

AE SIMULATOR A SERIAL PRODUCTION LINE SIMULATOR

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AE SIMULATOR A SERIAL PRODUCTION LINE SIMULATOR

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THESIS ABSTRACT

AE SIMULATOR A SERIAL PRODUCTION LINE SIMULATOR

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Consider an unreliable serial line with capacitated buffers between machines. Operators are required to repair machines when they fail and machines are blocked when the buffers are full and are starved when the buffers are empty. Adding buffer space and increasing the number of operators will certainly increase the throughput of that line. But the question that should be answered is “Is it worth adding buffer or operator from a cost perspective?” It may or may not be. If you produce something valuable or the cost of buffer and operator is relatively lower than the revenue per product, it is worth it. The increase in throughput when you add buffer or operator will answer this question. In this study, the trade-off between buffer allocation and number of operators is going to be investigated in unreliable serial lines. A tool which will help to estimate the throughput of unreliable serial lines has been developed and is discussed.

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CHAPTER 1

INTRODUCTION

Consider an unreliable serial line with capacitated buffers between machines. Operators are required to repair machines when they fail and machines are blocked when the buffers are full and are starved when the buffers are empty. Adding buffer space and increasing the number of operators will certainly increase the throughput of that line. But the question that should be answered is “Is it worth adding buffer or operator from a cost perspective?” It may or may not be. If you produce something valuable or the cost of buffer and operator is relatively lower than the revenue per product, it is worth it. The increase in throughput when you add buffer or operator will answer this question.

The challenge in this kind of environment is to estimate how many more buffers and/or operators should be allocated to the line. If everything would be deterministic, no randomness, it would be easy to estimate the necessary resource addition by simple math but due to stochastic nature of production lines, analytical models cannot help on that task and that is the time simulation will play an important role on estimating what should be done to increase the performance.

Simulation is a very powerful tool that can help someone to predict what is going to happen in the future but it requires a lot of work and effort and it is expensive to have a simulation study. A simulation study will begin with collecting information from the line

and building a simulation model of it. Then that collected information will be used in that simulation model and results will be analyzed to improve the performance of the line. Almost all of these can be done by someone who has knowledge about the line that is going to be simulated but simulation requires the one who is going to build the model and building a simulation model needs a lot of effort. On the other hand, if you want to improve the performance of a manufacturing line you need to experiment with variables to test the possible configurations. All these things need a lot of effort and time. Automation of some part of these tasks will save a lot of time. For that purpose, a tool, AE Simulator, that integrates Arena Simulation Software and Microsoft Excel through VBA project is created. AE Simulator minimizes the efforts required to build the simulation model and experiment with different configurations. That tool is going to help on estimating the throughput of unreliable serial lines from a perspective of the trade-off between buffer allocation and number of operators.

AE Simulator has two mechanisms that help on analysis of serial production lines. It builds the simulation model and changes the number of buffers and operators systematically to give an estimate about other possible scenarios. First mechanism evaluates the current situation and also gives an estimate about the minimum and maximum throughput that line can achieve. This sets light to where the current configuration's throughput lies on and how much more is possible. Second mechanism deals with the whole picture and generates the trade-off graph which tells the throughput of that line for all possible number of buffers and operators. Basically, it creates all the possible configurations by systematically changing the number of buffers and operators

and then evaluates this list and creates the trade-off graph. Trade-off graph helps on comparing the performance of possible scenarios.

The main objective of this study is to describe the serial production line problem and analyze the serial production lines from a buffer allocation and operator assignment perspective. Since the analysis of these systems will require a lot of effort as mentioned in earlier, another objective is to develop a software tool that formulates the analysis of the serial lines. The tool automates the process of building the simulation models and experimentation on the line that is going to be analyzed. Finally, the goal is to present case studies to validate the tool and methodology used.

In the next chapter, literature on buffer allocation and operator assignment problem particularly in serial production lines is given. Chapter 3 describes the problem that is the focus of AE Simulator and introduces the tool that is created to simulate serial manufacturing lines and gives an idea about how to use it to build simulation models and analyze the results. There are two case studies in Chapter 4 that show the usefulness of AE tool. Lastly, conclusion of the thesis is given in Chapter 5.

CHAPTER 2

BACKGROUND

In this chapter, some background information about buffer allocation and operator assignment in serial manufacturing lines is going to be given and several works in these areas will be described.

2.1 Buffer Allocation

There is an extensive literature on the design of production lines (Serial lines and Assembly lines). This study will focus on serial production lines. Serial production lines can be classified as balanced and unbalanced, both with reliable and unreliable machines. “In unreliable lines the typical workstation is a machine that operates with a constant processing time but it is subject to breakdowns. Reliable lines on the other hand generally involve human operators who are not subject to machine breakdowns but whose processing times are variable. Another useful distinction is between balanced and unbalanced lines. Balanced lines are defined as those in which probability distributions of processing times are identical in all workstations. In unbalanced lines the mean, variance may differ from station to station.” (Hillier 1999) Table 2.1 categorizes relevant research

on the design of serial production lines. Some researches may fall into more than one category however they will be reviewed in only one.

There are two different approaches to buffer allocation problem. First approach looks for rules of thumbs in designing a line which can help the practical line designers to select good buffer allocations without going through complex analysis. Second approach tries to develop numerical algorithms to select optimal buffer allocation. The goal of these approaches is to stay away from exhaustive search which means evaluate every single allocation.

Serial Lines		
	Reliable	Unreliable
Balanced	Freeman(1964), Conway(1988), Hillier(1991a), Harris(1999), Hillier(2000),	Conway(1988), Hillier(1991b), Papadopoulos(1999), Enginarlar(2002)
Unbalanced	Freeman(1964), Conway(1988), Powell(1994,1996), Harris(1999), Hillier(2000)	
Others	Buzacott(1967)(1968), Ignall(1977), Altiok(1983), Gershwin (1986)	

Table 2.1 Categorization of Serial Production Lines

2.1.1 Reliable Balanced Serial Lines

Freeman (1964) studied the two and three stage serial lines with constant processing time and exponential machine breakdowns. He showed the importance of buffer allocation and buffer sizes and made some generalizations about how to allocate buffers in this type of lines.

A leading work in this field had been done by Conway *et al.* (1988) who studied reliable serial production lines with exponential and uniform processing time distributions and unreliable workstations subject to exponential breakdowns. They provided some useful design rules for lines having low to moderate coefficient of variation. The results are below:

- Throughput increases at a decreasing rate when the number of buffers increases.
- *Bowl Phenomenon*: If possible buffers should be distributed evenly along the line and any remaining buffer should be placed around the center.
- When a single buffer is available, it should be allocated to the place where the effect of an infinite buffer would be most effective.
- Small number of buffers will recover most of the throughput that is lost due to randomness for the lines with low coefficient of variation.
- *Reversibility Principle*: Throughput of the mirror lines are the same.

Hillier (1991a, 1991b) studied the effect of CV of service times on the buffer allocation in serial production lines with two-stage Coxian distribution. Their results showed that for the lines with high variability buffers should be placed around the center stations. (Bowl Phenomenon) For the lines with low variability, equal allocation of buffers would be most effective. The effect of the coefficient of variation on production lines with low to high variability is considered in this study.

Harris and Powell (1999) studied the buffer allocation patterns in balanced and unbalanced reliable serial lines with lognormal processing times. They analyzed various lines such as the lines have a single bottleneck and two bottleneck and the lines that have

mean and variance imbalances. They developed an algorithm to search for the optimal allocation for a fixed number of buffer spaces. The results are consistent with the previous work of Powell and Pyke (1996) about the impact of imbalance in means and variances on the optimal allocation which says imbalance in mean processing time has a greater effect than imbalance in CV.

Hillier (2000) studied the reliable balanced and unbalanced 4, 5 and 6 station lines having exponential and erlang processing times. He analyzed the effect of CV on the optimal total number and pattern of buffer spaces and characterized the optimal pattern of buffer allocation in balanced lines. The CV of the processing times has a smaller effect on the optimal pattern of buffer allocation. In addition, he examined how the optimal buffer allocation changes when the line becomes unbalanced by assuming each station has a processing time with the same distributions but different mean.

2.1.2 Reliable Unbalanced Serial Lines

Powell (1994) analyzed the problem of buffer allocation in unbalanced three-station serial lines in which processing times are different in either or both the mean and the variance. They showed that imbalance in means has a greater influence on buffer space allocation than imbalance does in variance. In longer lines, a single buffer and a single bottleneck has less impact on the throughput of the line. When additional buffers would have positive impact on the throughput, they should be allocated from the center out by considering no more than one unit difference in buffer allocation.

Powell and Pyke (1996) extend the previous work to longer lines with a bottleneck station having a higher mean than others. The results are as follows:

Bottleneck stations draw the buffers toward it. Location and severity of the bottleneck and the number of available buffers will affect the optimal buffer allocation.

Equal buffer allocations are mostly optimal for the lines having low imbalances in mean processing times. Significant imbalances in processing times are needed to shift away from the equal buffer allocation.

2.1.3 Unreliable Balanced Serial Lines

Papadopoulos (1999) studied the short unreliable μ -balanced serial lines having exponential and erlang distributed processing times and exponential service and repair times. He investigated the effect of service time distribution, availability of the unreliable stations and repair rate on the buffer allocation and throughput.

Enginarlar et al. (2002) investigated the unreliable serial production lines with identical machines having erlang and rayleigh processing times and presented an approach to find the minimum number of buffering to meet a target production rate using the efficiency of the line.

2.2 Operator Assignment

Elsayed (1982) studied an optimum repair policy to minimize the machine interference where machines have two failure modes. One of the policies assumes one of the failure modes has priority over the other and second one assumes both failure modes

will be treated equally. He tried to find the optimum number of machines that is going to be assigned to an operator and he found second policy is better than the first one in terms of machine availability and operator efficiency.

Kwang-Fu Li (1985) worked on maximizing the throughput with different rules of assignment which are the assignment preference for slow stages and randomization. The line he investigated was the 2 stage 1 operator case which had unlimited buffer space. He showed that appropriate randomization will increase the throughput.

Kotcher (2001) predicted that increasing operators in a group of lightly loaded machine operators, overstaffing would improve throughput the line using simulation. This result recognized for the conditions where machines have frequent but unpredictable needs for operators but the operators are busy. This concept is important in an environment where operators are responsible for servicing multiple machines. This thesis addresses this problem. He also proposed a method to estimate cost of the operator-induced throughput loss.

2.3 Summary

In a serial line production line, generally, performance of the system is measured by the average throughput rate. Numbers of buffers, servers, and operators are the important factors that affect the performance of the system. In a line that is subject to machine breakdowns, the number of buffers and number of operators are inversely proportional with each other. Decreasing the number of operators will increase the need for buffers and vice versa. Since I have not found any work from a perspective of trade-

off between number of operators and buffer, this thesis will focus on both buffer placement and operator assignment and the effect of these on throughput of a manufacturing line. Conway who studied the unreliable and reliable balanced serial lines provided useful buffer placement rules to maximize the throughput. In this study operator assignment will be another issue that will be considered in the design of a manufacturing line. To get the maximum throughput from the line or to allocate minimum number of buffer space, an operator should be available when a machine breakdown occurs. But that is not the case almost every time since an operator may be working on another machine. When a machine gets breakdown at a time all operators are busy, the time a machine waits for an operator will become another important issue to investigate.

The work done here will fall into unreliable and balanced serial production lines. Because of the high number of variables in this category, analysis for that kind of lines cannot be done analytically. This leads to a need for a simulation model to analyze the unreliable serial lines. In this study, a tool, AE Simulator, is developed which helps on building simulation models of serial lines and analyzing them. This tool not only captures one category but also captures all kind of serial lines both reliable and unreliable or balanced and unbalanced.

CHAPTER 3

AE SIMULATOR

AE simulator is an Excel based tool that integrates Microsoft Excel and Arena Simulation Software through a VBA project. That tool helps to build a simulation model of a serial line with only limited knowledge of simulation and gives an estimate of the throughput of the simulated line. More specifically, if user has the inputs like processing times, efficiency levels, failure rates, and number of operators that are needed for the simulation model, the tool can estimate the throughput of that line and generate a trade-off graph which basically estimates the throughput of the line for different configurations of buffers and operators.

AE Simulator has two kinds of mechanisms that build simulation for serial a manufacturing line. Either it can evaluate a line with specific configuration or it can generate a “trade-off graph” of that line for different buffer levels and numbers of operators. General operation begins with the entry of line information to Excel spreadsheet and then user pushes a button which triggers a macro and that macro builds the simulation model. When simulation run finishes, the results are presented in a graphical format. More explanation of these two mechanisms will be given in the next

sections. In the next section, description of the serial line that can be simulated by AE Simulator will be given and assumptions that have been made will be explained.

3.1 Problem Definition

The objective of this study is the asynchronous serial lines (or flow line or production line) subject to machine breakdowns. The production line has N stations and $N-1$ finite capacity buffer locations labeled B_1, B_2, \dots, B_{N-1} in Figure 3.1. In other words, buffer B_i separates station S_i and S_{i+1} . Moreover, there are K operators to repair the machines when a machine fails. All the parts enter the first station and visit all the stations in the same order and leave the line from the last station. In asynchronous lines, as long as there is enough space in the downstream buffer or the downstream station is idle, the workstations can pass the parts on when processing is completed. We assume that there is always a part available to process in front of the first workstation and there is always enough space for completed parts after the last workstation.

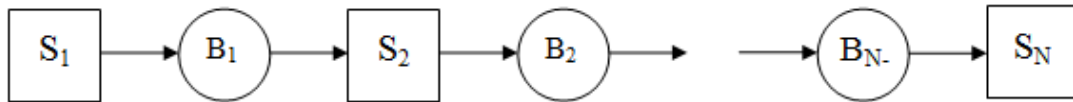


Figure 3.1 N-Station Serial Line

The stations are subject to blocking and starving. A station is said to be *blocked* if completed parts cannot be passed to the downstream buffer or station and a station is considered to be *starved* when the machine is idle and there are no available parts to process in the upstream buffer. Blocking and starving at the bottleneck station will

always cause losses in throughput. For non-bottleneck stations, blocking and starving might or might not lead to production loss.

Moreover stations are also subject to random machine breakdowns. The failures are single machine dependent failures means when a machine fails the line will continue to operate as long as there are available parts to process in the upstream buffer or when there is buffer space to pass the parts to the downstream buffer. When a failure occurs, the part stays on that machine and gets processed from the point it stops after the machine gets repaired.

When a machine fails, one of K available operators is assigned to repair that machine. An operator may be responsible for more than one machine but he can fix only one machine at a time. When a machine fails at a time that all operators are busy, it has to wait for an available operator before the repair can start. Once a machine is repaired, it becomes active and is again subject to breakdown. AE Simulator will focus on serial lines that are discussed here and throughput of these kinds of serial lines is going to be estimated. The mathematical model for finding throughput of a serial line that is subject to breakdown is given below.

Basic terms of the model are defined below.

S_i	station $i, i= 1,2,\dots,N$
N	number of stations in the line
K	number of operators
μ_i	service rate of station i

$\mu_N=(\mu_1, \mu_2, \dots, \mu_N)$ is the service time vector. Elements of that vector represent the service rate for each station.

TTF_i average time to failure of station i

$TTF_N=(TTF_1, \dots, TTF_N)$ is the TTF vector. Elements of the vector represent the TTF values for each station.

TTR_i average time to repair of station i

$TTR_N=(TTR_1, \dots, TTR_N)$ is the TTR vector. Elements of the vector represent the TTR values for each station.

B_i Buffer between stations S_i and S_{i+1}

$B_N= (B_1, B_2, \dots, B_{N-1})$ is the buffer vector, the elements of the vector are the capacities of the $N-1$ intermediate buffers.

$X_N (B_N, K)$ relative throughput of an N-station line with B_N vector and K_N vector

K_N $\begin{bmatrix} & \dots & \\ \vdots & \ddots & \vdots \\ & \dots & \end{bmatrix}$ This $N \times N$ matrix represents the operator assignment

in the line. Elements of that matrix are binary. There are N stations and there can be up to N operators in the line. (n,m) element of the matrix shows the assignment of the n^{th} operator to the m^{th} station.

T_N $\begin{bmatrix} & \dots & \\ \vdots & \ddots & \vdots \\ & \dots & \end{bmatrix}$ This $N \times N$ matrix represents the travel time from one

station to another. (n,m) element of the matrix shows the travel time of the operator from n^{th} station to the m^{th} station.

The objective is to find $X_N(B_N, K)$ as a function of μ_N, B_N, TTR_N, TTF_N , vectors and K_N, T_N matrices

3.2 Simulation Model

AE Simulator estimates the performance of a line by building the simulation model of that line. A macro behind the spreadsheet opens a new model file from Arena Simulation Software and places the necessary modules to that model file and populates them with the information that is entered by the user. Simulator can generate an unreliable N-station serial line with capacitated buffers between stations. Figure 3.2 shows a snapshot from a 4-station serial line. There are some repetitive tasks that need to be done to build a simulation model for an N-station serial line. The tool repeats those repetitive tasks N times to finalize the model.

Arena logic for that serial line has the following parts. There is unlimited supply in front of the first machine and unlimited space after the last machine. Parts enter from first station and visit all the station one by one and leave the system. There are buffer slots between two stations. Parts move to the next station if there is available space in front of the next station. There are random breakdowns which seize the machine and then look for an operator to repair that machine. After repair process, breakdown process begins from the beginning after some random time. Figure 3.3 shows the whole process of entry of information to the spreadsheet, building simulation model and creation of graph.

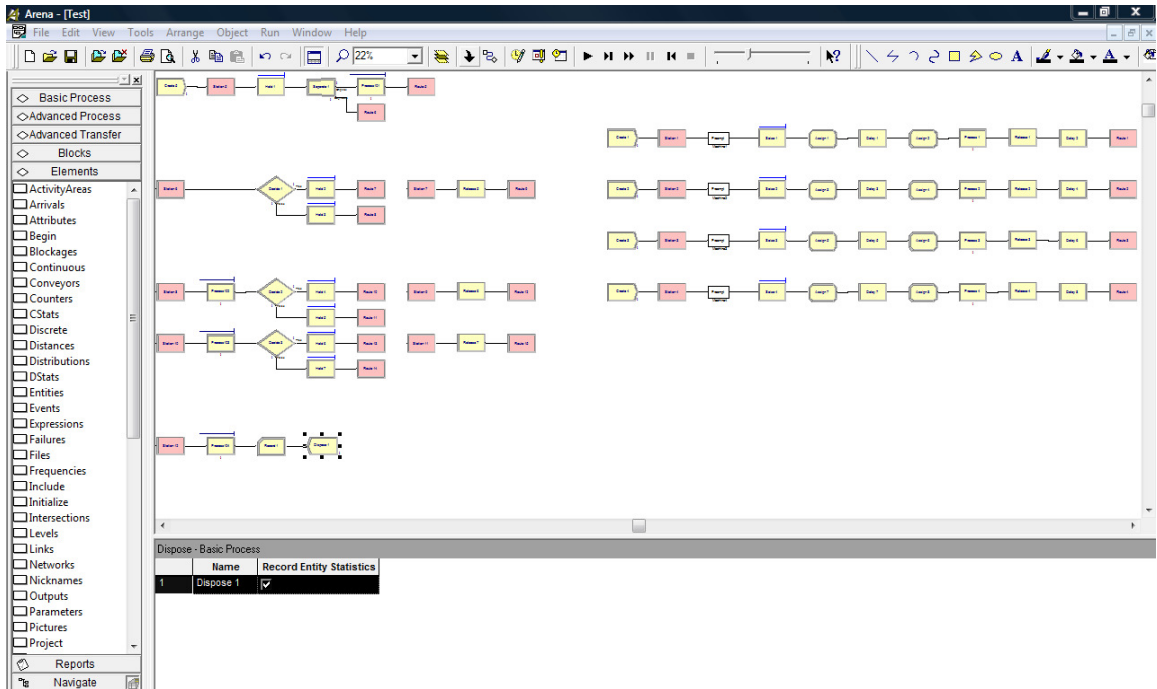


Figure 3.2 Snapshot from a 4-Station Serial Line

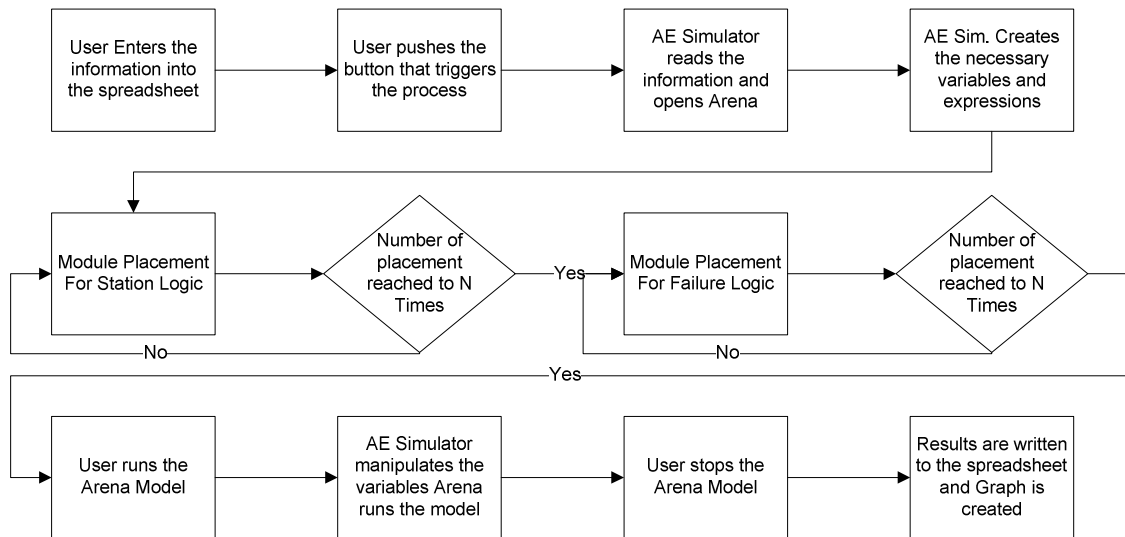


Figure 3.3 AE Simulator – Process Flowchart

3.3 Verification

Verification of the models AE Simulator generates is going to be done again by AE Simulator. “Evaluate a configuration” option of AE Simulator runs a scenario that can help on verification of the model. That scenario is the line unlimited buffers and unlimited operators. Throughput of that scenario can be calculated analytically easily and this number will be calculated by the AE Simulator. Throughput of the verification line is presented to the user after he/she enters the machine’s attributes for each station. One can easily compare the result AE Simulator gives with the number in the spreadsheet to make sure the model is verified. For illustration purposes, a sample line is created and shown here. That is an unreliable balanced 5-station serial line with constant processing times of 1 minute. Fail rate of each station is 0.25. Travel time from one station to another is neglected and there is always one operator when a fail occurs. The model is run for 50k minutes of 50 replications. Table 3.1 below shows the simulated value and the number AE Simulator calculates.

	Simulated	Expected
Throughput	0.899 ± 0.004	0.900

Table 3.1 Throughput of Verification Models (parts/min)

3.4 General Guide for AE Simulator

This section explains the inputs that are need for simulation model and gives some general guidance on which format the inputs should be entered to the spreadsheet.

All time units are in minutes if not otherwise stated. If you have your parameters in any other time units, first you should convert that time unit to minutes before entering it to the spreadsheet.

One should select the processing time distribution from the combo box or type it as “Constant”, “Exponential” or “Normal” and then enter the necessary parameters for the selected distribution. Spreadsheet prevents a user from typos by using data validation. Mean row should be filled with the mean of that processing time and standard deviation row should be filled with standard deviation of that distribution. If the distribution type is an Exponential or Constant distribution, that row should be kept empty.

Efficiency levels, e_i , will be entered between 0 and 100. In literature, efficiency is defined as the ratio of the uptime to the total time and downtime of the machine includes both the repair time and the machine’s waiting time for an operator to become available. One cannot calculate that waiting time with analytical methods and simulation is the only tool that can estimate the waiting time. Since it is hard to estimate this waiting time, the assumption is that there is always one operator available when a machine breakdowns. This way waiting time will be neglected in the definition of efficiency. In this study, efficiency is going to be described as the ratio of the average time to failure to the total time with the assumption of zero waiting time. For instance, if e_i is 100 for a machine, this means this machine does not fail at all and it is working a 100% of time. If e_i is 80%, this means this machine is available for 80% of time and for the remaining 20% of time it is under the process of repair. Every time that machine fails, there was an operator available to repair.

Fail rate, f_i , represents the frequency of failures for a period of time. Here it is represented as the number of failures in an hour. More specifically, to define a machines' failure characteristic it is not enough to determine the efficiency level by itself. Moreover, the frequency of the failures has to be defined to make it complete. For instance, a machine may have 90% efficiency with different number of fail rate values. Table 3.2 shows different fail rates at the same efficiency level and their corresponding uptimes and downtimes as an example. The only change from one configuration to another is the time it is going to be available. Figure 3.4 shows a representation of the availability of these machines.

	Fail Rate	Efficiency	TTF	TTR	Total Uptime	Total Downtime
Configuration 1	0.5	90%	108	12	108	12
Configuration 2	1	90%	54	6	108	12
Configuration 3	2	90%	27	3	108	12

Table 3.2 Uptime and Downtime for 90% Efficiency

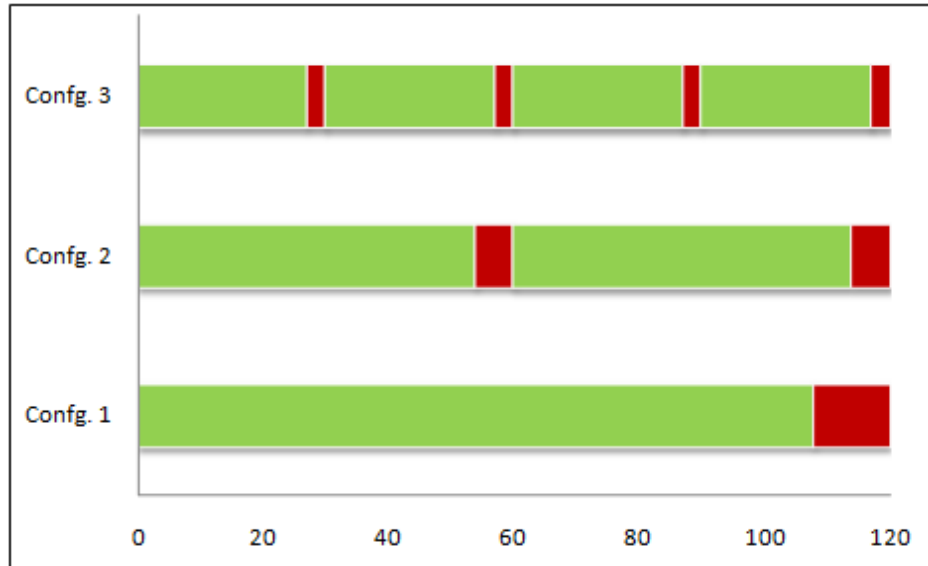


Figure 3.4 Availability of Machines

“Travel time” is the travel time from one station to another one. When a machine fails, an operator will go to that station to repair that machine. At the same time, other machines are still subject to breakdowns and they may require an operator to repair that failed machine. Travel time is the time it takes to walk to the failed station from the last station repaired. It also includes the response time to a failure. In other words, when a machine fails the time to respond to that failure is not an only travel; also there is some time that is the time an operator will be aware of that fail and he will get ready to repair that machine.

“Operator Assignment” represents which operator assigned to which machines in the line. An operator will be responsible for only the machines he/she is assigned. For an N-station serial line, operator assignment table is a KxN matrix with elements of 0 and 1. As mentioned before, when the (k,n) element of that matrix is 1, it means nth operator is assigned to kth machine in the line.

Buffers represent the number of available spaces between stations. In other words, it is the maximum number of parts it can hold. User should enter the buffer vector, B , into the spreadsheet.

Maximum number of buffers is the number that can be put between two stations. AE Simulator will not evaluate configurations that have more buffers between two stations. This value is the upper bound of the buffer variable. This option is required only in generating trade-off graph.

Also user has to decide on the number of replication, warm-up period and replication length parameters. Number of replication will be used in how many times a configuration is going to be run. Since simulation is a sampling method, more number of replications means less error in results. Warm-up period will be used to pass the transient state and reach to stable state of the simulation. Replication length is the run time of simulation. When AE Simulator calculates the throughput of the line it is going to take the difference of replication length and warm-up period as the total time. User can use the half widths that are written to the spreadsheet to determine if run length is enough to be confident on the results.

3.5 Evaluate a Configuration

AE Simulator can evaluate a specific configuration and gives the throughput of that configuration. User has to input processing times, efficiency levels and failure rates for each station, travel times of operators from one station to another and operator assignment as inputs to Excel. Then AE Simulator triggers a macro which makes Arena

to build the simulation model by itself for that configuration. It runs the original configuration and four more scenarios which are run to compare with the original configuration. These four scenarios are the same configuration except the number of buffers and operators. The same configuration with zero buffers and one operator, zero buffers and unlimited operators, unlimited buffers and one operators, unlimited buffers and unlimited operators are the other scenarios that are going to be run. Steps that are needed to be followed to evaluate a configuration and their explanation and a sample line that will be used as an example are given below.

The sample line that is going to be used as an example is a 6-station serial line. All the machines in this line are subject to breakdowns. Processing times, efficiency and fail rate values for each machine are given in Table 3.3. Processing times are in minutes and fail rate is in number of fails in one hour. There are 2 operators available to repair the machines and their assignments to machines are given in Table 3.5. Travel times from one station to another in minutes are given in Table 3.4. Buffer values of each buffer slot are given in Table 3.6. This sample line will be evaluated using AE Simulator.

	Mach. 1	Mach. 2	Mach. 3	Mach. 4	Mach. 5	Mach. 6
Pr. Time	Const(1)	Expo(1)	Nrm(1,0.1)	Expo(1)	Const(1)	Expo(1)
Efficiency	95%	93%	90%	91%	96%	94%
Fail Rate	0.1	0.2	0.05	0.08	0.11	0.15

Table 3.3 Service Time and Failure Characteristics of the Sample Line

	Mach. 1	Mach. 2	Mach. 3	Mach. 4	Mach. 5	Mach. 6
Mach. 1	0	1	1.5	2	2.5	3
Mach. 2	1	0	1	1.5	2	2.5
Mach. 3	1.5	1	0	1	1.5	2
Mach. 4	2	1.5	1	0	1	1.5
Mach. 5	2.5	2	1.5	1	0	1
Mach. 6	3	2.5	2	1.5	1	0

Table 3.4 Travel Times for the Sample Line

	Opr. 1	Opr. 2	Opr. 3	Opr. 4	Opr. 5	Opr. 6
Mach. 1	1	0	0	0	0	0
Mach. 2	0	1	0	0	0	0
Mach. 3	1	0	0	0	0	0
Mach. 4	1	0	0	0	0	0
Mach. 5	1	0	0	0	0	0
Mach. 6	1	0	0	0	0	0

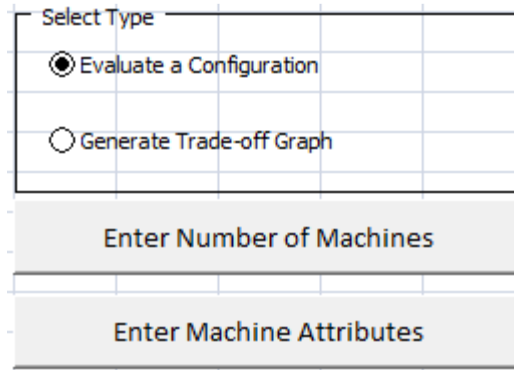
Table 3.5 Operator Assignment for the Sample Line

	Buffer 1	Buffer 2	Buffer 3	Buffer 4	Buffer 5
Values	4	6	3	2	5

Table 3.6 Buffer Values for the Sample Line

Step 1: Select Evaluate a Configuration

Evaluate a Configuration option should be selected from the “Select Type” option box as shown in Figure 3.5.

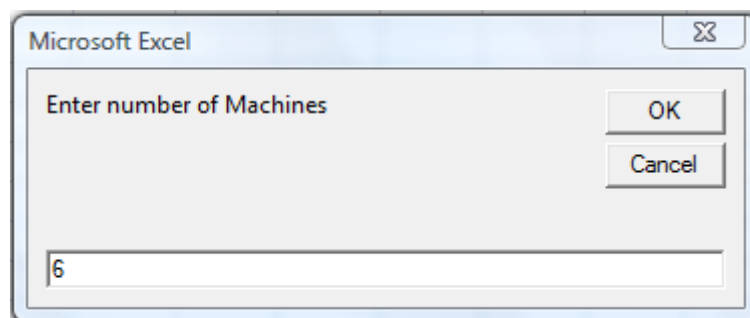


The image shows a dialog box titled "Select Type". It contains two radio button options: "Evaluate a Configuration" (which is selected) and "Generate Trade-off Graph". Below the options are two buttons: "Enter Number of Machines" and "Enter Machine Attributes".

Figure 3.5 AE Simulator – Select Type

Step 2: Enter Number of Machines

“Enter Number of Machines” button as seen in Figure 3.6 should be used to enter the number of machines in the line that is going to be simulated. Figure 3.5 shows the interface for entry of number of machines for the sample line.



The image shows a dialog box titled "Microsoft Excel" with a close button. The main area contains the text "Enter number of Machines" and two buttons: "OK" and "Cancel". At the bottom, there is a text input field containing the number "6".

Figure 3.6 AE Simulator – Number of Machines Entry

Step 3: Enter Machine Attributes

“Enter Machine Attributes” button should be used to enter the station attributes which are processing distribution and times, efficiency percentage and failure rate for each station. Firstly, processing times of each station is entered into Excel spreadsheet. Necessary processing distribution should be selected from the combo box and parameters should be entered for the corresponding distribution. All time units are in minutes. Secondly, efficiencies for each station should be entered to efficiency row. The efficiency numbers should be between 0 and 100. Lastly, failure rates should be entered to failure rate row. The time unit here should be entered in number of fails in one hour period. Figure 3.7 and Figure 3.8 shows the interface for service time and efficiency, fail rate entry to AE Simulator for the sample line.

Service Time Table						
	Mach.1	Mach.2	Mach.3	Mach.4	Mach.5	Mach.6
Distr. Type	Constant	Exponen	Normal	Exponen	Constant	Exponen
Mean	1	1	1	1	1	Constant
StDev			0.1			Exponential Normal

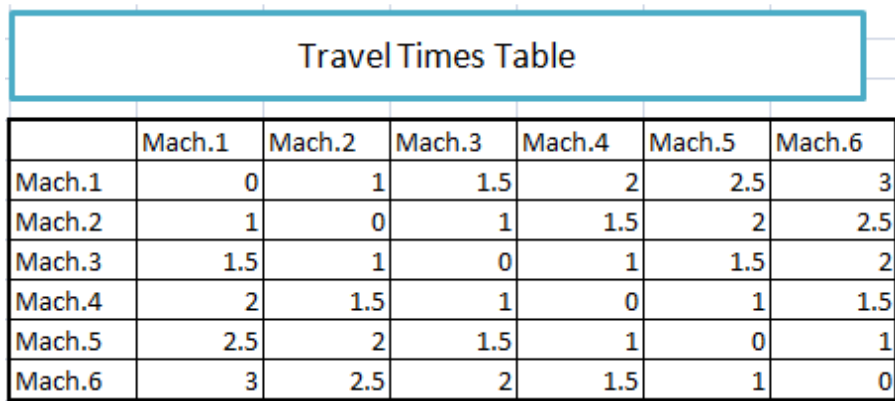
Figure 3.7 AE Simulator – Service Time Entry

Efficiency and Fail Rate Table						
	Mach.1	Mach.2	Mach.3	Mach.4	Mach.5	Mach.6
Efficiency	95	93	90	91	96	94
Fail Rate	0.1	0.2	0.05	0.08	0.11	0.15

Figure 3.8 AE Simulator – Efficiency Fail Rate Entry

Step 4: Enter Travel Times

“Enter Travel Times” button can be used to enter the travel times from one station to another. All travel times are assigned as zero by default. User should enter the travel times in minutes. If user wants to ignore the travel time in the model, Step 4 may be skipped. Figure 3.9 shows the AE Simulator interface for travel times entry for the sample line.



	Mach.1	Mach.2	Mach.3	Mach.4	Mach.5	Mach.6
Mach.1	0	1	1.5	2	2.5	3
Mach.2	1	0	1	1.5	2	2.5
Mach.3	1.5	1	0	1	1.5	2
Mach.4	2	1.5	1	0	1	1.5
Mach.5	2.5	2	1.5	1	0	1
Mach.6	3	2.5	2	1.5	1	0

Figure 3.9 AE Simulator – Travel Times Entry

Step 5: Enter Operator Assignment

“Enter Operator Assignment” button as seen in Figure 3.10 can be used to enter which operator assigned to which machine. AE Simulator assumes that there are N operators which are all assigned to N machines for an N-station serial line. If an operator is assigned to a machine, a 1 should be put to that element of the matrix. Figure 3.11 shows the AE Simulator interface that is populated with the sample line data.

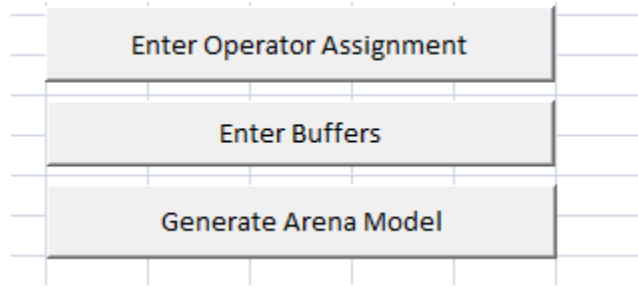


Figure 3.10 AE Simulator – Operator Assignment Button

Operator Machine Assignment						
	Opr.1	Opr.2	Opr.3	Opr.4	Opr.5	Opr.6
Machine1	1	0	0	0	0	0
Machine2	0	1	0	0	0	0
Machine3	1	0	0	0	0	0
Machine4	1	0	0	0	0	0
Machine5	1	0	0	0	0	0
Machine6	1	0	0	0	0	0

Figure 3.11 AE Simulator – Operator Assignment Entry

Step 6: Enter Buffers

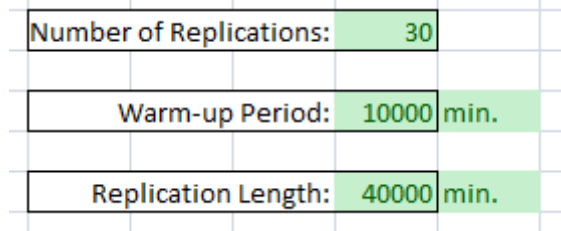
“Enter Buffers” button as seen Figure 3.10 can be used to enter the buffer values for each buffer space. Figure 3.12 shows the AE Simulator spreadsheet that is populated with sample line data.

Buffers				
Buffer1	Buffer2	Buffer3	Buffer4	Buffer5
4	6	3	2	5

Figure 3.12 AE Simulator – Buffer Values Entry

Step 7: Enter Replication Length, Warm-up period, Number of Replications

Before generating Arena model replication length, warm-up period and number of replications should be entered into spreadsheet. AE Simulator will use these numbers in generation of the simulation model. Replication length and warm-up period are in time units of minutes. Simulation parameters entry for the sample line is given in Figure 3.13.



Number of Replications:	30
Warm-up Period:	10000 min.
Replication Length:	40000 min.

Figure 3.13 AE Simulator – Simulation Parameters Entry

Step 8: Generate Arena Model

This step generates the simulation model in Arena Simulation Software by using the information entered into spreadsheet. This step may take some time to build so it is better to wait until a complete model appears in your desktop. The button as seen in Figure 3.10 will be used for this step.

Step 9: Run and Stop the Simulation Model

After you get the model ready in Arena, Run button has to be pushed or from the Arena menu Run/Go has to be clicked. Running all replication will take some time; user should wait until he/she sees a popup box which says “Do you want to see the reports”. No should be selected from the popup window and simulation run should be stopped by using the Stop button or from the Arena menu Run/End has to be clicked. This will

trigger another code that is going to calculate the performance metrics we are interested in and put them in a graphical format.

Step 10: Output Graph

Figure 3.14 is the graph AE Simulator created at the end of the run. The graph tells the throughput of the scenarios that are run in Arena. The one in the middle is the original configuration that is inputted by the user. First two of the scenarios are the cases with 0 buffers and last two of the scenarios are the cases with unlimited buffers. First two of them can be assumed as minimum outcome of the line and last two of the scenarios can be assumed as the maximum the line can achieve.

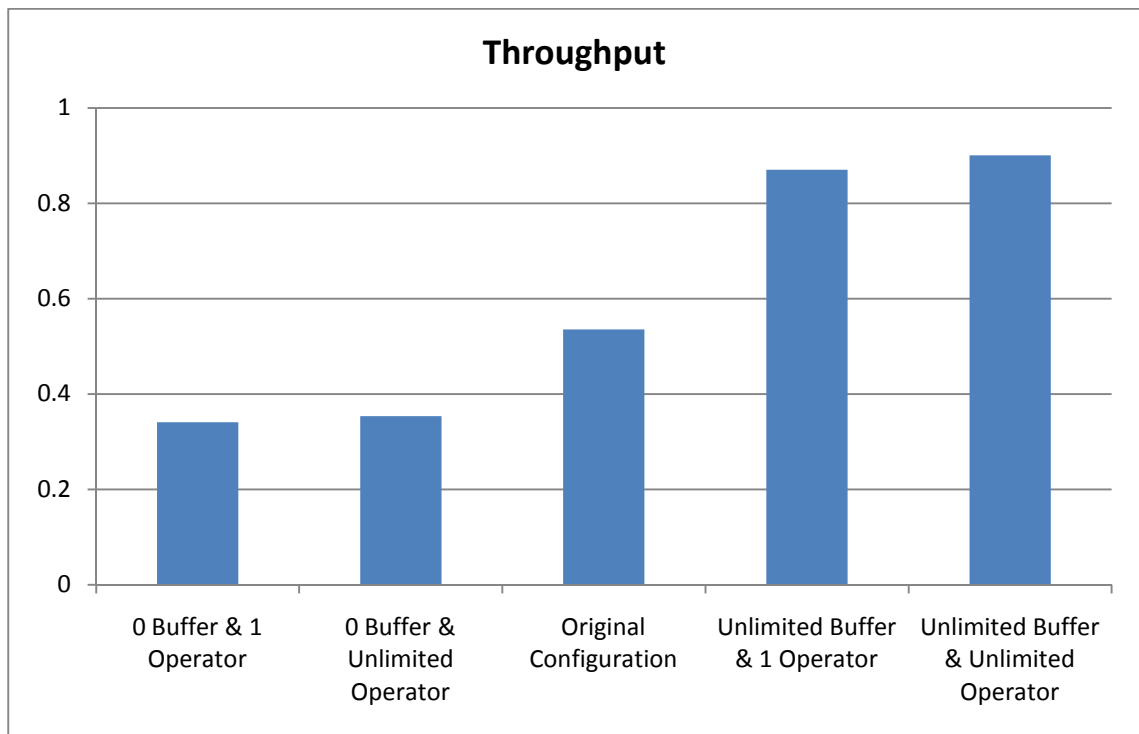


Figure 3.14 Results from Evaluation of 6-Station Line

3.6 Generate Trade-off Graph

AE Simulator can generate a trade-off graph of a serial line. Trade-off graph shows the effect of number of buffers and number of operators on throughput for a given set of information. User has to input processing times, efficiency levels and failure rates for each station, travel times of operators from one station to another into spreadsheet. Then AE Simulator triggers a macro which makes Arena to build the simulation model by itself. Then simulation model is run and results are presented. This mechanism creates a list of all possible scenarios by changing number of operators and number of buffers and evaluates these scenarios and gives the trade-off graph.

While creating the possible scenarios, AE Simulator uses the processing times, efficiency values, fail rates and travel times as given by the user and changes the number of buffers and operators. The tool changes the number of operators from 1 to the maximum number that can be allocated which is the number of stations. Here the assumption is any operator can repair any machine. The other variable that is going to be changed is the number of buffers. AE Simulator allocates buffers evenly throughout the line. In other words, if the number of buffer value is x it means there are x number of buffers in each of the buffer slot.

Steps that are needed to be followed to generate trade-off graph of a serial line is given below. Steps are the same with “Evaluate a Configuration” option. The only difference is some steps are skipped in generation of trade-off graphs.

A 6-station serial line with exponential processing times is going to be used as an example. All machines are subject to breakdowns. Processing times, efficiency and fail rate values are given in Table 3.7. Travel times are given in Table 3.8.

	Mach. 1	Mach. 2	Mach. 3	Mach. 4	Mach. 5	Mach. 6
Pr. Time	Const(1)	Expo(1)	Nrm(1,0.1)	Expo(1)	Const(1)	Expo(1)
Efficiency	95%	93%	90%	91%	96%	94%
Fail Rate	0.1	0.2	0.05	0.08	0.11	0.15

Table 3.7 Service Time and Failure Characteristic of the Sample Line

	Mach. 1	Mach. 2	Mach. 3	Mach. 4	Mach. 5	Mach. 6
Mach. 1	0	1	1.5	2	2.5	3
Mach. 2	1	0	1	1.5	2	2.5
Mach. 3	1.5	1	0	1	1.5	2
Mach. 4	2	1.5	1	0	1	1.5
Mach. 5	2.5	2	1.5	1	0	1
Mach. 6	3	2.5	2	1.5	1	0

Table 3.8 Travel Times for the Sample Line

Step 1: Select “Generate Trade-off Graph”

“Generate Trade-off Graph” option should be selected from the “Select Type” option box as seen in Figure 3.15.

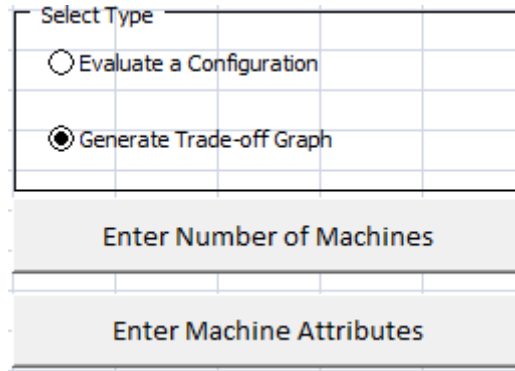


Figure 3.15 AE Simulator – Select Type

Step 2: Enter Number of Machines

“Enter Number of Machines” button should be used to enter the number of machines in the line as seen in Figure 3.16.

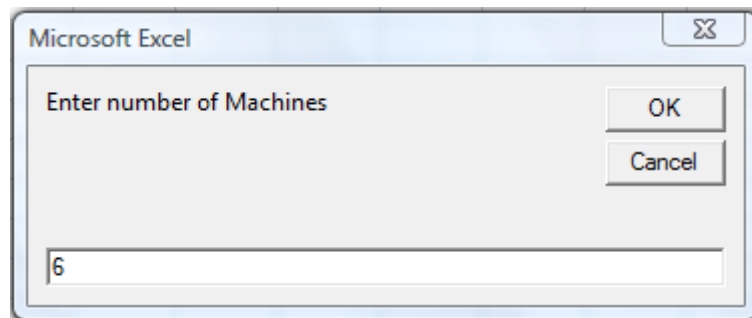


Figure 3.16 AE Simulator – Number of Machines Entry

Step 3: Enter Machines' Attributes

“Enter Machines' Attributes” button should be used to enter the machines' attributes which are processing time distribution and corresponding parameters, efficiency and fail rate values for each station. First processing distribution should be selected from the combo box or the name of the distribution should be typed into the cell as “Constant”,

“Exponential” and “Normal” and then corresponding parameters of these distributions should be entered into the cells. If the distribution is either constant or exponential, standard deviation row should be kept empty. The time unit for processing times is in minutes. Figure 3.16 shows the spreadsheet that is populated with sample line data.

Service Time Table						
	Mach.1	Mach.2	Mach.3	Mach.4	Mach.5	Mach.6
Distr. Type	Exponen	Exponen	Exponen	Exponen	Exponen	Exponential
Mean	1	1	1	1	1	1
StDev						

Figure 3.17 AE Simulator – Service Times Entry

Step 4: Enter Travel Times

“Enter Travel Times” button should be used to enter the travel times from one station to another. Travel times will be in time units of minutes. A snapshot from the spreadsheet with travel times data of sample line is given in Figure 3.17.

Travel Times Table						
	Mach.1	Mach.2	Mach.3	Mach.4	Mach.5	Mach.6
Mach.1	0	1	1.5	2	2.5	3
Mach.2	1	0	1	1.5	2	2.5
Mach.3	1.5	1	0	1	1.5	2
Mach.4	2	1.5	1	0	1	1.5
Mach.5	2.5	2	1.5	1	0	1
Mach.6	3	2.5	2	1.5	1	0

Figure 3.18 AE Simulator – Travel Times Entry

Step 5: Enter Replication Length, Warm-Up period, Number of Replications

Before generating Arena model replication length, warm-up period and number of replications should be entered into spreadsheet. AE Simulator will use these numbers in generation of the simulation model. Replication length and warm-up period are in time units of minutes.

Number of Replications:	30	
Warm-up Period:	10000	min.
Replication Length:	40000	min.

Figure 3.19 AE Simulator – Simulation Parameters Entry

Step 6: Generate Arena Model

This step generates the simulation model in Arena Simulation Software by using the information entered into spreadsheet. This step may take some time to build so it is better to wait until a complete model appears in your desktop.

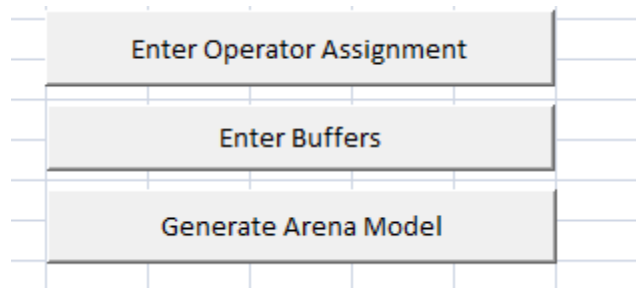


Figure 3.20 AE Simulator – Model Generation

Step 7: Trade-off Graph

Figure 3.21 is the trade-off graph that will be generated after simulation runs are finished. It tells the throughput values from 0 buffers to 10 buffers and 1 operator to 6 operators. For this configuration it is seen having more than 2 operators does not make any difference that is why all lines other than 1 operator lay on the path.

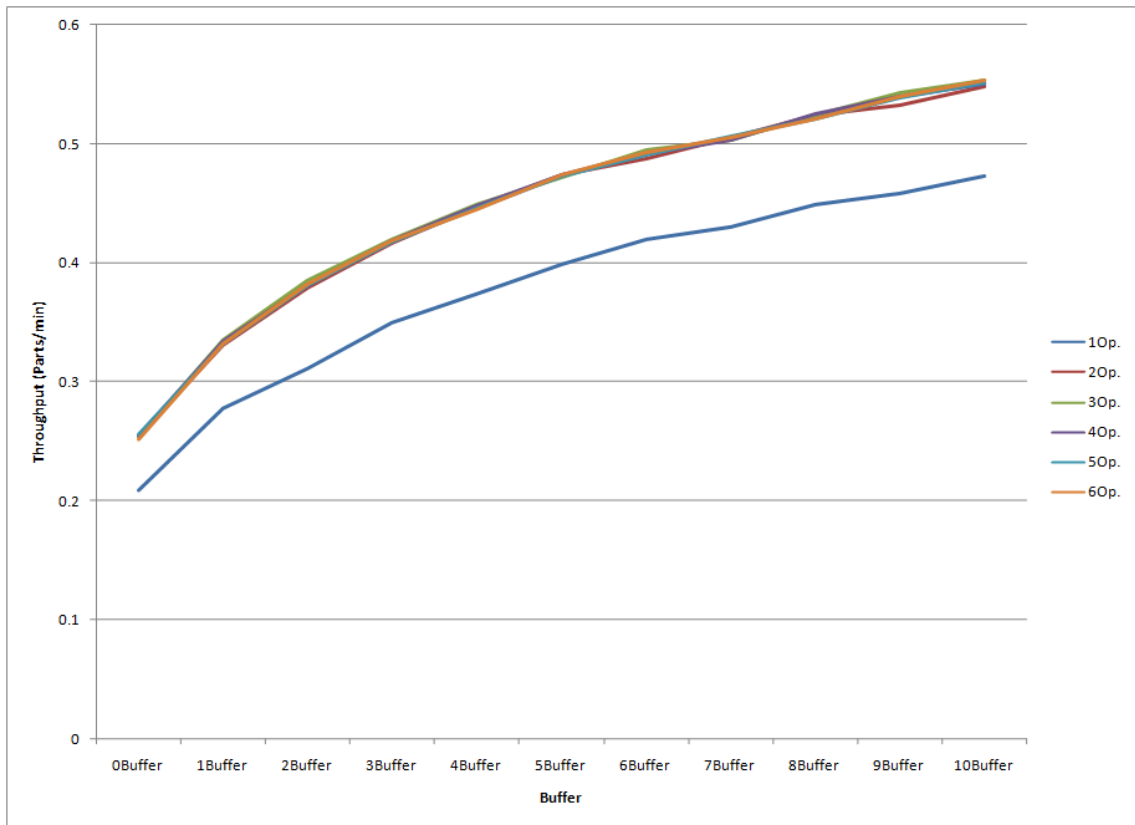


Figure 3.21 Trade-off Graph for the Sample Line

CHAPTER 4

CASE STUDIES

Chapter 4 presents two case studies that show the usefulness of the tool. The steps that are explained in the previous chapter are followed to analyze these two cases. First case study will deal with evaluating a configuration and second will deal with generating a trade-off graph.

4.1 Case 1 – Line X

Case 1 will deal with generating a trade-off graph which will set a light on the effect of number of buffers and operators on throughput. This graph can be used to predict the throughput of Line X in different circumstances. AE Simulator will minimize the modeling efforts to the minimum.

Line X is a 20-station unreliable balanced serial line. Processing times of each machine is constant 1 minute and they are given in Table 4.1.. Efficiency values of stations differ from 90% to 98% and Table 4.1 shows the efficiency values for each station. Fail rate values differ between 1 fail in 4 hours to 1 fail in 46 hours and they are listed in Table 4.1. Travel times from one station to another are presented in Table 4.2. Steps that are

explained in the previous chapter are going to be followed and trade-off graph is going to be generated for Line X.

	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	M ₇	M ₈	M ₉	M ₁₀	M ₁₁	M ₁₂	M ₁₃	M ₁₄	M ₁₅	M ₁₆	M ₁₇	M ₁₈	M ₁₉	M ₂₀
Processing Times	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Efficiency	91	96	90	98	91	93	93	95	98	95	92	93	95	96	93	92	97	92	94	91
Fail Rate	0.10	0.08	0.24	0.14	0.22	0.14	0.16	0.14	0.21	0.02	0.19	0.24	0.16	0.21	0.06	0.19	0.23	0.08	0.18	0.21

Table 4.1 Service Time and Failure Characteristics for Line X

	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	M ₇	M ₈	M ₉	M ₁₀	M ₁₁	M ₁₂	M ₁₃	M ₁₄	M ₁₅	M ₁₆	M ₁₇	M ₁₈	M ₁₉	M ₂₀
M ₁	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80	8.20	8.60
M ₂	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80	8.20
M ₃	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80
M ₄	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40
M ₅	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00
M ₆	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60
M ₇	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20
M ₈	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80
M ₉	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40
M ₁₀	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00
M ₁₁	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60
M ₁₂	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20
M ₁₃	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80
M ₁₄	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40
M ₁₅	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00
M ₁₆	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60
M ₁₇	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20
M ₁₈	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80
M ₁₉	8.20	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40
M ₂₀	8.60	8.20	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00

Table 4.2 Travel Times for Line X

AE Simulator creates the possible scenarios and runs these scenarios. The figure below shows the trade-off graph which shows the throughput values in each of these scenarios. One can use that trade-off graph to see what can happen with the other possible scenarios and compare it with the current one. This may help a lot before making any improvements on the line. Graph will easily tell the performance increase on any buffer or operator change and analyst can decide on how much he/she needs according to demand or any other criterion.

Figure 4.1 consists of scenarios from one operator to five operators and from zero buffers to fifteen buffers. These variables are determined in spreadsheet. It is seen increasing number of operators until three operators will increase the throughput. Having more than three operators does not affect the performance of the line. Throughput values for scenarios having more than three operators do not differ statistically. On the other hand, increasing number of buffers will certainly improve the line's performance for this case in which maximum number of buffers is 15.

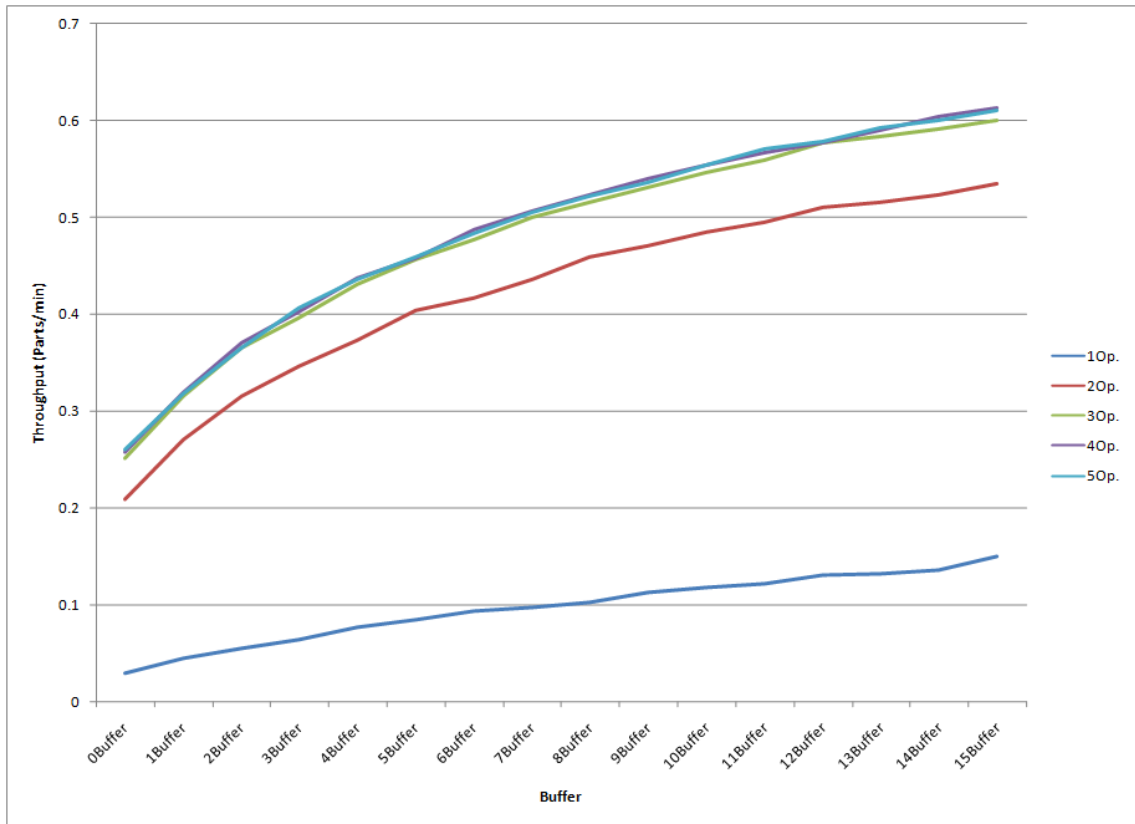


Figure 4.1 Trade-off Graph for Line X

4.2 Case 2 – Line Y

Case 2 is going to deal with evaluation of a configuration option of AE Simulator. This option gives you the chance to evaluate a configuration you have on hand. User enters the information to the spreadsheet and gets the result graph. AE Simulator will give the throughput of original serial line and 4 more scenarios which are described before. This graph can be used to see where Line Y performs right now. It tells how much that line can achieve with unlimited buffer and operator resource.

Line Y is a 20-station unreliable serial line. Processing times, failure characteristics of each machine are given in Table 4.3.

Table 4.4 lists the values for each buffer slot and Table 4.6 shows the operator assignment. Travel times are given in Table 4.5. Throughput of that serial line is going to be estimated using AE Simulator.

	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	M ₇	M ₈	M ₉	M ₁₀	M ₁₁	M ₁₂	M ₁₃	M ₁₄	M ₁₅	M ₁₆	M ₁₇	M ₁₈	M ₁₉	M ₂₀
Processing Times	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Efficiency	91	96	90	98	91	93	93	95	98	95	92	93	95	96	93	92	97	92	94	91
Fail Rate	0.1	0.1	0.2	0.1	0.2	0.1	0.2	0.1	0.2	0.02	0.19	0.24	0.16	0.21	0.06	0.19	0.23	0.08	0.18	0.21

Table 4.3 Service Time and Failure Characteristics for Line Y

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	B ₁	B ₂	B ₃	B ₄	B ₅	B ₆	B ₇	B ₈	B ₉	B ₁₀	B ₁₁	B ₁₂	B ₁₃	B ₁₄	B ₁₅	B ₁₆	B ₁₇	B ₁₈	B ₁₉
Value	4	6	3	2	5	6	7	8	2	3	4	7	6	2	6	3	4	3	2

Table 4.4 Buffer Values for Line Y

	M ₁	M ₂	M ₃	M ₄	M ₅	M ₆	M ₇	M ₈	M ₉	M ₁₀	M ₁₁	M ₁₂	M ₁₃	M ₁₄	M ₁₅	M ₁₆	M ₁₇	M ₁₈	M ₁₉	M ₂₀
M ₁	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80	8.20	8.60
M ₂	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80	8.20
M ₃	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40	7.80
M ₄	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00	7.40
M ₅	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60	7.00
M ₆	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20	6.60
M ₇	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80	6.20
M ₈	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40	5.80
M ₉	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00	5.40
M ₁₀	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60	5.00
M ₁₁	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20	4.60
M ₁₂	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80	4.20
M ₁₃	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40	3.80
M ₁₄	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00	3.40
M ₁₅	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60	3.00
M ₁₆	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20	2.60
M ₁₇	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80	2.20
M ₁₈	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40	1.80
M ₁₉	8.20	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00	1.40
M ₂₀	8.60	8.20	7.80	7.40	7.00	6.60	6.20	5.80	5.40	5.00	4.60	4.20	3.80	3.40	3.00	2.60	2.20	1.80	1.40	0.00

Table 4.5 Travel Times for Line Y

	O ₁	O ₂	O ₃	O ₄	O ₅	O ₆	O ₇	O ₈	O ₉	O ₁₀	O ₁₁	O ₁₂	O ₁₃	O ₁₄	O ₁₅	O ₁₆	O ₁₇	O ₁₈	O ₁₉	O ₂₀
M ₁	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₂	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₃	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₄	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₅	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₆	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₇	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₈	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₉	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₀	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₁	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₂	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₃	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₄	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₅	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₆	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₇	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₈	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₁₉	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
M ₂₀	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.6 Operator Assignment for Line Y

Figure 4.2 tells the throughput of Line Y. By looking at the graph and comparing the original scenario with others it is seen that line can produce a lot more than the current situation. Increasing number of buffers and operators will definitely increase the line's performance a lot. By generating trade-off graph for that line, one can estimate how much capacity expansion will be optimal for Line Y.

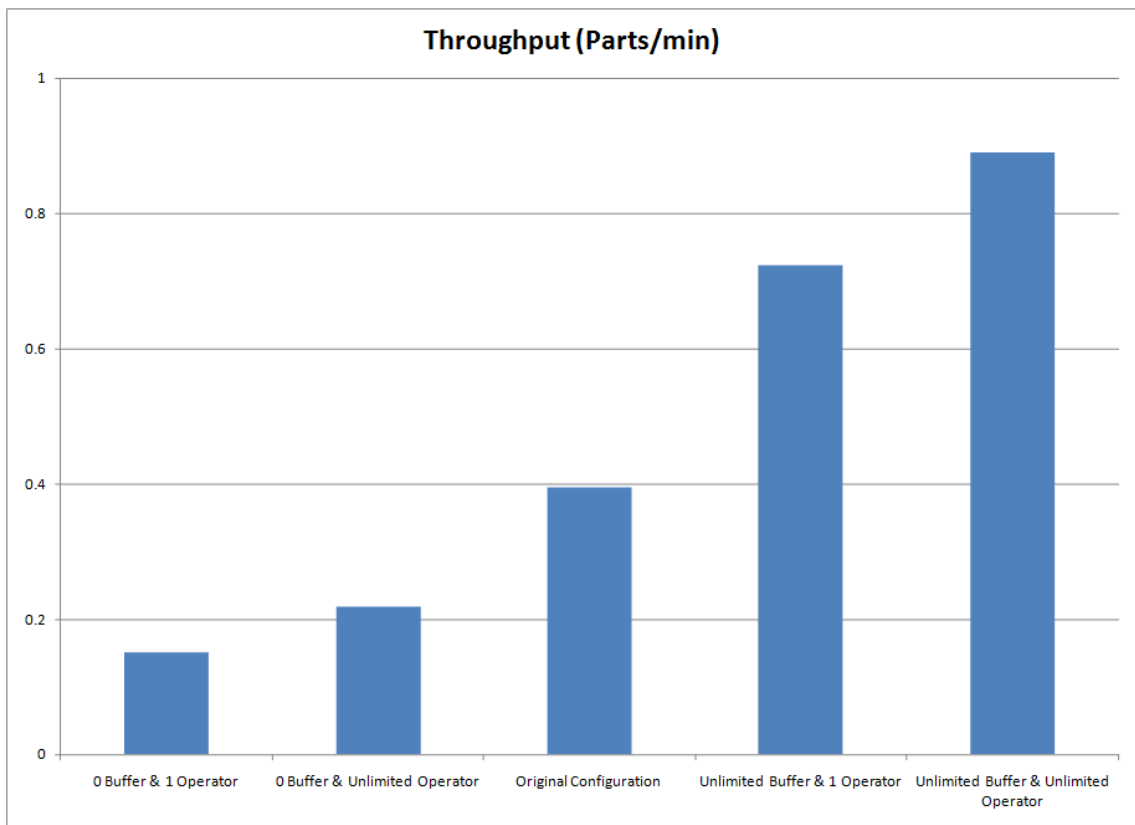


Figure 4.2 Throughput values for Line Y

CHAPTER 5

CONCLUSION

The objective of the study is to help an analyst to determine an optimal allocation of operator and buffer space for an unreliable serial line. For that purpose, an Arena integrated Excel tool, AE Simulator, is created to automate the process of building a simulation model. This tool takes away all the modeling efforts of a simulation model and only requires entering some information of the line into spreadsheet. It has two mechanisms that will aid in estimating the throughput of a serial line.

One of them evaluates a configuration which means if one has all the line information as machine characteristics, operator assignments, travel times and buffer values AE Simulator can evaluate that line and give the throughput. It does not only evaluate the configuration given by the user but also evaluates more configurations that are the configurations lead to minimum and maximum throughput of the same line. This option will tell the analyst where the original configuration stands between min and max so it answers the question of if anymore effort should be spent to increase the throughput.

Second mechanism deals with searching for all the possible scenarios and generating a trade-off graph of the line. This option requires user to enter machine characteristics and travel times and creates the possible scenarios by changing the number

of buffers and operators and evaluates these scenarios. An analyst can look at the trade-off graph and tell if the line needs any more operators and buffers.

Right now AE Simulator can only generate trade-off graph for evenly allocated buffers. It allocates same amount of buffer to every buffer slot. As a future work it can be improved to a state that will consider allocating buffers according to some design rules. So bottleneck stations can have more buffers around them. As a conclusion, AE Simulator is a very powerful tool that can estimate any kind of serial line's throughput in an easy way and some more improvements can make it a wonderful performance evaluation tool that a manufacturing engineer should have on hand.

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