48.77	26,336	26,553
Station 5	259.31	551		0.50	53.84	54.42	107.15	278	11.03	10	31.38	551	832
Station 6		1							100.00	10			90
Station 7		1							100.00	10			21
Station 10	29.94	56		0.25	15.54	15.59	27.70	278	28.67	10	7.39	56	335
Station 12	3,923.47	8,146		1.00	67.59	85.86	162.50	37	23.40	10	50.70	8,146	8,193
Station 13	22,723.15	47,144		1.00	79.26	80.13	165.00	546	7.61	10	48.43	47,144	47,696
Station 15	1,124.70	2,335							100.00	10		2,335	2,338
Station 16		1							100.00	10			21
Station 18		1								10			364
Station 19	3,833.65	7,957		6.50	73.13	82.41	164.25	63	16.90	10	50.35	7,957	8,028
Station 20	2.49	4		12.00	35.06	39.44	73.00	8	11.11	10	23.01	3	12
Station 21	167.75	351		2.00	52.97	54.94	113.00	161	13.17	10	34.09	351	518
Station 22	37.01	77	9.00	9.00	70.50	70.50	139.00	8	12.50	10	45.96	77	85
Station 23		1							100.00	10			42
Station 24	39.80	83		2.00	41.00	42.00	82.00	82	11.91	10	24.39	83	167
Station 47	102.39	212	0.50	0.50	69.08	70.02	147.95	73	12.16	10	44.34	594	668
Station 48	1,889.50	3,933		8.00	73.18	79.69	157.00	90	16.33	10	50.24	3,933	4,031
Station 26	20.54	43		2.00	20.84	21.01	42.00	125	24.60	10	11.80	43	169
Station 32	74.00	153		3.50	53.58	54.34	112.25	70	14.09	10	32.05	153	224
Station 36	1.54	3		0.10	0.89	0.89	1.95	276	100.00	10	0.34	1	278
Station 37		1							100.00	10			74
Station 40	475.91	992		0.50	70.76	72.97	147.00	128	10.61	10	44.35	992	1,124
Station 41	0.06	2	1.50	1.50	2.19	2.19	3.00	4	100.00	10	0.63		4
Station 42	227.50	477		0.50	66.35	69.16	143.75	71	13.51	10	43.35	477	551
Station 43		1	2.50	2.50	2.50	2.50	2.50	1	100.00	10			1
Station 46	284.37	594		0.50	69.08	70.02	147.95	73	12.16	10	44.34	594	668

Table 45 Simulation IV Queue Results (Simul8, n.d.)

RESOURCE	% UTILIZATION			CURRENT USE			AVERAGE USE			MAXIMUM USE				
SIM V SIM VI SIM VII	Exponential	Normal	Weibull	Exponential	Normal	Weibull	Exponential	Normal	Weibull	Average	Exponential	Normal	Weibull	Allocation
Resource 1	98.18	93.58	97.11	5	5	5	4.91	4.68	4.86	5	5	5	5	5
Resource 2	98.42	97.37	97.83	10	10	10	9.84	9.74	9.78	10	10	10	10	20
Resource 3	98.73	94.33	97.93	5	5	5	4.65	4.44	4.61	5	5	5	5	5
Resource 5	0	0	0	0	0	0	0	0	0	0	0	0	0	23
Resource 6	98.42	97.37	97.83	4	4	4	3.94	3.90	3.91	5	4	4	4	4
Resource 7	98.42	97.37	97.83	10	10	10	9.84	9.74	9.78	10	10	10	10	10
Resource 8	3.18	7.51	7.02	3	12	9	3.18	7.51	7.02	4	9	17	16	100
Resource 9	2.95	2.92	2.94	3	3	3	2.95	2.92	2.94	3	3	3	3	100
Resource 10	0	0	0	0	0	0	0	0	0	0	0	0	0	2
Resource 11	2.06	2.33	2.57	1	0	0	0.10	0.12	0.13	2	2	2	3	5
Resource 12	39.16	36.98	40.98	1	0	5	5.09	4.81	5.33	2	11	12	11	13
Resource 13	98.42	96.81	97.83	13	13	13	12.80	13.00	12.72	13	13	13	13	13
Resource 14	95.15	89.99	92.90	5	5	4	4.76	5.00	4.65	8	5	5	5	5
Resource 15	94.85	95.58	96.04	1	1	1	0.95	1.00	0.96	2	1	1	1	1
Resource 16	98.38	61.91	94.52	2	0	2	1.97	0	1.89	1	2	1	2	2
Resource 17	0	0	0	0	0	0	0	0	0	0	0	0	0	100
Resource 18	98.42	96.71	97.83	5	5	5	4.92	4.84	4.89	10	5	5	5	5
Resource 19	78.74	77.90	78.26	8	8	8	7.87	7.79	7.83	5	8	8	8	4

Table 46 Simulation V VI VII Resource Results (Simul8, n.d.)

ACTVITY							
SIM VII	WAITING %	WORKING %	COMPLETED JOBS	AVERAGE USE	MAXIMUM USE	CURRENT CONTENTS	RESOURCE STARVED %
BATCH	100		28864		1		
ROUTE	100		55528		1		
GENERATE UNIQUE JOBS	100		88		1		
Station 1			23	0.804	2		
Station 2			49	4.768	12	6	
Station 3			10	4.821	5	5	
Station 4			206	9.702	10	10	
Station 5			367	2.226	5	2	
Station 6			133	0.94	5	1	
Station 7			22	1.107	4	2	
Station 8	100						
Station 9	2.175						97.825
Station 10			255	0.911	3	1	
Station 12			38	8.899	10	10	
Station 13			540	3.881	4	4	
Station 14							
Station 15				2.911	3	3	
Station 16			24	0.149			
Station 18			290	4.929	10	5	
Station 19			63	0.423	8	8	
Station 20	3.961	53.18	8	0.506	1	1	42.859
Station 21			118	3.256	4	4	
Station 22			36	1.327	4		
Station 23	5.747	42.859	8	0.434			51.394
Station 24			78	1.881	2	2	
Station 26			97	0.345	2		
Station 28			6	0.03	1		
Station 29			4	0.03	1		
Station 30			1		1		
Station 31				0.03	1		
Station 33			1	0.06	1		
Station 32			71	0.434	3		
Station 36			252	1.417	4	2	
Station 37			73	0.268	3		
Station 38			1	0.03	1		
Station 40					5	4	
Station 41				3.744	2		
Station 43				0.03	1		
Station 42			72		5	3	
Station 45			2	0.06	2		
Station 46			72	2.518	5	2	
Station 47			118	0.762	3	1	
Station 48			90	7.762	8	8	

Table 47 Simulation VII Activity Results (Simul8, n.d.)

QUEUE SIM VII	AVERAGE QUEUE SIZE	MAXIMUM QUEUE SIZE	MINIMUM QUEUEING TIME	(NON-ZERO) QUEUEING TIME	AVERAGE QUEUEING TIME	AVERAGE (NON-ZERO) QUEUEING TIME	MAXIMUM QUEUEING TIME	# OF NON-ZERO QUEUEING TIMES	% QUEUED LESS THAN TIME LIMIT	ST DEV OF QUEING TIME	QUEUE CURRENT CONTENTS	QUEUE ITEMS ENTERED
BATCH	0	327	0	0	0	0	0	0	100	0	0	28,864
ROUTE	0	303	0	0	0	0	0	0	100	0	0	55,528
Station 1	128.29	275	1	1	78.78	78.78	148.20	23	4.35	38.08	275	298
Station 2	0	0	0	0	0	0	0	0	0	0	0	55
Station 3	74.72	162	0	71.34	74.37	111.55	149.05	10	3.33	62.96	161	176
Station 4	6,418.37	13,776	0	8.00	80.09	83.99	162.86	206	9.72	48.50	13,776	13,992
Station 5	147.30	317	0	0.05	36.54	37.87	73.70	356	14.36	21.75	317	686
Station 6	0	1	0	0	0	0	0	0	100	0	0	134
Station 7	4.99	12	0	0	0	0	0	0	0	0	12	12
Station 9	1,121.80	2,410	0	0	0	0	0	0	0	0	2,410	2,410
Station 10	1.35	6	0	0.02	0.90	0.93	3.22	248	100	0.66	3	259
Station 12	1,996.32	4,297	0	1	66.51	86.53	164	38	22.92	51.39	4,297	4,345
Station 13	11,466.83	24,637	0	1	77.94	78.81	162.86	538	7.72	47.61	24,637	25,181
Station 15	571.48	1,229	0	0	0	0	0	0	100	0	1,229	1,232
Station 16	0	1	0	0	0	0	0	0	100	0	0	24
Station 18	0	1	0	0.09	0.00	0.09	0.09	1	100	0	0	295
Station 19	1,937.23	4,165	0	6.50	72.69	81.92	161.51	63	16.90	50.24	4,165	4,236
Station 20	5.13	8	0	12.00	49.22	55.38	98.00	8	11.11	36.32	6	15
Station 21	90.73	200	0	0.24	49.40	51.95	101.17	116	13.92	36.72	200	322
Station 22	0.42	4	0	0.86	2.16	4.57	14	17	94.44	3.55	0	36
Station 23	39.05	80	9.00	9.00	70.50	70.50	139	8	12.50	45.96	80	88
Station 24	3.61	8	0	0.24	6.76	7.72	14.03	70	67.50	4.74	8	88
Station 47	29.37	67	0.50	0.50	26.70	26.70	58.50	119	25.21	17.29	65	184
Station 48	941.97	2,037	0	8.00	71.87	78.26	151.20	90	16.33	48.96	2,037	2,135

Table 48 Simulation VII Queue Results (Simul8, n.d.)

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