ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL, AND MATERIAL ENGINEERING

MECHANICAL DESIGN AND MANUFACTURING ENGINEERING PROGRAM

Modeling and optimization of the TV assembling line of the Ethiopian Hi-Tech Engineering Industry using arena simulation software

A Thesis submitted to the school of Graduate Studies of Adama Science and Technology University (ASTU), School of Mechanical, Chemical and Material Engineering, for the partial fulfillment of the requirements of the Degree of Master of Science in Manufacturing Engineering.

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Advisor: Habtamu Beri (PHD)

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By: Gonfa Angasu

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DECLARATION

I, Gonfa Angasu hereby declare that the thesis entitled **"Modeling and Optimization of the TV Assembling Line of the Ethiopian Hi-Tech Engineering Industry using arena Simulation software"** submitted to the Adama Science & Technology University, Adama, in partial fulfillment of the requirements for the award of the degree of Master of Science in Manufacturing Engineering, Mechanical Design & Manufacturing Engineering Program, School of Mechanical, Chemical and Material Engineering is a record of original and independent research work done by me under the guidance of **Dr. Habtamu Beri** Dean, School of Mechanical, Chemical and Material Engineering, Adama Science & Technology University.

It has not been presented as a thesis in any other university and all sources of materials and supporters used for this thesis are accordingly sited and acknowledged.

__________________ _______________

Gonfa Angasu Date

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

Habtamu Beri (PHD) _________________ ____________

Advisor Signature Date

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ABSTRACT

Arena simulation model of a manufacturing system is used to estimate and appropriately represent the status of real system. This enable companies to easily measure approximate status and performance of the existing situation without incurring cost of disrupting the manufacturing system. So it is important to develop arena simulation model of the manufacturing system. For manufacturing industry to stay in market or to compete in local/global market the main requirement/influential factors are response time, production capacity, production cost, market price and the quality of the product they produce. In case of Hi-Tech Engineering industry the main problem corresponds with the response time, production capacity and production cost. These problems motivated for conducting this research in modeling and performance evaluation of manufacturing systems to find the main causes of the problems and to propose the possible alternative solutions among which the best preferable was chosen. To conduct this research, arena simulation software play a great role in designing a model of a real system and conducting experiments with this model for the purpose of understanding the behavior of the system and evaluating various strategies and scenarios for the operating or manufacturing system. To do so, Arena simulation software are used to model and measure performance of existing manufacturing system assembly/production lines by using the input data collected from the existing real system and low performance results which is 25.18% are obtained. Based on the simulation model result of the existing system, availability of different bottle necks are identified on the line and the causes of the bottle necks investigated. Depending on the causes different scenarios are proposed, analyzed and compared to solve/improve observed problems of the existing manufacturing system like, production capacity/volume, and production cost and response time.

Finally the scenario with better performance measure which has the production efficiency of 98% has been selected and taken as the optimum model for the production/assembly line.

Key words: *modeling, production/assembly line, simulation and optimization*.

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List of Abbreviations

OP1= Unpack frame from carton

OP2= Disassemble frame

OP3= Stick eva mat sponge

OP4= Put screen on the frame

OP5= Fix left & right press panel

OP6= Put sticker panel cable HT cable

OP7= Fix EVA mat

OP8= Fix boss bracket

OP9= Fix power board bracket

OP10= Fix power board

OP11= Fix main board

OP12= Fix up & down terminal

OP13= Insert panel & HT cable

OP14= Insert speaker & power cable

OP15= Fix back cabinet

OP16= Load software

OP17= AC & DC test

OP18= HDMI & YPBPR test

OP19= AV & coax test

OP20= USB & SCART test

OP21= Antenna test

OP22= TV & VGA test

OP23= Cleaning

OP24= Put sticker & bar code, packed power cable

OP25= Warranty &manual, remote control register sr. no

OP26= Covering screen cover

OP27= Put safety bush

OP28= Packed by cartoon

WIP=work in process

DES=Discrete event simulation

CHAPTER ONE: INTRODUCTION

1.1 Introduction

For any manufacturing industry to competent in the global as well as local market, the core decisive factor is the level to which they satisfy their customers in terms of required quantity, quality and lead time. Many companies are at least exposed to one of these parameters. To fulfill these parameters companies should strive for continuous updating of their performance. To update their performance, they face the challenge of continuous improvement and development of production technologies. To overcome these challenges it is important to identify the influential parameters affecting the performance of manufacturing system. To identify the factors affecting performance of manufacturing system without incurring more cost, it is useful to have the simulation model of the manufacturing system specially arena simulation model. The arena simulation model helps to imitate the real dynamic manufacturing system with the included resources of the system and also used to identify the major bottle necks of the manufacturing without implementing any change to the existing manufacturing system. With increased demand for customization and a larger range of products, production companies face a host of new challenges. Standardization of work, operator training and learning, production line re-balancing, smoother introduction of new products into the production line, quicker identification of problems associated with the introduction of these new products to the production system become significant challenges with the phenomenal growth in the number of products with short lifecycles. Simplifying the operator’s instructions as well as the means of instructing during operation gains priority because of the frequency with which changes are made which result from the introduction of new products. This challenge takes on special meaning in the context of the Hi-Tech Engineering Industry since a sizeable amount of the workforce is constituted by temporary and inexperienced workers. The focus therefore has to be on increasing the production/assembly line performance in order to increase customer satisfaction in terms of quantity, quality and response time.

1.2 Background of the company

Hi-Tech Industry (HTI) was established as one of the companies under the Metals and Engineering Corporation (METEC) in 2011. The company manufactures electronic and electromechanical technology products. It is Located at 40 km outside of Addis Ababa in the

Legedadi neighborhood. Its produces and assembles of communication radios (both for military and commercial purposes), various types of radar systems, electronic devices such as TV sets, electromechanical devices such as energy meters, harmonic analyzers, optical devices such as night vision devices, thermal imagers, and security cameras, other electronic technology products.

Its major services are:

- Training on electronics technology.
- Maintenance of communication devices, and reconditioning of night vision devices and various armament electronics parts.
- Installation of security cameras and intercoms.
- Overhauling and upgrading of communication radios, night vision devices and other optical devices.
- Installation of instrumentation and control systems.

Its major product customers are:

- Ethiopian Electric Power Company (EEPCO)
- METEC sister companies
- Ministry of Defense
- Police Force
- Various government organizations

The major service customers are:

- Bishoftu Automotive and Locomotive Industry
- Gafat Armament Industry
- Homicho Ammunition Engineering Industry
- Ministry of National Defense Force
- Police Force
- In different sectors such as Sugar Factory, Fertilizer Factory, Hydropower Plant. At present, the company has around 110 employees, of which 60 are females.

The main target of Hi-Tech Engineering Industry is to satisfy both of its customer either the product or service. The company has five workshop which produce different products. These are

(i) Office and house hold equipment workshop

(ii) Energy metro workshop

(iii)Electro optics workshop

(iv)Communication Equipment workshop

(v) Biomedical workshop

Among the above the focus is only on Office and house hold equipment workshop in which LCD TV are assembled because of it has high demand and product scarcity among the products in addition to highly labor intensive, needs high resource and long process steps to manufacture and assemble the products relative to the others .The specific product model TV32" is selected due to its high demand and scarcity of the model relatively. The main target of the factory is to produce 200 LCD TV 32"per day. The company works one shift per day which is eight hours (8hrs).Total number of tasks/work stations to produce TV on the existing production line is twenty eight (28).

1.3 Production processes and layout of TV assembly line.

1.3.1 Production/Assembly processes

In the office and house hold equipment workshop the TV 32" is assembled step by step as follows:

Table**1.1**: The sequential activities and operation of the TV32" assembly line

Assembly operation stations /steps	Activities to be performed	Abbreviations of the operation stations
1	Un pack frame from carton	OP1
2	Disassemble frame	OP2
3	Stick eva mat sponge	OP3
4	Put screen on the frame	OP4
5	Fix left & right press panel	OP5
6	Put sticker panel	OP6

	cable HT cable	
7	Fix EVA mat	OP7
8	Fix boss bracket	OP8
9	Fix power board bracket	OP9
10	Fix power board	OP10
11	Fix main board	OP11
12	Fix up & down terminal	OP12
13	Insert panel & HT cable	OP13
14	Insert speaker & power cable	OP14
15	Fix back cabinet	OP15
16	Load software	OP16
17	AC & DC test	OP17
18	HDMI & YPBPR test	OP18
19	AV & coax test	OP19
20	USB & SCART test	OP20
21	Antenna test	OP21
22	TV & VGA test	OP22

23	Cleaning	OP23
24	Put sticker & bar code, packed power cable	OP24
25	Warranty &manual, remote control register serial number	OP25
26	Covering screen cover	OP26
27	Put safety bush	OP27
28	Packed by cartoon	OP28

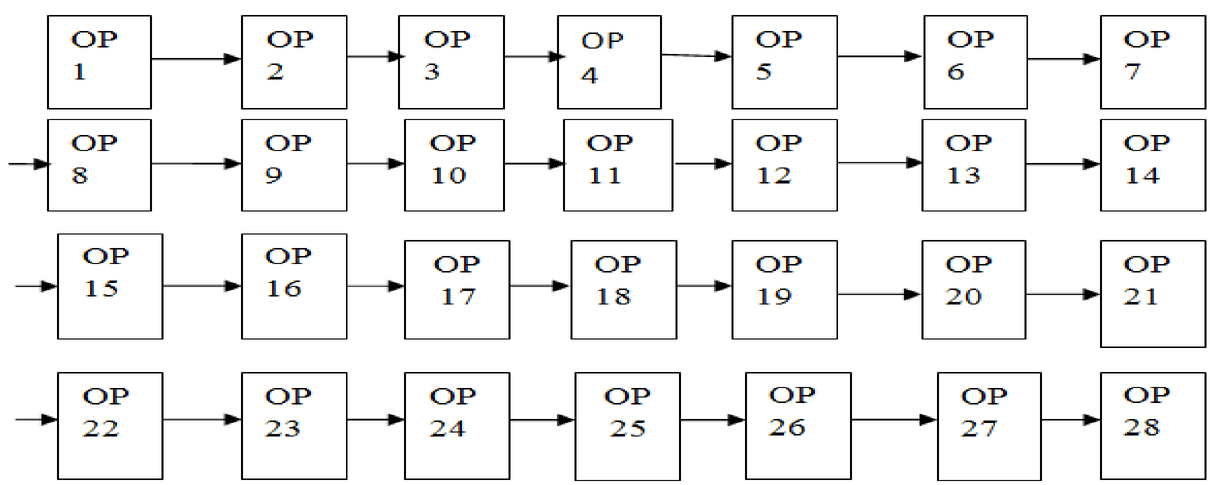

Figure 1.1: The flow diagram of the TV assembly line.

1.3.2 Layout of the TV assembly line workshop

For more description some of the working procedures of the TV product assembly steps are illustrated using figures in appendix-AI. Similarly the picture of other activities has been drawn in the appendix-AI.

Figure 1.2: Layout of the existing office and house hold equipment workshop.

This data has been taken from Hi-Tech Engineering Industry house hold equipment department 2016. Average daily actual production and production plan/customer demand has been given below. The average actual daily production, volume, unit cost and price have been given in the table 1.2.

Table 1.2: The average actual daily production, volume, unit cost and price.

Parameters	Model-19	Model-23	Model-32	Model-42
Average Daily actual production	59	59	59	59
Daily Production capacity/installed capacity	300	300	300	300
Daily average demand /plan projection	200	200	200	200
Production cost/unit in ETB	8,000	12,000	14,000	16,000
Product price/unit in ETB	10,000	15000	16000	18,000

Profit / unit in ETB	2000	2000	2000	2000
Amount loss/unit in ETB	2000	2000	2000	2000
Total amount loss(141*profit/unit) in ETB	2000*141=28,2000	2000*141= 28,200	2000*141= 28,200	2000*141= 28,200

This leads loss of about 141 (200-59) sales of the product daily which has unit price of 16,000 and unit production cost of 14,000.This implies loss of profit of 2000*141ETB=28,2000ETB per day. This indicates the ineffectiveness and inefficiency of the production/assembly line and daily productivity of the production/assembly line cannot satisfy the customer demand. It directly related to lead time, production cost and production capacity. Hence the research aims to identify bottlenecks which constrain the performance and effectiveness of assembly process and search/explore strategies to increase throughput while reducing production costs.

1.2 Statement of the problem

According to its periodic performance report, the main problem in Hi-Tech Engineering Industry is the daily actual production is below the daily production plan .But the capacity of the production/assembly line is beyond the production plan. This indicates the ineffectiveness or the availability of bottle neck on the production/assembly line .In other words, the daily actual production of the production/assembly line cannot satisfy the customer demand which makes the company not to survive in market. Therefore, the research aims to identify bottlenecks which constrain the performance and effectiveness of assembly process. Hence strategies to increase throughput while reducing production costs are being explored. To control the above parameters it is better to control manufacturing process. Before implementing any change to the manufacturing system/ production line it is better to use computer simulation of the manufacturing process which offers a cost effective solution not only to visualize the processes but also enables to identify bottlenecks in the system.

Therefore, to enhance and improve the production line output, modeling and optimization of the manufacturing processes is one of the research areas that should be investigated intensively.

Thus, the basic research questions in this thesis work include:

- How can the worker productivity fulfill the production plan?

- What criteria will be appropriate to identify and eliminate bottlenecks in the production line?
- How can simulation modeling be applied in TV assembly line?

1.3 Objective of the study

1.3.1 General objective

The general objective of this research is to model the manufacturing process of TV to identify the bottlenecks which reduce its productivity and find ways to enhance performance that leads to more productive and assist the management to arrive at a better after evaluation of performance of various alternative model results obtained from the simulation software.

1.3.2 Specific objectives

- Developing a computer based simulation model of the existing production line.
- Analyzing the existing production line.
- Evaluating capacity utilization of the existing production line.
- Identifying bottle neck in the production line.
- Evaluating capacity utilization of the alternative models/scenarios.
- Analyzing the production rate of alternative models.
- Evaluating the WIP of different models.

1.4 Methodology

To meet the objective of this research the main tasks listed in specific objective should be conducted consequently.

These tasks are achieved through literature survey, data collection, data analysis, model development and analysis and to finally get conclusion about the different models.

A complete literature survey on manufacturing systems, assembly line balancing, and different modeling and simulation techniques has discussed. Under the term assembly line balancing (ALB) various optimization models has introduced and discussed which aims at supporting the decision maker in configuring efficient assembly systems. In addition, different simulation software that is available which can suit the system is studied.

1.4.1 Data collection

To carry out the research company which has mostly manufacturing related problems especially assembly line output low performance problems, is selected to carry out the case study. In addition to this, the willingness of the company to undertake the study plays a significant role in selecting a company for the case study. To meet the specific objectives the parameters addressed in problem statements i .e low performance which need improvement determines the data required for the research. Accordingly, the data collection includes the following parameters which can influence and can be used in measuring of the performance of the manufacturing process are:

- Total number of tasks
- Processing times of each task
- Transfer time of WIP between stations
- Priorities between processes
- Arrival frequencies of entities or time between arrivals
- Number of workers for each task
- Layout of production/assembly line
- Working hours
- Production output
- Number of rework
- unscheduled stop

1.4.2 Data analysis

The collected data is analyzed by Arena input analyzer and the simulation model is developed.

1.4.3 Model development and simulation

Based on the data analysis using arena software the model for the existing system was developed and its performance results are measured and presented to identify the cause of the bottle necks. Depending on the causes different models/alternative scenarios proposed to be developed to decrease their effect then their performance results are measured and evaluated to select the best alternative solution among the proposed models. Finally conclusions and recommendations has made on the findings.

1.4.4 Organization of the research work

The whole thesis work may encompass up to six main chapters which will be presented as follows. The first chapter briefly explains about the problem statements and the methodology to solve it. The second chapter is concerned with related literatures review of simulation modeling of manufacturing processes and performance analysis. The third chapters discusses about case Study Company /manufacturing process and statistical analysis. Simulation model development and simulation result presentation which are the core points of the research are discussed in chapter four. In chapter five different scenarios are proposed and their simulation models are developed and discussed. The last chapter, chapter six, presents the findings of the study as a conclusion and recommendation and a list of activities which should be performed and should be encompassed in future works in order to enhance the development of TV production industry.

1.5 The scope of the study

The scope of this research work is limited to measuring performance of the existing production line and proposing different alternatives model for the production line and, analyzing using simulation software then the best model of the production line having better performance measure for the product in the manufacturing system was selected.

1.6 Significance of the Study

Performance improvement is the key for any industry, in order to compete and be productive in today's competitive market. Therefore, any manufacturing company especially TV manufacturing company can benefit from this thesis by accepting the main points of the work and making some minor improvements to the rest of the points.

1.7 Limitation of the study

In this research, the limitation to the work is the unavailability /expensiveness of commercial version arena software to include all the entities behavior in the system so that all the dynamic nature of the resources could be included and visualized. The other limitation is that the student version arena software can handle only 150 entities in a system, as a result it is impossible to simulate the system beyond the amount of the entities specified.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Researcher has under gone different research papers which have been given below:

Every model developed whether it is simulation, analytical or physical's aim is to analyze its performance, to use it as a reference or etc. The aim in this thesis is performance analysis and this done using different performance matrices as a starting point. Performance measures (benefit measures the higher the better) or (cost measure the lower is the better) are devices to aid decision makers discriminate between competing manufacturing arrangements, and improving the performance of the existing system. The following are some of the specific issues that simulation is used to address to analyze its performance:

- Number and type of machines for a particular objective
- Throughput analysis
- Time-in-system analysis
- Bottleneck analysis
- Queue sizes

Therefore, the above parameters can be used as a performance metrics, to analyze the performance of a manufacturing system. Any type of manufacturing system can be modeled and its performance can be analyzed. The simulation, modeling, and analysis of manufacturing systems for performance improvement have become increasingly important during the last few decades [21]. Different performance measures can be used to analyze the manufacturing model. These are total cost, throughput, flow times, etc. the performance measure used in this thesis is throughput which is related with WIP, cycle time and etc. Different factors can affect the performance of any manufacturing system. Researchers have shown that setup number have a smaller influence on performance measures like total cost and also the influence of the demand and the holding cost rate on performance measures like total cost is approximately equal [18]. Manufacturing system modeling can also apply to mixed model production lines. In mixed model production line, different product types are simultaneously manufactured by processing small batches. In this case, every decision makers wants to determine the bottlenecks before changing any traditional lines into mixed model production line [17]. Performance evaluation is also an important phase in the design of assembly lines in a mixed model production environment. The main problems faced by mixed model lines planner are:

- How to balance the line when different products have different work contents,
- How to determine the optimum launch sequence that minimizes losses

Therefore, in order to improve the performance in any manufacturing system, it is necessary to improve constraints also known as bottlenecks. In a mixed model assembly lines, the two main problems that should be solved are balancing the assembly lines and deciding different product sequence and lot sizes [17]. Sometimes the transportation system like AGV or conveyor causes constraint or bottleneck [17]. Therefore, improving transfer time of the AGV's is very important in maximizing the system performance. In model development, different inputs and model assumptions are required. The model inputs required are like production sequence and schedule, shift of operators, time between arrivals, capacity of conveyor, etc. Assumptions on arrivals, how many units can arrive to the system simultaneously, allowances required must be made [17].

The other area that manufacturing system modeling can apply is in the production line bottleneck analysis [20]. The bottleneck in a production system occurs when workloads arrive at a given point more quickly than that point can handle them. A discrete event simulation approach can be used to compare several methods for production line bottleneck analysis [20]. In any system, there is always some processes, tasks, machines, etc that is being the limiting factor by preventing a greater throughput and thus resulting in low capacity utilization of the entire system. Knowing the bottleneck in a system allows us to increase the flow by improving just one process in the system rather than all its remaining parts. In other words in a system where there is bottleneck, nothing done elsewhere in the value stream cannot improve its throughput.

There are two ways of detecting bottleneck in a production line: simulation and analytical based. For analytical methods, the system performance is assumed to be described by a statistical distribution. However, in the real production processes where there are complex structures and dynamics, it is practically in applicable to use analytical methods. In such a case, simulation based approach is more preferable [20]. There are different bottleneck detection methods, in modeled production line, developed over the last decades [20]. These are:

- Active period method Turning point method
- Arrow based method
- Criticality indicators based methods

The active period method developed by Toyota central research and development laboratories is based on the analysis of machine status information like determining periods during which a machine is active without interruption (a new method for bottleneck detection). A machine can have five distinct states: working, waiting, blocked, tool change and under repair. If a machine is not working even if it is in a good condition, it will be considered inactive. Therefore, waiting and blocked are considered inactive and the machine with longest active period is considered to be bottleneck [20]. Turning point is defined to be the machine where the trend of blockage and starvation changes from blockage being higher than starvation to starvation being higher than blockage. A turning point machine has the highest percentage of the sum of operating time and down time compared to other machine in the segment [20]. This is considered as a quick bottleneck identification method. The arrow based method detects the bottlenecks in a longer lines allowing the probabilities of starvation and blockage for each machine and placing arrows directed from one machine which has a higher starvation or blockage to the other with the lower ones. Therefore, based on this a machine which has no emanating arrows is considered as bottleneck [20].

The criticality indicators based method is based on the evaluation of the so called "criticality indicators" for each workplace and comparison of the indicator values to the bottleneck. The above four-bottleneck detection methods have their own advantages and disadvantages. Out of them, criticality indicators based method gives relatively good result and it is in prospective to be used for automated synchronization of the production line [20]. There is also other paper that was done by concerning on bottleneck detection (a new method for bottleneck detection). The paper presents a new method to identify and rank the bottlenecks in a manufacturing system. A manufacturing system may have a dominant bottleneck that will appear as a bottleneck most often during analysis or it may have momentary bottlenecks that keep shifting in the system with time due to failure. There are various methods available for detecting momentary and average bottlenecks in the past:

- Shifting bottleneck detection based on the duration of machine being active without interruption,
- Bottleneck detection based on utilization of machine (machine with high utilization is considered as bottleneck),
- The machine with the longest average up-stream queue length is considered bottleneck,
- Analytical approach based on estimation of the blockage and starvation problem of a machine.

To identify bottlenecks and rank them, the proposed method analyzes departure time data. It also recognizes four valid states. These are:

- Cycle
- Blocked-up
- Blocked-down
- Fail states

In the paper, the machine that has the largest combination percentage of residence time in cycle and fails states is considered bottleneck or the machine with the minimum combined percentage of residence time in blocked-up and blocked-down state is considered as bottleneck machine. Consistency of inter-departure time was also considered in the identification of bottleneck station. Bottleneck ranking was assigned based on the rule that the most severe bottleneck will have the highest combined percentage of residence in cycle and fail state.

In the proposed method, the author tried to present a process that is less affected by data error. He proposed a set of rules that may help to identify the data elements in error based on the valid states of machine defined earlier. In conclusion, a method was presented in this paper which analyzes inter departure time and failure cycle data to identify and rank bottlenecks in a manufacturing system. This research was limited to deterministic cycle time.

Different areas other than performance and bottleneck analysis have also been addressed using simulation modeling. Now a day, customer's need is changing rapidly. Participating only on production of standardized products is not enough to compete in the market. Therefore, productions of customized products are necessary. This customization of products needs the flow lines, resource requirements, etc to change whenever a new product is introduced. Due to this, the computer model developed for this kind manufacturing system must adapt to this changes. However, Simulation models require a large amount of data, which makes its modification more difficult. Small changes in the manufacturing environment can produce many different (though related) changes to the data input for the simulation model. Some examples of changes that are likely to occur are: (a) the answers needed from the simulation, (b) the products that are being made on the shop floor, (c) new production processes or characteristics of the current production processes, and (d) changes to the plant layout [19]. Therefore, it is desirable to have adaptable simulation models that are easy to change with little or no programming effort because it will reduce the time, effort and cost of using simulation [19].

Adaptable simulation models that can represent the changing shop floor are also required to use them in real-time scheduling and operational setting. As manufacturing system progresses from concept to a detailed design and to an installed and operating facility, the simulation model of the system must change [19]. In addition, many manufacturing corporations use simulation models to evaluate the impact of moving a manufacturing facility to another location. When comparing a number of locations across the country or around the world, the analyst will have to modify the simulation model repeatedly to incorporate information about the specific location. This can be a very time-consuming effort therefore requires adaptability of the models. Adaptability is closely related to jobs and machine flexibility. Based on machine and job flexibility, it was concluded that adaptable simulation models have the ability to handle changes like [19].

- Requirements changes or changes in the answers to be provided by the simulation model,
- Internal and external changes in the production environment: Internal changes are changes in the process and material handling equipment and the interconnections among them. External changes are changes to the products to be made and the production quantities, for example, which are not changes in the physical manufacturing system.
- Updated data provided by related information systems such as process planning and shop floor control. The above paper has reviewed the concepts of adaptability and suggested a method to measure a simulation model's adaptability. In the proposed adaptability index, comparison is also made between the efforts needed to change the model to the effort required to build a completely new model [19].

Based up on the above literature review researcher has taken a case study of Hi-Engineering Industry for modeling and optimization of assembly line using simulation.

Currently, manufacturing industry including Hi-Tech Engineering Industry is facing different problems. These include low capacity utilization, unorganized flow of processes, which in turn are resulting in low overall performance. They are also facing with questions like:

- What are parameters are influencing the performance of existing system?
- How performance of a system improved?
- What is the effect of varying the number of resources such as labor to the existing system?
- What is the effect of upgrading accuracy of resources such as labor skill?
- What is the effect of changing the input of the production line of the existing process?

- How can productivity be increased?

In the past, managers had dealt with this kind of problems by simply using their own judgment, which was incurring unnecessary costs. Due to this, the modeling concept came in to consideration. Modeling has been defined in many ways by different authors. In its simple definition, modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. Simulation and analytical modeling are two of the basic modeling tools being used today. In this thesis, simulation is used to model the production/assembly line of the product.

2.2 Modeling of manufacturing system

Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes to the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it. A good model is a judicious tradeoff between realism and simplicity. Simulation practitioners recommend increasing the complexity of a model iteratively. An important issue in modeling is model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output.

Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account). Typically, simulation models are stochastic and dynamic [33].

What is simulation?

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. The operation of the model can be studied, and hence, properties concerning the behavior of the actual system or its subsystem can be inferred. In its broadest sense, simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time. Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance. For instance, simulation can be used to answer questions like: What is the best design for a new telecommunications network? What are the associated resource requirements? How will a telecommunication network perform when the traffic load increases by 50%? How will a new routing algorithm affect its performance? Which network protocol optimizes network performance? What will be the impact of a link failure?

The subject of this study is discrete event simulation in which the central assumption is that the system changes instantaneously in response to certain discrete events. For instance, in an M/M/1 queue – a single server queuing process in which time between arrivals and service time are exponential - an arrival causes the system to change instantaneously. On the other hand, continuous simulators, like flight simulators and weather simulators, attempt to quantify the changes in a system continuously over time in response to controls. Discrete event simulation is less detailed (coarser in its smallest time unit) than continuous simulation but it is much simpler to implement, and hence, is used in a wide variety of situations. Figure 2.1 is a schematic of a simulation study. The iterative nature of the process is indicated by the system under study becoming the altered system which then becomes the system under study and the cycle repeats. In a simulation study, human decision making is required at all stages, namely, model development, experiment design, output analysis, conclusion formulation, and making decisions to alter the system under study. The only stage where human intervention is not required is the running of the simulations, which most simulation software packages perform efficiently. The important point is that powerful simulation software is merely a hygiene factor - its absence can hurt a simulation study but its presence will not ensure success. Experienced problem formulators and simulation modelers and analysts are indispensable for a successful simulation study. [3]

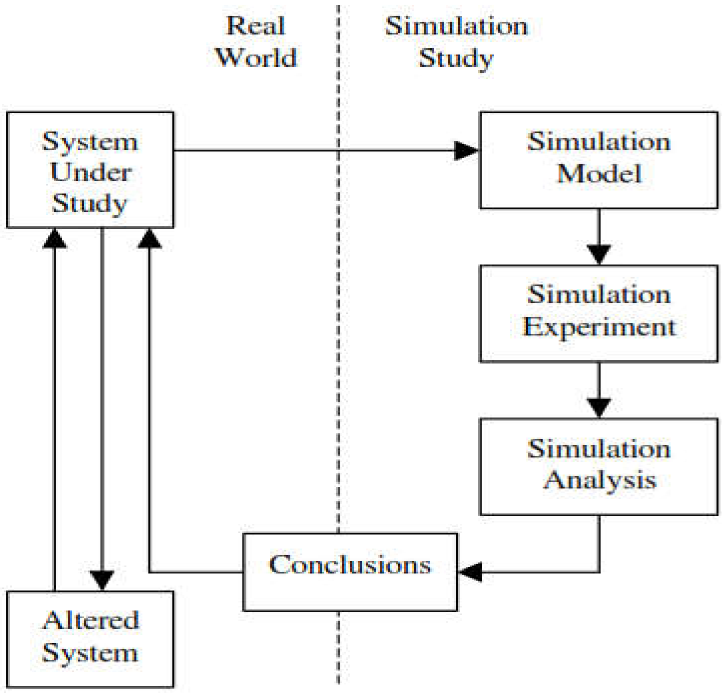

Figure 2.1: Simulation study schematic simulation model

Simulation Experiment Simulation Analysis

The steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis are:

Step1. Identify the problem.

Step2. Formulate the problem.

Step3. Collect and process real system data.

Step4. Formulate and develop a model.

Step5. Validate the model.

Step6. Document model for future use.

Step7. Select appropriate experimental design.

Step8. Establish experimental conditions for runs.

Step9. Perform simulation runs.

Step10. Interpret and present results.

Step11. Recommend further course of action.

Although this is a logical ordering of steps in a simulation study, much iteration at various sub-stages may be required before the objectives of a simulation study are achieved. Not all the steps may be possible and/or required. On the other hand, additional steps may have to be performed. The next three sections describe these steps in detail.[5]

How to develop a simulation model?

Simulation models consist of the following components: system entities, input variables, performance measures, and functional relationships. For instance in a simulation model of an M/M/1 queue, the server and the queue are system entities, arrival rate and service rate are input variables, mean wait time and maximum queue length are performance measures, and 'time in system= wait time + service time' is an example of a functional relationship. Almost all simulation software packages provide constructs to model each of the above components. Modeling is arguably the most important part of a simulation study. Indeed, a simulation study is as good as the simulation model. Simulation modeling comprises the following steps:

Step 1: Identify the problem. Enumerate problems with an existing system. Produce requirements for a proposed system.

Step 2: Formulate the problem. Select the bounds of the system, the problem or a part thereof, to be studied. Define overall objective of the study and a few specific issues to be addressed. Define performance measures - quantitative criteria on the basis of which different system configurations will be compared and ranked. Identify, briefly at this stage, the configurations of interest and formulate hypothesis about system performance. Decide the time frames of the study, i.e., will the model be used for a one-time decision (e.g., capital expenditure) or over a period of time on a regular basis (e.g., air traffic scheduling). Identify the end user of the simulation model, e.g., corporate management versus a production supervisor. Problems must be formulated as precisely as possible.

Step 3: Collect and process real system data. Collect data on system specifications (e.g., bandwidth for a communication network), input variables, as well as performance of the existing system. Identify sources of randomness in the system, i.e., the stochastic input variables. Select an appropriate input probability distribution for each stochastic input variable and estimate corresponding parameter(s). Software packages for distribution fitting and selection include Expert Fit, Best Fit, and add-ons in some standard statistical packages. These aids combine goodness-of-fit tests, e.g.2 test, Kolmogorov-Smirnov test, and Anderson-Darling test, and parameter estimation in a user friendly format. Standard distributions, e.g., exponential, Poisson, normal, hyper exponential, etc., are easy to model and simulate. Although most simulation software packages include many distributions as a standard feature, issues relating to random number generators and generating random varieties from various distributions are pertinent and should be looked into. Empirical distributions are used when standard distributions are not appropriate or do not fit the available system data. Triangular, uniform or normal distribution is used as a first guess when no data are available. For a detailed treatment of probability distributions see [34].

Step 4: Formulate and develop a model. Develop schematics and network diagrams of the system (How do entities flow through the system?). Translate these conceptual models to simulation software acceptable form. Verify that the simulation model executes as intended. Verification techniques include traces, varying input parameters over their acceptable range and checking the output, substituting constants for random variables and manually checking results, and animation.

Step 5: Validate the model. Compare the model's performance under known conditions with the performance of the real system. Perform statistical inference tests and get the model examined by system experts. Assess the confidence that the end user places on the model and address problems if any. For major simulation studies, experienced consultants advocate a structured presentation of the model by the simulation analyst(s) before an audience of management and system experts. This not only ensures that the model assumptions are correct, complete and consistent, but also enhances confidence in the model.

Step 6: Document model for future use. Document objectives, assumptions and input variables in detail.

How to design a simulation experiment?

A simulation experiment is a test or a series of tests in which meaningful changes are made to the input variables of a simulation model so that we may observe and identify the reasons for changes in the performance measures. The number of experiments in a simulation study is greater than or equal to the number of questions being asked about the model (e.g., Is there a significant difference between the mean delay in communication networks A and B?, Which network has the least delay: A, B, or C? How will a new routing algorithm affect the performance of network B?). Design of a simulation experiment involves answering the question: what data need to be obtained, in what form, and how much? The following steps illustrate the process of designing a simulation experiment.

Step 7: Select appropriate experimental design. Select a performance measure, a few input variables that are likely to influence it, and the levels of each input variable. When the number of possible configurations (product of the number of input variables and the levels of each input variable) is large and the simulation model is complex, common second-order design classes including central composite, Box-Behnken, and full factorial should be considered. Document the experimental design.

Step 8: Establish experimental conditions for runs. Address the question of obtaining accurate information and the most information from each run. Determine if the system is stationary (performance measure does not change over time) or non-stationary (performance measure changes over time). Generally, in stationary systems, steady-state behavior of the response variable is of interest. Ascertain whether a terminating or a non-terminating simulation run is appropriate. Select the run length. Select appropriate starting conditions (e.g., empty and idle, five customers in queue at time 0). Select the length of the warm-up period, if required. Decide the number of independent runs - each run uses a different random number stream and the same starting conditions by considering output data sample size. Sample size must be large enough (at least 3-5 runs for each configuration) to provide the required confidence in the performance measure estimates. Alternately, use common random numbers to compare alternative configurations by using a separate random number stream for each sampling process in a configuration. Identify output data most likely to be correlated.

Step 9: Perform simulation runs. Perform runs according to steps 7-8 above.

How to perform simulation analysis?

Most simulation packages provide run statistics (mean, standard deviation, minimum value, maximum value) on the performance measures, e.g., wait time (non-time persistent statistic), inventory on hand (time persistent statistic). Let the mean wait time in an M/M/1 queue observed from n runs be W...,,W,W . It is important to understand that the mean wait time W is a random n_{21} variable and the objective of output analysis is to estimate the true mean of W and to quantify its variability. Notwithstanding the facts that there are no data collection errors in simulation, the underlying model is fully known, and replications and configurations are user controlled, simulation results are difficult to interpret. An observation may be due to system characteristics or just a random occurrence. Normally, statistical inference can assess the significance of an observed phenomenon, but most statistical inference techniques assume independent, identically distributed data. Most types of simulation data are auto correlated, and hence, do not satisfy this assumption. Analysis of simulation output data consists of the following steps.

Step 10: Interpret and present results. Computing numerical estimates (e.g., mean, confidence intervals) of the desired performance measure for each configuration of interest. To obtain confidence intervals for the mean of auto correlated data, the technique of batch means can be used. In batch means, original contiguous data set from a run is replaced with a smaller data set containing the means of contiguous batches of original observations. The assumption that batch means are independent may not always be true; increasing total sample size and increasing the batch length may help. Test hypotheses about system performance. Construct graphical displays (e.g., pie charts, histograms) of the output data. Document results and conclusions.

Step 11: Recommend further course of action. This may include further experiments to increase the precision and reduce the bias of estimators, to perform sensitivity analyses, etc.

2.3 Application of Simulation in Manufacturing

Simulation has plenty of application in manufacturing sector [21]. Different authors have considered this in their paper. According to those papers, the following are some of the specific issues that simulation addresses in manufacturing:

The need for and the quantity of equipment and personnel:

- Number and type of machines for a particular objective
- Number, type, and physical arrangement of transporters, conveyors, and other support equipment (e.g., pallets and fixtures)
- Location and size of inventory buffers
- Evaluation of a change in product volume
- Evaluation of the effect of a new piece of equipment on an existing manufacturing system Evaluation of capital investments
- Labor-requirements planning.

Performance evaluation:

- Throughput analysis
- Time-in-system analysis
- Bottleneck analysis Evaluation of operational procedures.
- Production scheduling
- Inventory policies

- Control strategies [e.g., for an automated guided vehicle system (AGVS)]
- Reliability analysis (e.g., effect of preventive maintenance)
- Quality-control policies

In any factory, there can be different sources of randomness. Each source of system randomness needs to be modeled by an appropriate probability distribution, not what is perceived to be the mean value. Note that sources of randomness encountered in practice are rarely normally distributed. Some sources of randomness in simulated manufacturing systems are :

- Arrivals of orders, parts, or raw materials
- Processing, assembly, or inspection times
- Machine times to failure
- Machine repair times
- Loading/unloading times
- Setup times
- In our case, workers moving from one place to the other while working, conveyor delay can also be some source of variation.

A structured approach to simulation modeling of manufacturing systems:

The enhancement of simulation modeling and analysis by increasingly powerful computational platforms has enabled development of high fidelity models of manufacturing system. Such high fidelity modeling has important benefits in prototyping system performance. However, it must be supported by underlying modeling discipline or structured approach to modeling factory operation. The ability to create high fidelity models has important potential benefits in prototyping system.[6]

Long simulation or development time is one of simulations main drawbacks. Therefore, in this paper, a structured approach to simulation modeling or a modeling discipline to be used to aid the model development process is proposed. Most simulation packages are based on the process-interaction modeling framework in which a set of “processes” or “transactions” travel through a set of “blocks” or “resources” in the model. An event occurs or a future event is scheduled, when a process passes through a block. Clearly one benefit is that this approach provides the modeler with built-in “infrastructure” for the simulation (i.e. event calendar, clock etc) so that the modeler may concentrate on specifying the model. The processes follow a “seize-hold-release” behavioral pattern. This pattern does not model material-handling system well. Due to this, most simulation software has adopted specialized abstractions (Conveyors).These shortcomings in process interaction simulation have sparred interest in new approaches to simulation like object-oriented approaches to simulation. The object oriented programming (OOP) paradigm focuses on the specification of objects, with attributes and methods. This research is based on this specific framework. The goal of the research is to develop a set of domain specific modeling tool for manufacturing system. The first step in that process is to specify a reference model for manufacturing upon which the simulation tools are based. A reference model is a standardized representation for a problem domain such as manufacturing. Based on the reference model, a set of manufacturing specific modeling abstractions are presented.

Guiding Principles for Conceptual Model Creation in Manufacturing Simulation: Conceptual models serve as abstractions of user's perceptions of a system. The choice and detailing of these abstractions are key to model, use and understanding for analyst and project stakeholders. Conceptual modeling is almost certainly the most important aspect of a simulation project. Conceptual models serve as abstractions of user's perceptions of a system being either real or proposed. Important purposes of conceptual models are: to foster analysts understanding of a domain to help developers and users to communicate, to serve as a basis for design, and to serve as documentation of the original requirements of the system. Clearly, quality of conceptual modeling does influence project management (time scales, organization, iterations), project contents (problem definition, model development, experimenting, validation & verification), and last but not least project success in terms of credibility and acceptance of solutions. Conceptual model creation entails two activities:

- The identification of the phenomena to be modeled and
- The mapping of the phenomena into grammar's constructs

In his survey on conceptual modeling for simulation distinguishes between three basic approaches in guiding the analyst: principles of modeling, methods of simplification, and modeling frameworks. Principles of modeling advocate an evolutionary development of models start small and simple, and adapt and extend the model incrementally. On the other hand, methods of simplification work the other way around by suggesting ways for model pruning. While both approaches offer relevant assistance for conceptual modeling they do not a priori address the creation of the conceptual model, i.e., the identification of elementary model components appealing to a domain and to project's stakeholders. Modeling frameworks distinguish themselves from the aforementioned approaches by specifying a procedure for detailing a model in terms of its elements, their attributes and their relationships. Examples include the general case of systems representation and domain related cases.[1]

Clearly, the “implicit” practice of conceptual modeling has an impact on model quality in terms of its transparency and completeness with respect to key decision variables. Moreover, the interest in innovative chain configurations in business, such as for example, supply chains, health care chains, and transportation networks, stress the importance of high quality conceptual modeling. This follows both from systems’ complexity, and from the presence of multiple autonomous stakeholders. In this article, we attempt to evaluate the current practice of conceptual modeling for the manufacturing field to some extent. Two cognitive approaches are suggested as being fundamental in the process of identifying the phenomena to be modeled:

- Decomposition: breakdown of a system into semi independent components corresponding to its many functional parts,
- Classification: grouping of similar types of objects.

2.4 model verification and validation

Verification is the process of determining that the model operates as intended. In other words, it is the process of debugging the model. All the verification activities are closely related to the model. An empirical way to check if the model is behaving as the modeler intended is to and to calculate the outputs the model is supposed to give. This process is by no means sufficient or enough to declare a model as verified, but it helps to identify subtle errors. In fact, determining that a model is absolutely verified may be impossible to attain. During the verification stage, the modeler must test each major component of the model. These can be done by doing static testing (correctness proofs, structured walk through) or by doing dynamic testing (execute the model under various conditions) [31].Validation is the process of ascertaining that a model is an acceptable representation of the "real world" system. The validation process is concerned with establishing the confidence that the end user will have on the model. Some critical questions to ask during this stage are does the model adequately represents the relationships of the "real" system?, is the model generated output "typical" of the real system? Validation requires that the model be tested for reasonableness (continuity, consistency, and degeneracy) [7]. A point to start the validation process empirically is to question the structural assumptions of the model as well as the data assumptions made early in the SMP. A more sophisticated way to validate a model may require the use of some analytical tools such as Queuing Theory, but for it additional data may be needed [31].

In summary, verification and validation can be informal (audits, face validations, Turing test, walk through), Static (consistency checking, data flow analysis), Dynamic (Black-box testing, regression testing), Symbolic (cause-effect diagrams, path analysis), Constraint (assertion checking, inductive assertions), and Formal (Logical deduction, Predicate calculus, proof of correctness). For more details in any of these tests, see [32].

2.5 Simulation and Optimization

The optimization of simulation model deals with the situation in which the analyst would like to find which of possibly many sets of model specifications which are input parameters or structural assumptions, lead to optimal performance [29]. Accordingly, a simulation can be considered as a „mechanism that turns input parameters into output performance measures". Mentioned in the research [2].There are four classical approaches for optimizing simulation: stochastic approximation (gradient-based approaches); (sequential) response surface methodology; random search; sample path optimization (stochastic counterpart). Nevertheless, these four main classical approaches have not been used in practical application [28]. Because of the substantial requirement from high technical issue and computer time to solve the problem [30].Since the met heuristic optimization is advanced where optimization procedure does not depend on type of problem or system to be optimized, there is an integration of simulation and optimization [13]. Figure 2.2 represents the coordination between optimization and simulation [5].

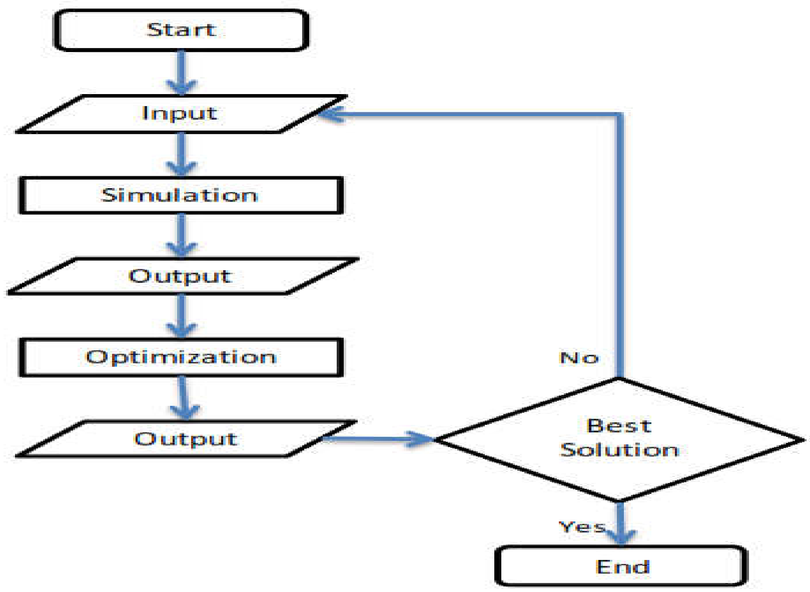

Figure 2.2: Coordination between optimization and simulation (Glover et al. 1999)

2.6 Simulation-based Multi-objective Optimization

Simulation is an analytical tool to create, maintain, evaluate or improve a system or process. It is the imitation of the operation of a real-world process or system over time and presents a huge potential for manufacturing process development and improvement [22, 23].

It has been demonstrated that simulation techniques are the most suitable approach for process improvement of complex systems with high variability. The variability and difficulty of the processes within complex systems demand the analytic power of DES. One of the more highlighted characteristics of DES studies is the possibility to apply “what-if” questions or scenarios to the existing systems without disturbing them. Within these scenarios new alternatives, ideas, systems and work proceedings can be tried out without disturbing the real system, or be developed even before a system is constructed [24].

Since simulation is not an optimization tool by itself, a step that combines simulation and optimization is required when several possible combinations of the system are analyzed. Traditionally, simulation and optimization have been considered as different approaches in the operational research domain, but they are many times integrated and finally the concept is to use the detail system behavior of simulation in combination with the ability of optimization to reach an optimal or close to optimal solutions [24]. It has been demonstrated that the combination of optimization and simulation tools allows decision makers to quickly determine optimal system configurations, even for complex integrated facilities [25]. When multiple objectives are simultaneously considered, Simulation-based Multi-objective Optimization (SBO) is the most promising approach. SBO facilitates the search for trade-offs between several conflicting objectives [26].

Depending on the type of problem to analyze, there are different optimization methods that can be used in combination with simulation, of which several are presented by Figueira and Almada-Lobo [24]. Different authors have described how simulation and optimization techniques applied together have improved production or material handling systems. Nevertheless, there are not many cases found in the literature where DES and SBO are applied together to support the design and/or development of production and logistics systems of high product mix and low volume production.

2.7 Arena Simulation Modeling

Simulation is one of several alternative methods of analyzing systems. Another technique is the use of mathematical analysis. Analytical modeling involves building a system description using some formal, mathematical notation. Unfortunately mathematical analysis is limited to a relatively small number of simple systems and the opportunity to represent manufacturing systems in this way is felt to be limited [9].

In a simulation, the analyst controls all the factors making up the data and can manipulate them systematically to see directly how specific problems and assumptions affect the analysis. Because simulation software keeps track of statistics about model elements, performance can be evaluated by analyzing the model data.

The Arena modeling system from Systems Modeling Corporation is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system. First released in1993, Arena employs an object-oriented design for entirely graphical model development. Simulation analysts place graphical objects called modules on a layout in order to define system components such as machines, operators, and material handling devices ([27].Arena is built on the SIMAN simulation language. After creating a simulation model graphically, Arena automatically generates the underlying SIMAN model used to perform simulation runs [27]. Arena allows the interactions with other computer tools such as Visual Basic, Excel, etc., and it is very well integrated in Windows environment. With Arena, it is possible to choose the level of complexity by using «basic features » or features that are more specific. It is even possible to create customized tools in the program [8]. Consequently, Arena is a very good tool for doing research, since it can be linked with other programs in Windows environment and models as complex and accurate as needed can be created. Because of the above advantages of the software and its availability (student version); Arena simulation software is selected for this research work. The commercial version software is available in the market but it is expensive to afford. Therefore, by taking some assumptions it is decided to use the student version Arena software. Other important features of Arena Simulation modeling is determination of replication numbers. Since the individual replication results are independent and identically distributed, you could form a confidence interval for the true expected performance measures, which is assumed sample, mean across an infinite number of replications. Hence, it is determined by using formula [27].

In a simulation project, the ultimate use of input data is to drive the simulation model. This process involves the collection of input data, analysis of the input data, and use of the analysis of the input data in the simulation model. Furthermore, about 11steps involved in developing a simulation model, designing a simulation experiment, and performing simulation analysis has identified [7].Kirkpatrick et al. [16] initially presented the simulated annealing algorithm, which attempts to solve hard combinatorial optimization problems through controlled randomization. Since then the algorithm has been applied to many optimization problems in a wide variety of areas. Moreover, simulated annealing algorithm has been adopted in simulation optimization methods as a global optimization.

Saraph [16] uses simulation to imitate demand and supply of water in a continuous process biotech manufacturing facility. Therefore, a simulation model is an easier way to build up models to represent real life scenarios, to identify bottlenecks, to enhance system performance in terms of productivity, queues, resource utilization, cycle times, lead times, etc. A reconfigurable assembly line can provide flexibility for high mix low volume manufacturing systems, which can meet growing customer demand.

Simulation can help users by contributing in design, in management and in the decision making of production systems. It is able to model all kinds of company processes: physical, informational and decisional. Simulation models can be built at all hierarchical (operational, tactical, and strategic) and detailing levels (machine, cell, shop, *etc.*). Moreover, the whole manufacturing system life cycle can be modeled and simulated (design, analysis, implementation, operation). Today however, not all the possibilities of computer simulation are currently used. Computer simulation is limited in its uses and its applications [10].According to our literature review, there is no research works that are similar to the proposed approach in this paper. All reviewed articles proposed computer application in order to build manufacturing simulation model. Habchi and Berchet [10] propose an approach for modeling and simulation of manufacturing systems. This approach, which models and simulates both operation and control subsystems, is based on the interaction of three main kinds of concepts: the product processing system, the moving entity, and the systemic decomposition and analysis of manufacturing systems. An algebraic specification of these concepts and their modeling are proposed using UML. Anglani, *et al.* [11] present a procedure to develop flexible manufacturing system simulation models, based on the UML analysis/design tools and on the ARENA® simulation language. They proposed a definition of a systematic conceptual procedure to design flexible manufacturing system simulation models and of a set of rules for the conceptual model translation in a simulation language. Under the same manufacturing system kind, Madan *et al.* [12] present a framework for the determination of an efficient level of simulation model fidelity, which will achieve acceptable output accuracy with minimum resources and thereby reduce model building effort and computation time. Firstly, they formally define different levels of model fidelity using building blocks available in modeling, where an operation at a higher level is either decomposed into more detailed operations or subjected to more constraints at a lower level. Secondly, five models with different fidelities are defined. Then, simulation models that conform to these OO models are constructed. Finally, Boesel *et al.* [14] propose a framework for simulation-optimization software for JGC Corporation of Japan which statistical error control within a heuristic search procedure is implemented.

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CHAPTER THREE: CASE STUDY OF THE COMPANY (HI-TECH ENGINEERING INDUSTRY)

3.1 Data collection process and methods to develop simulation model

To develop a simulation model of the existing production/assembly line, the input data of the important parameters should be available. That means, the ultimate use of input data is to drive the simulation model. This process involves the collection of input data, analysis of the input data, and use of the analysis of the input data in the simulation model. For simulation model development of the TV manufacturing of factory the following data were collected:

- Total number of tasks
- Processing times of each task
- Priorities between processes
- Arrival frequencies of entities or time between arrival of each assembly line
- Manning level for each task/work stations
- Working hours
- Production output
- Number of rework
- unscheduled stop
- Transfer time of WIP between stations

These input data may be either obtained from historical records or collected in real time. The collection of input data is often the most difficult process involved in conducting a simulation modeling and analysis project. Initially, data collection begins from identifying and observing the different operations done on the assembly line. After observing all operations or tasks which are done on the assembly lines; we define individual work elements to each work stations. Individual work element is a minimum rational work element having a specific limited objective. A case study on Hi-Tech Engineering Industry, Based on this, the number of tasks on the assembly line is determined and the processing time for each task is collected and tabulated in the following tables. All processing times and arrival frequencies were found to be probabilistic rather than deterministic. The processing time was defined as the time span from entry to the station to the end of process completion excluding the times of stoppages, rework times, and queue times. Sometimes workers are going upstream ahead of the conveyor and picked up the

WIP from the moving conveyor. This makes difficult and complex the data collection process. Processing time for each task was measured in seconds and was taken using digital stop watch in every workstation. The number of data collection in this model is 15 data for each process that involved. According to the determined parameters of the required data, each data used for the simulation model development is presented one by one as follows:

i) **Total number of tasks:** To get the number of tasks on the production/assembly line both a simple observation as described above on the fig 3.1 on the TV assembly/production line and historical data which have the same result are used. Accordingly, there are twenty eight (28) numbers of tasks and workstations on the line to get output of the product.

ii) **Production output:** As it is illustrated in table 3.3 the daily actual production volume of the product is obtained from the historical data. Accordingly the average actual production volume of the product is about 59 pieces per day. Because, the company's working hour is eight (8) hours per day.

Table3.1: Daily actual production volume of the TV32" product

Month /Date	Daily actual production volume																								Average
	1	2	3	4	5	6	8	9	10	11	12	13	15	16	17	18	19	22	23	24	25	26	27	29	30	
June	20	25	30	45	39	50	24	30	28	41	24	38	47	20	40	40	55	58	48	40	34	45	50	36	32	32
July	39	45	54	46	45	28	43	53	29	32	26	3	28	57	39	46	38	42	64	35	55	50	40	34	31	34
Aug	50	34	45	50	56	60	46	64	71	80	30	30	58	70	69	30	59	46	89	48	54	39	56	78	70	48
Sep	80	76	67	78	49	40	45	55	74	76	67	56	76	78	80	85	60	86	84	65	70	58	45	76	68	58
Oct	56	59	54	60	58	55	85	84	89	60	55	50	80	84	56	67	89	65	54	70	75	79	64	80	72	59
Nov	78	67	100	80	90	86	85	90	90	98	96	102	98	95	86	65	89	103	111	106	90	95	90	97	79	87
Dec	91	98	112	109	113	106	88	85	112	109	102	114	86	100	118	98	92	104	112	107	80	86	90	112	118	91
																										59

From the above tables; we can see how the production volume of the company changes even within consecutive days and months. As a result of this, the capacity utilization of the company changes from day today. The average capacity utilization with respect to the installed capacity can be simply calculated as follows.

Average capacity utilization = Average production volume/ Installed production capacity = 59/300 = 20%.

Transfer time of WIP between stations=adding average 4 seconds for each WIP between new and previous work station.

(iii) Processing times of each task: The following table 3.4 illustrates the processing time for each task on the assembly line recorded using stop watch.

Table 3.2: Processing times of each task at each workstation.

No.	Operations	Observed time in seconds															Average time (sec.)
1	Un pack frame from carton	60	56	58	68	60	57	62	64	63	62	55	54	60	60	60.5	60
2	Dis assemble frame	40	35	40	41	42	39	38	40	40	37	40	43	44	40	42	40
3	Stick eva mat sponge	65	60	64	65	65	64	65	66	67	68	65	65	63	64	65	65
4	Put screen on the frame	35	34	37	35	36	35	38	36	35	34	40	35	39	35	33	36
5	Fix left & right press panel	35	36	34	36	34	30	32	35	36	35	35	38	37	34	39	35
6	Put sticker panel cable HT cable	35	38	39	38	32	36	35	35	37	40	33	35	35	35	35.5	36
7	Fix EVA mat	90	86	92	90	96	94	89	85	90	92	88	86	95	90	90	90
8	Fix boss bracket	73	71	75	73	74	65	70	76	76	71	72	74	75	78	68	73
9	Fix power board bracket	25	20	23	19	20	23	23	22	25	21	18	24	18	20	24	22
10	Fix power board	40	36	37	45	41	46	42	37	39	40	45	43	34	43	40	41
11	Fix main board	60	59	53	62	64	64	68	70	58	54	68	71	56	54	59	61
12	Fix up & down terminal	90	94	89	95	88	91	87	85	89	94	96	95	90	87	88	91
13	Insert panel & HT cable	90	86	94	89	93	95	88	91	91	93	92	87	89	90	93	91
14	Insert speaker & power cable	108	98	108	110	112	104	111	113	107	99	100	111	98	112	100	107
15	Fix back cabinet	90	88	89	104	101	86	90	97	96	99	97	86	85	89	90	93
16	Load software	25	25	29	25	20	24	26	20	29	27	25	27	25	23	20	25
17	AC & DC test	60	63	65	62	56	59	59	58	64	59	65	62	64	64	59	61
18	HDMI & YPBPR test	50	47	48	56	53	49	50	53	58	48	50	51	50	52	50	51
19	AV &coax test	45	54	56	50	45	48	49	50	41	39	40	41	50	48	40	46

20	USB & SCART test	54	48	49	49	57	50	49	54	56	58	58	60	61	60	60	55
21	Antenna test	60	64	57	60	65	56	59	59	55	63	65	64	60	65	64	61
22	TV & VGA test	40	35	41	39	38	40	39	42	45	43	46	37	38	35	44	40
23	Cleaning	60	63	67	65	57	60	64	56	59	61	66	59	61	62	58	61
24	Put sticker & bar code, packed power cable	35	36	39	40	37	38	38	36	37	38	40	41	35	40	35	38
25	Warranty &manual, remote control register sr. no	40	38	36	42	43	48	45	37	40	44	35	36	40	34	35	40
26	Covering screen cover	15	12	18	13	15	14	18	16	16	15	16	15	14	13	15	15
27	Put safety bush	15	17	20	20	14	16	18	19	17	14	12	17	15	15	14	16
28	Packed by cartoon	40	38	43	36	42	43	43	41	37	39	40	40		45	40	41

iv. Priorities between processes and the number of workers on each work station on the assembly line

As described in the table 3.5 below, the priorities between activities are obtained from the simple logical observation and the numbers of workers at each work stations are obtained from both observation and historical data which shows the same result. As it is illustrated the number of workers at each work stations is unity.

Table 3.3: Priorities between processes and number of workers on each workstation.

Operation name	**No. of operators**	**Observed time**													
Un pack frame from carton	1	–	60	56	58	68	60	57	61.5	64	63	62	55	54	60
Dis assemble frame	1	1	40	35	40	41	42	39	38	40	40	37	40	43	44
Stick eva mat sponge	1	2	65	60	64	65	65	64	65	66	67	68	65	65	63
Put screen on the frame	1	3	35	34	37	35	36	35	38	36	35	34	40	35	39
Fix left & right press panel	1	4	35	36	34	36	34	30	32	35	36	35	35	38	37
Put sticker panel cable HT cable	1	5	35	38	39	38	32	36	35	35	37	40	33	35	34.5
Fix EVA mat	1	6	90	86	92	90	96	94	89	85	90	92	88	86	95
Fix boss bracket	1	7	73	71	75	73	74	65	70	76	76	71	72	74	75
Fix power board bracket	1	8	25	20	23	19	20	23	23	22	25	21	18	24	18
Fix power board	1	9	40	36	37	45	41	46	42	37	39	40	45	43	34
Fix main board	1	10	60	59	53	62	64	64	68	70	58	54	68	71	56
Fix up & down terminal	1	11	90	94	89	95	88	91	87	85	89	94	96	95	90
Insert panel & HT cable	1	12	90	86	94	89	93	95	88	91	91	93	92	87	89

Insert speaker & power cable	1	13	108	98	108	110	113	109	109	105	110	99	106	104	110
Fix back cabinet	1	14	90	88	89	104	106	86	90	97	96	99	104	86	85
Load software	1	15	25	25	29	25	20	24	26	20	29	27	25	27	25
AC & DC test	1	16	60	63	65	62	56	59	59	58	64	59	65	62	64
HDMI & YPBPR test	1	17	50	47	48	56	53	49	50	53	58	48	50	51	50
AV &coax test	1	18	45	54	56	50	45	48	49	50	41	39	40	41	50
USB & SCART test	1	19	54	48	49	49	57	50	49	54	56	58	58	60	61
Antenna test	1	20	60	64	57	60	65	56	59	59	55	63	65	64	60
TV & VGA test	1	21	40	35	41	39	38	40	39	42	45	43	46	37	38
Cleaning	1	22	60	63	67	65	57	60	64	56	59	61	66	59	61
Put sticker & bar code, packed power cable	1	23	35	36	39	40	37	38	38	36	37	38	40	41	35
Warranty & manual, remote control register sr. no	1	24	40	38	36	42	43	48	45	37	40	44	35	36	40
Covering screen cover	1	25	15	12	18	13	15	14	18	16	16	15	16	15	14
Put safety bush	1	26	15	17	20	20	14	16	18	19	17	14	12		15
Packed by cartoon	2	27	40	38	43	36	42	43	43	41	37	39	40	40	

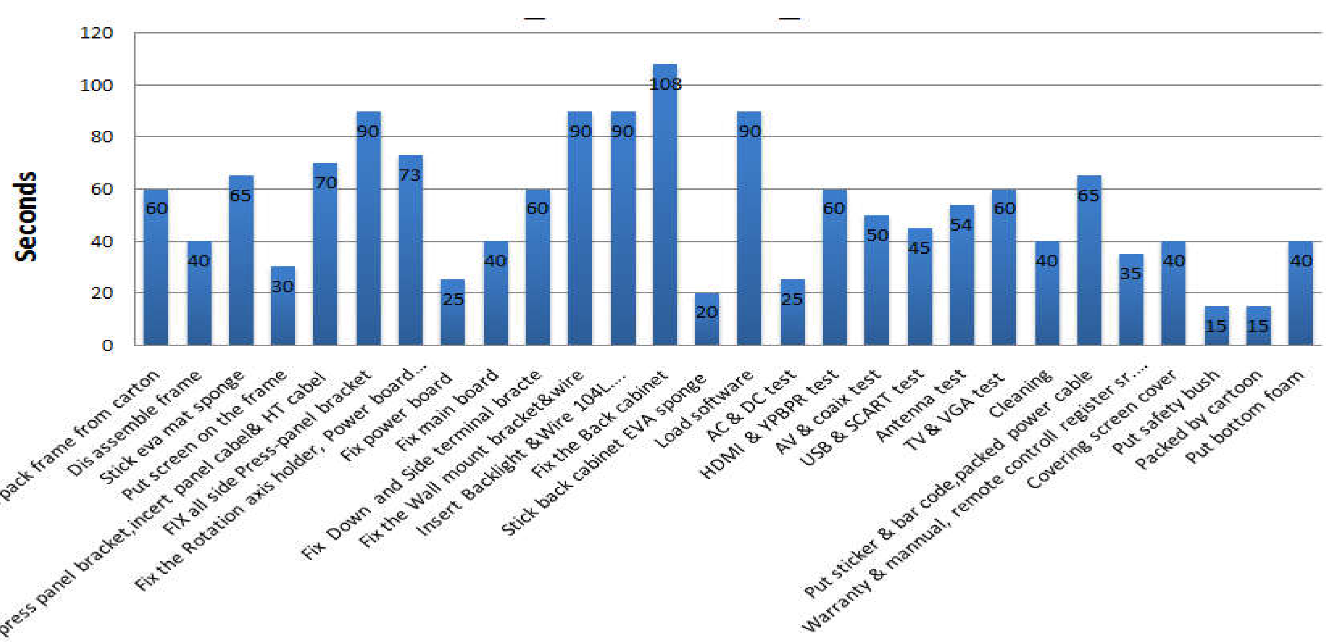

Figure 3.1: Time utilization at each workstation of current assembly line.

iv. Number of rework: The number of rework per day at each workstation is approximately 10% of the final output as historical data obtained from interview as shown in the table 3.5 below. As the interviewees witness, out of 59 products produced per day about six products are the result of the rework. This is due to the skill gap and lack of experience of the workers.

Table 3.4: Number of product obtained as result of rework per day.

S. No.	Interviewee	No. of rework out of the daily output
1	operators	6
2	supervisors	6
3	Plant manager	6
4	Quality supervisors	6
5	Quality manager	6

iv. **Unscheduled stop**: As indicated in the table 3.6 below the company scheduled production line stopping probability time interval for different reasons like entrance, tea break, lunch time, exit/stop. This data is obtained from both historical and direct observation of the situation. As the interviewees say, unscheduled time or idle time occur due to employee dissatisfaction with low payment.

Table 3.5: Existing scheduled and actual stop of the production/assembly line

S. No.	break reason	Scheduled (hr)	Actual (hr)	Idle (min.)
1	entrance	8:00	8:40	40
2	Tea break	10:30-10:45	10:30-11:00	15
3	Lunch time	12:00-1:00	12:00-2:00	60
4	Tea break	3:30-3:45	3:30-4:00	15
5	Exit/stop	4:50	4:40	10
Productive time		7:20hr	5hr	
Schedule and actual deviation		40min.	3hr.	2:20hr

v. **Transfer time of WIP between stations**: On the assembly line, the Transfer time of WIP between consequent stations are frequently recorded as well as obtained from the historical data of the company. I n both cases the transfer time of WIP between each station are approximately four (4) seconds on conveyors and it is added to each processing time of each tasks or work stations.

vi. **Arrival frequencies of entities or time between arrival of entities to enter assembly line**

The following arrival time is recorded using stop watch on the assembly/production line for 14 entities as shown in the table 3.7 below.

Table 3.6: Recorded entities arrival and inter-arrival time/time between arrivals.

Part number	Arrival time	Inter arrival time(sec)
Entity 1	0	20
Entity 2	20	25
Entity 3	45	23
Entity 4	68	21
Entity 5	89	23
Entity 6	112	26
Entity 7	148	21
Entity 8	169	26
Entity 9	197	25
Entity 10	122	26
Entity 11	148	32
Entity 12	180	43

Entity 13	223	29
Entity 14	252	24

3.2Arena input analyzer to analyze data for model development

Since the both the entity arrival and service time are probabilistic not deterministic the statistical distribution function of each are required to determine the pattern of the data. To get the statistical distribution arena input analyzer is used.

3.2.1 Arena input analyzer result of entities arrival distribution function to the work stations

The data collected in table 3.7 above is used to decide entity arrival distributions expression using arena input analyzer is as follows.

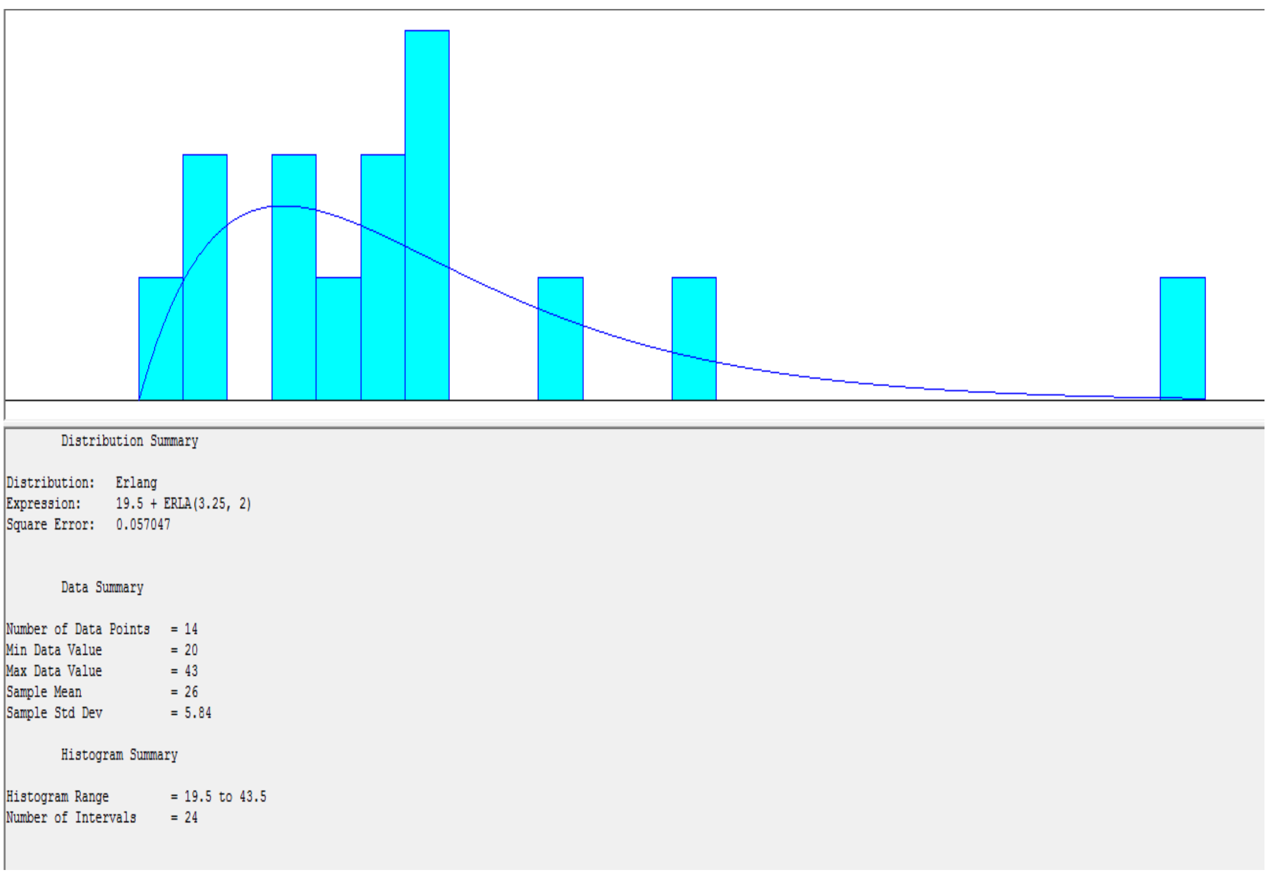

Figure 3.2: The histogram showing spare part arrival distribution.

From the above figure 3.4 it is observable that the entities inter arrival distribution follows the probabilistic statistical expression of **19.5+ERLA (3.25, 2)** to arrive at the assembly line station to be processed.

Therefore, the expression is used as the input data in arena software to develop the simulation model of the assembly/production line.

3.2.2 Arena Input analyzer result of processing time distribution function of each operation

In a similar way the entity inter arrival time expression is decided, the entities service time distribution was decided from the data collected in table 3.7 above using arena input analyzer and the result of each work station/operation service or processing time is illustrated in the table 3.8 below.

Table 3.7: Input analyzer result of processing time distribution function of each operation on the assembly line.

No.	Operation	Data distribution function
1	Un pack frame from carton	TRIA(54, 61, 68)
2	Disassemble frame	TRIA(34.5, 40, 44.5)
3	Stick eva mat sponge	NORM(64.8, 1.68)
4	Put screen on the frame	32.5 + GAMM(1.06, 3.13)
5	Fix left & right press panel	NORM(35.1, 2.08)
6	Put sticker panel cable HT cable	TRIA(32, 34.4, 40)
7	Fix EVA mat	TRIA(84.5, 90, 96.5)
8	Fix boss bracket	TRIA(64.5, 75.3, 78.5)
9	Fix power board bracket	17.5 + 8 * BETA(1.02, 0.925)
10	Fix power board	33.5 + 13 * BETA(1.45, 1.24)

11	Fix main board	52.5 + 19 * BETA(0.916, 1.02)
12	Fix up & down terminal	84.5 + 12 * BETA(1.31, 1.25)
13	Insert panel & HT cable	85.5 + 10 * BETA(1.61, 1.48)
14	Insert speaker & power cable	TRIA(98, 109, 113)
15	Fix back cabinet	85 + EXPO(8.27)
16	Load software	POIS(24.7)
17	AC & DC test	55.5 + 10 * BETA(1.26, 0.93)
18	HDMI & YPBPR test	46.5 + GAMM(1.9, 2.36)
19	AV &coax test	38.5 + 18 * BETA(0.956, 1.2)
20	USB & SCART test	47.5 + 14 * BETA(0.894, 0.833)
21	Antenna test	54.5 + 11 * BETA(0.964, 0.652)
22	TV & VGA test	NORM(40.1, 3.16)
23	Cleaning	55.5 + WEIB(6.37, 1.87)
24	Put sticker & bar code, packed power cable	34.5 + 7 * BETA(0.99, 1.18)
25	Warranty & manual, remote control register serial number	33.5 + 15 * BETA(1.05, 1.45)
26	Covering screen cover	TRIA(11.5, 15, 18.5)
27	Put safety bush	11.5 + WEIB(5.21, 2.1)
28	Packed by cartoon	NORM(40.5, 2.36)

3.3 Simulation model development

Model assumptions:

In Ethiopian Hi-Tech Engineering Industry, there is one shift per day. Workers distribution through the specified time per shifts can be delayed by different kind of incidents. The actual working time for whole system is 8:00 working hours per day. Since it is not expected that a person will work without some interruptions, the operators may take time for their personal needs. Assumptions are taken for modeling the variation of workers performance at time to rest, machine failure, and power off. The model for one shifts are modeled and analyzed. Raw material is assumed as a constant input, no interruption of operation is occurred in continuous and random for assembling. The manufacturer working time is 8:00 working hours per day. Distribution is fitted to input analyzer; it evaluates the distribution's parameter and calculates a number of measures of the data. In order to select which type of distribution is used, the author has compared the square error of each distribution.

The larger the square error value, the further away the fitted distribution is from the actual data.

To develop simulation model there are requirements and these requirements are the availability of the following:

(i) The historical, measured and observed input data collected above as determinant influential parameters to meet the objective.

(ii) The analyzing tool which is arena input analyzer used to make the data suitable to use directly in the arena software. That means the statistical input data distribution expression is determined from the recorded inter arrival time using the arena input analyzer.

(iii) The software or arena software used to develop the simulation model.

By using the above collected data as input for each operation of the assembly line the following existing system model is developed by Arena software.

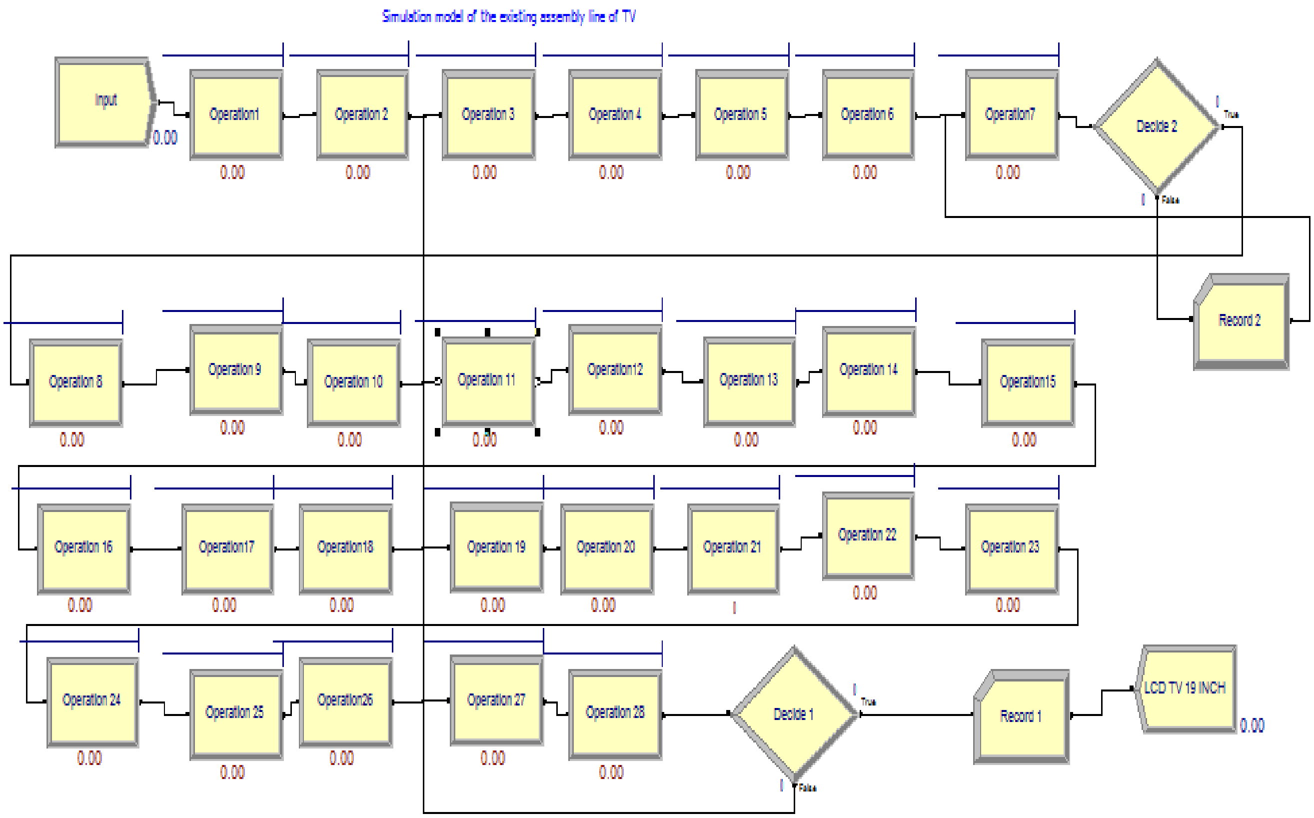

Figure 3.3: The simulation model of the existing system.

3.4 Decision of replication number and its calculation

Number of replication is number of simulation runs that should be executed to analyze statistically the differences between the simulation model and the real system thereby we can estimate the error we introduce in modeling the real system. It has an integer value greater or equal to 1.

The input distributions of simulation models are usually probabilistic in nature. This input variability naturally results in some variation in the output measures of performance. Because the output measures have some variation, it is inappropriate for the simulation practitioner to recommend any given course of action based on the results from a single simulation run or replication. To reduce the chance of making a wrong recommendation, it is necessary to run a number of simulation replications and then make the recommendations based on all of the available data. The question is: If not one replication, then how many? This is the purpose of replication analysis.

The replication analysis process begins with selecting an initial number of replications. Summary Statistics from this initial set of replications are then used to calculate whether or not additional replications are required at a particular level of confidence. If more replications are required, then there is a need to run additional replications and recalculate the summary statistics and replication formulas for the process.

Therefore; we must begin with some arbitrary number of replications to begin the replication analysis. Relatively, a smaller number of initial replications will increase the probability that the initial number is insufficient and that additional replications will be required. Conversely, a larger number of initial replications will decrease the probability that the initial number of replications is insufficient. However, a larger number of unnecessary initial replications will result in increased time on the part of the practitioner. Although this may not be a problem for relatively small simple models run on fast microcomputers, it could become a serious issue for larger, more complex models. The practitioner must also remember that it is not just one model that will need to undergo replication analysis, but all of the alternative models. A reasonable practitioner compromise to this situation is to initially run some small number of replications. A common number of initial replication is ten. This provides a sufficient number of replications to have reasonable statistical confidence given that additional replications can always be subsequently added [21].

3.4.1 Calculations of replication number

In order to perform the replication calculations, we must first calculate the mean and standard deviation of the first ten replication means. The following table 3.9shows the average output and standard deviation for ten replications of TV assembly lines.

These summary statistical values are then used to calculate what is known as the standard error of the data using the following formula:

Standard Error=$\{t_{1\ \frac{\alpha}{2}\ ,\ (n\ \ 1)}\} \frac{s}{\sqrt{n}}$……………………………………………(Eq.3.1)

Where: t=t probability distribution value for 1-α/2 from appendix-Axi.

n-1degrees of freedom.

s=standard deviation of the replication means (it is the amount of dispersion around the mean value that data may exhibit)

n=number of observations in the sample

The standard error is essentially the amount of dispersion around the mean value that data may exhibit. The first term *t* comes from the *t* probability distribution table (Appendix-Axi). The *t* value depends on two parameters, the α level and the number of degrees of freedom. The α level has to with the level of confidence at which we wish to conduct our analysis. If we want to be 95% confident in the results of our analysis, then the α level is1minus the confidence level, or 0.05. We are interested in the dispersion around both sides of the mean, so we divide the α level in half. The mathematical formula for the sample standard deviation of the replication averages is:

$$s = \sqrt{\frac{\sum_{1}^{n}(\bar{x\iota} - x)}{(n-1)}} \text{..(Eq.3.2)}$$

Where,

s= Standard deviation of sample
$\bar{x\iota}$= The replication average
x= The replication averages average
n= Number of replications
Considering the first 10 replications we have the following:
Table 3.8: Mean, standard deviation and half width for initial 10 replications of the assembly line.

Number of Replications	Assembly line output
1	7*5=35
2	5*5=25
3	9*5=45
4	8*5=40
5	8*5=40
6	6*5=30
7	10*5=50
8	6*5=30
9	2*5=10
10	4*5=20
Mean	6.5=(325/10)=32.5
Standard Deviation	2.4
Half width	1.72

The half width statistic is used to help in determining their liability of the results from the replication. In other word half width is a sampling error we introduce in taking sample. Therefore the value of half width can be simply determined by using the above formula3.1.

Standard Error=$\{t_{1-\frac{\alpha}{2}}\,,\ (n-1)\}\ \frac{s}{\sqrt{n}}$

Considering a 95% confidence level the value of t can be read from t probability distribution table (Appendix-Axi)

Hence: $t_{(\text{at } 95\%,9)}=2.262$

Half width for assembly line (h)

$=\{t_{1-\frac{\alpha}{2}}\,,\ (n-1)\}\ \frac{s}{\sqrt{n}}$=(2.262*2.4)/√10=1.72

Therefore, the percentage error for the assembly line

=(6.5+1.72)/6.5=0.01264=0.01264%

To achieve specific half width h, presumably smaller than the one we got in the initial set of 10 replications, we set h equal to the half-width formula above and solved for n.

$n=\{t^{2}_{1-\alpha/2,(n-1)}\}*s^{2}/h^{2}$………………………………………………………..(Eq.3.3)

The difficulty with this is that it wasn't really solved for n since the right hand side still depends on n. However to get at least a rough approximation to the sample size required, were placed the t probability distribution value in the formula above with the standard normal probability distribution value. This led to the following as an approximate required sample size to achieve a confidence interval with a half width equal to a pre-specified desired value h:

$n \quad (z^{2}_{(1-\frac{\alpha}{2})} \quad \frac{s^{2}}{n^{2}})$…………………………………………………………………. (Eq.3.4)

Where S is sample standard deviation from initial set of n replications. The above equation can Further be approximated as:

$n \quad n_{o} \quad \frac{{}^{2}_{o}}{2}$ ……………………………………………………………………... (Eq.3.5)

Where, n_0 is the number of initial replications we had and h_o is the half width. If error level from the initial sample of 10 replications is not quite satisfying, the initial half width can be reduced thus greater precision level can be achieved.

Assume we wanted half width for the assembly line to be1.7 and taking the value of Z at 95%

confidence level to be 1.96 form z table (Appendix-Axii) then the number of replication for the line became:

From equation (3.4)

$n = (1.96)^2 * (2.4)^2/(1.7)^2 = 8.64 \approx 9$ replications (assembly line first approximation)

From equation (3.5)

$n = 10*(1.72*1.72)/(1.7*1.7)=10.2 \approx 10$ replications (assembly line second approximation).

Therefore, 10 replications are taken for the assembly line and would give low acceptable error.

3.5 Verification and validation of existing simulation model

A model is an abstract and simplified representation of a real system which includes the most important system components and the behavior or interaction between these components. However, a model cannot represent the real system exactly rather it can approximate the system how it behave and interact. This is mainly due to the assumptions made while developing the model. Therefore; there is some variation between the constructed model and the real system. This variation directly affects the performance measures of the system. The performance measures extracted from a model will only represent the real system if the model is a good representation of the system. Therefore; our criteria for judging the goodness of models will be based on how performance measures extracted from the model correspond to the measures which would be obtained from the real system.

By its nature a model is more abstract than the system it represents. Viewed in one way, abstraction, and assumptions we make to achieve it, eliminate unnecessary detail and allow us to focus on the elements within the system which are important from a performance point of view; viewed in another way, this abstraction process introduces inaccuracy. Inevitably some assumptions must be made about the system in order to construct the model. However, having made such assumptions we must expect to put some effort in to answering questions about the goodness of our model. There are two steps to judging how good a model is with respect t other system. We must as certain whether the model implements the assumptions correctly which is called model verification and whether the assumptions which have been made are reasonable with respect to the real system which is called model validation.

3.5.1 Verification of existing simulation model

Verification is the process of ensuring that the simulation model operates as intended. This means that the practitioner has included all of the intended components in the model and that the model is actually able to run. In other words, verification is the process of ensuring that the model design (conceptual model) has been transformed in to a computer model with sufficient accuracy. Sometimes, model verification confuse with model validation. Verification is the continuous process of insuring that the model operates as intended, where as validation is the process of insuring that the model represents reality. It is pointless to attempt to see if the model represents reality in case the model does not even operate as intended. I n other words, you should not attempt to validate a model that has not successfully under gone the verification process. From a verification perspective, animation provides the information about the internal behavior of the model.

A model which includes all of the components specified under the system definition phase and capable of running without any errors or warnings is considered to be verified successfully.

The model logic was checked whether it manifest the characteristics of the flow process of the real model. In other words, the arrival times, processing time stations take and stations where queues are developed are examined and compared with the real system.

3.5.2 Validation of existing simulation model

A model which includes all of the components specified under the system definition phase and capable of running without any errors or warnings is considered to be verified successfully real model. In other words, the arrival times, processing time stations take and stations where queues are developed are examined and compared with the real system.

Model validation for this study is made using statistical validity by comparing the output of the real system and the simulation model output of the existing system. If there is no statistically significant difference between the data sets, then the model is considered valid. Conversely, if there is a statistically significant difference, work before further analysis may be conducted. The output of TV32"model in the real manufacturing system at an average per eight hours; ranges from 20 to118TV with an average output of 59 TV. The output level the simulation model offered per eight hour shift is 35TV at an average the assembly line. Even the output of the real system highly varied, the output of the simulation model approaches the average output of the real system. Therefore the model can be said to represent the real system, and is said to be valid. In addition to this; workstations with relatively high work in progress and low work in progress in real system a real so observed in the simulation model. For instance, in the assembly line Un pack frame from carton (OP1),Stick eva mat sponge (OP3), Fix EVA mat (OP7), Fix up & down terminal (OP12), Insert panel & HT cable, (OP13),Insert speaker & power cable (OP14) and Fix back cabinet (OP15) stations are observed with high WIP in real system: in case of the running the simulation model for this line, this station is registered with high level of WIP similarly other stations also observed the same phenomena. Therefore, this can also strongly validate the developed model to represent the real system.

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CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Introduction

Output analysis is the examination of data generated by a simulation model. Its purpose is to predict the performance of a system or to compare the performance of two or more alternative system designs. Output analysis also predicts the initial model performance and look after the weaknesses.

Therefore, based on the output of the simulation model the performance measures are analyzed for the existing manufacturing system and for different proposed scenarios to enhance performance measuring parameters of the assembly lines like increase capacity utilization, increase output, increase production rate, minimize production time, minimize work in process, increase line balance efficiency, and minimize line delay. Historical, measured and observed input data collected in chapter three are the causing parameters (human resource, schedule utilization, number of reworks, work stations) that affect the following performance measuring parameters of the production line.

- ➢ Production volume.
- ➢ Production rate.
- ➢ Capacity utilization.
- ➢ Response time/waiting time.
- ➢ Number of rework.
- ➢ WIP inventory.

4.2. Performance measures by running the model for existing manufacturing system

Performance measures by running the model for the existing manufacturing system has been given in table 4.1 and simulation of existing manufacturing system has shown in figure 3.5.

Table 4.1: Performance measures by running the model for the existing manufacturing system (refer appendix-AI category overview report).

No.	Response parameter	Existing
1	WIP	68 pieces
2	Number of output/production rate	7pieces/hr
3	Waiting time	712.75sec/hr
4	Scheduled utilization	Refer appendix
5	VA time	1519.83 sec.
6	Average Capacity =utilization capacity/installed or scheduled capacity	35/139=25.18%
7	Number of rework	26 pieces
8	Production volume or Total output per 5hrs	35 pieces
9	Total time	2232.58 sec.
10	No. of resource/workers	28

- Input = 139
- Output (P) per 5 hours = 35 TV.
- Production rate (R_p) = 7 Per hr.
- Make span or work content time (T_{wc}) = 1519.83 sec
- Work in process (WIP) = 68.
- Number of work stations=28
- Production efficiency (E_p) = Output /Input = 35/139 = 25.18%
- line balance efficiency (E_p)= 1519.83/(28*106.34)=51.04%

Capacity utilization: the instantaneous capacity utilization for each station of production line is obtained from (appendix-AIV).

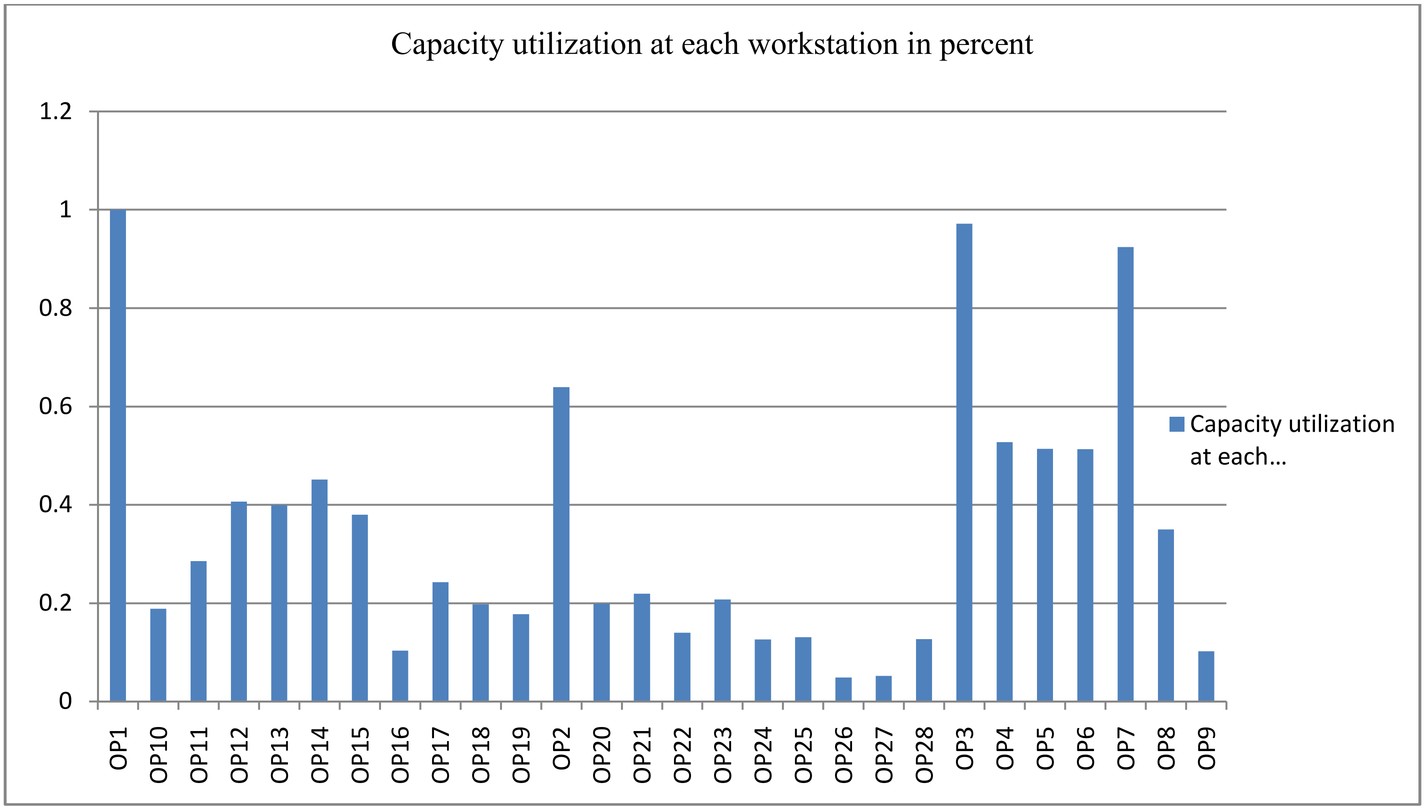

Figure 4.1: The instantaneous capacity utilization of the existing assembly line.

4.3. Identifying the characteristics of the low performance/bottle necks

From the simulation report shown in appendix-AII it can be seen that Un pack frame from carton (OP1),Stick eva mat sponge(OP3), Fix EVA mat (OP7), Fix up & down terminal (OP12), Insert panel & HT cable, (OP13),Insert speaker & power cable (OP14) and Fix back cabinet (OP15) and stations have the behavior of the bottle neck station described below like :

- Large number of WIP
- Long waiting time.
- Long operating time.
- High capacity utilization.
- Small instantaneous work station output.
- High non-value added and value added time.
- High scheduled utilization.

Therefore, these assembly line stations are the bottle necks for assembly line. (Refer Appendix-AI and busy number of resources at each work station Appendix-AII).The existing assembly line simulation report/result indicates different performance measuring parameters. These are the number of output , input, WIP, the waiting time, the operating time, capacity utilization, value added time, non-value added time, scheduled utilization , number of busy resources, and accumulated time of the simulation. As per the indicated report/result of the simulation the output of the assembly line is constrained by the certain workstations having the characteristics listed above.

From the above figure 4.2 for assembly line we can see clearly how the capacity utilization of different resources of lines is varied. This shows that the work content of the line is not distributed uniformly among stations. In other word the lines are not balanced. Using equations 2.5 and 2.6 (chapter 2); line balance efficiency (E) and balance delay (d) of assembly line can be calculated as follows:

$E_b = T_{wc} / W.T_S$

Where E_b =balance efficiency, T_{wc} =total work content time (make span), W=number of workers on the line, T_S =the maximum available service time on the line. The complement of balance efficiency is balance delay (d), which indicates the amount of time lost due to imperfect balancing as a ratio to the total time available.

$d = (W\ T_S – T_{wc)} / W\ T_S$

Hence, line efficiency and delay for assembly line is:

- Number of workers of the assembly line W=28
- T_{wc} =1519.83 sec
- The maximum available service time is measured at station OP1 (T_S)=103 sec
- Total service time available on the assembly line to devote on the assembly of single TV, W*Ts = 28*103 = 2884 sec
- Line balance efficiency E_b = 1519.83/ (28*106.34) *100% =51.04% and
- Delay d = (2884- 1519.83)/ 28*106.34*100% = 45.82%

In other word this means that; of the total service time available on the assembly line, 28.83%is idle time which is lost for nothing.

However, typical good line balance efficiencies in manufacturing industry range between 0.90

and 0.95 [17].

Therefore, there is still a room for line efficiency improvement for the line. To avoid/minimize the bottle neck different alternative scenarios are developed in the next chapter.

From the simulation of the existing manufacturing system the following problems are found as a result of the simulation of the production/assembly line. These are:

(a) The output of the assembly line is affected at the different work stations or there are different bottle necks at different work stations in which the output of one work station is lower than the output of the preceding work station like work station 7 or output of one work station is large than the output of the succeeding workstation. The imbalance of work stations highly affects the production volume.

(a) There are under capacity utilization (idleness) at different workstations.
(b) Low production output with respect to the installed capacity.
(c) The efficiency of the assembly line is 51.04%. It is below the good value of line balance efficiency in manufacturing systems. This indicates the inefficiency of the line.
(d) Large amount of work in process is available at work stations 1 and 7 of the assembly line.
(e) There are large number of reworks due to ineffectiveness/ luck of operators' skill.

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CHAPTER FIVE: ALTERNATIVE MODEL DEVELOPMENT

5.1 Introduction

This section is concerned on the development of different alternative models in which all problems that have been identified in the simulation model analysis will be seen and solved for better performance of TV manufacturing. Problems that are identified in simulation model analysis are listed below.

a. The output of the assembly line is affected at the different work stations or there are different bottle necks at different work stations in which the output of one work station is lower than the output of the preceding work station or output of one work station is large than the output of the preceding workstation. The imbalance of work stations highly affects the production volume.
b. There are under capacity utilization (idleness) at different workstations.
c. Low production output with respect to the installed capacity.
d. The efficiency of the assembly line is 51.04%. It is below the good value of line balance efficiency in manufacturing systems. This indicates the inefficiency of the line.
e. Large amount of work in process is available at work station 7 of the assembly line.

5.2 Identify the cause of the low performance/bottle necks

What might be influential factors/causes the bottle necks on the production line output? Causes of the low performance? The followings factors affect the performance of the production line.

i. Schedule utilization: productive and non-productive time.
ii. Operators' skill level.
iii. Number of workstations on the assembly/production line.
iv. Number of operators on the production/assembly line
v. Unscheduled stop of working time.

5.3 Finding ways to enhance performance/ to decrease bottle neck

To enhance the performance measured in the simulation model of the existing system, the central point is to focus on the ways to improve the causes of the low performance of the production/assembly line listed above. In improving the causes of low performance, the improved causing parameter should be considered to develop new proposed alternative simulation model.

Therefore, by making improvements to each performance affecting parameters listed above, different proposed alternative model are developed below.

5.4 Proposed alternative simulation model of the assembly/production line.

To enhance the performance of the production/assembly line, different alternative models are developed depending on the influential factors considered above:

- Adding resources to bottle neck stations to balance the line.
- Merging similar operations with low resource utilization together and assign to one worker.
- Increasing level of resource at stations with high WIP to increase the production output.
- Decreasing the number of reworks by giving training for operators.
- Combination of all the above three alternatives.
- Avoiding unnecessary wastage of time and unscheduled stop for tea and lunch to decrease cycle time.

(i) Adding resources to bottle neck stations to balance the line (Scenario 1)

Table5.1: The performance measurement of the identified bottle neck workstations on the assembly line.

S. No	Bottleneck stations	Resource (man power)	Scheduled capacity	Capacity utilization	Average Number of busy resources	Added Resource/ Manpower
1	1	tech	1	1.0000	1.0000	3
2	3	tech	1	0.9714	0.9714	2
3	7	tech	1	0.9242	0.9242	3
4	12	tech	1	0.4065	0.4065	1
5	13	tech	1	0.3992	0.3992	1
6	14	tech	1	0.4515	0.4515	2
7	15	tech	1	0.3800	0.3800	1
Total			7			1 3

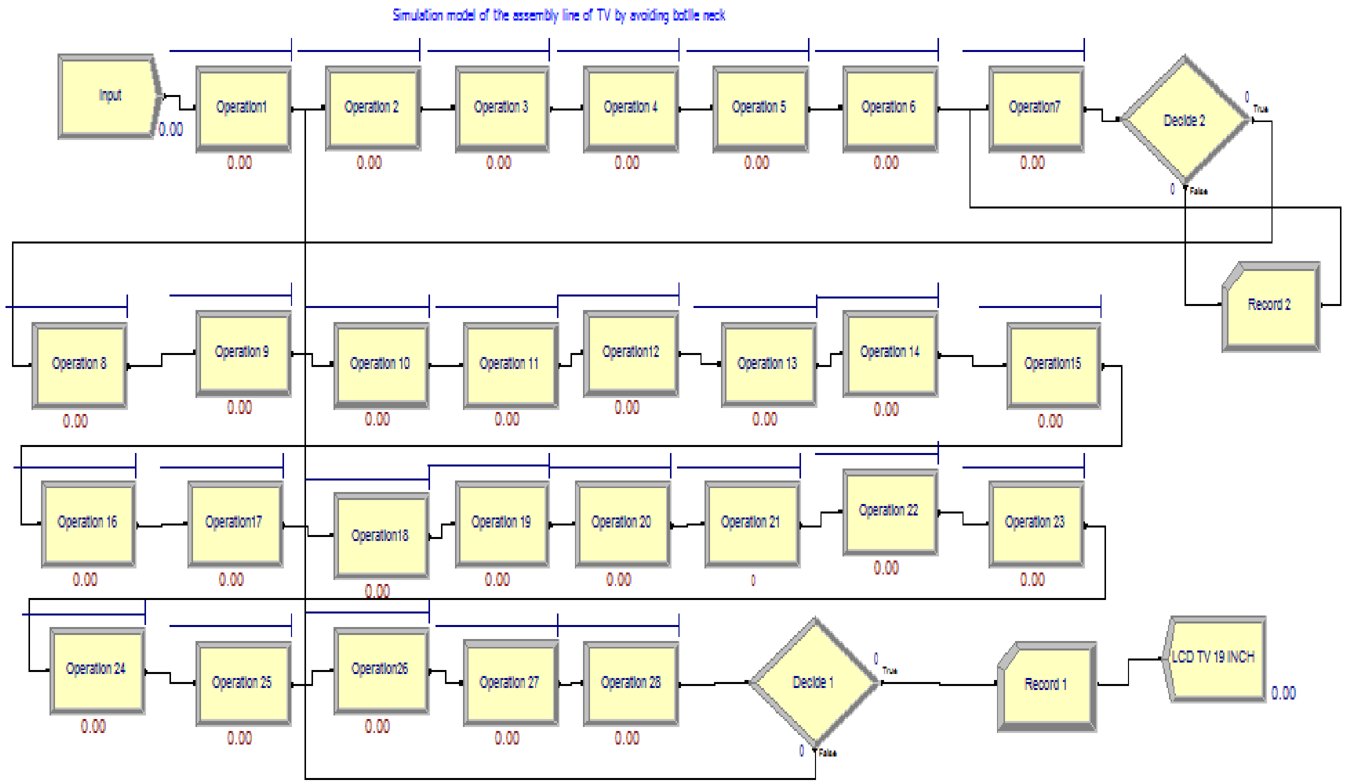

Figure 5.1: The scenario/model-1 of the assembly line.

Table 5.2: The performance measured from the simulation model of the scenario-1.

No.	Response parameter	Model-1
1	Average WIP	66
2	Number of output/production volume	14
3	Waiting time	590.61
5	Scheduled utilization	Indicated on appendix
6	VA time	1554.55
7	Average Capacity=capacity utilization/installed or scheduled capacity	70/139=50.35%
8	No. of Rework	86

9	Total output/total production volume	84
10	Total time	2145.16
11	No. operators	41

Output rate=14units Running the simulation model of the first scenarios for assembly line, we have the following performance measurement:

- Input=139
- Number of work stations=28
- The number of workers of the line is= 28
- Line balance efficiency E_b=(1554.55)/(28*106.68)=52.04 %
- Output(P) per 5hours= 70
- Production rate (R_p)=14 per hr
- Make span or work content time (T_{wc})=1554.55
- Work in process(WIP) =66
- Production efficiency(E_p)=Output/Input= 70/139=50.36 %

Capacity utilization: the instantaneous capacity utilization for each station of the line is:

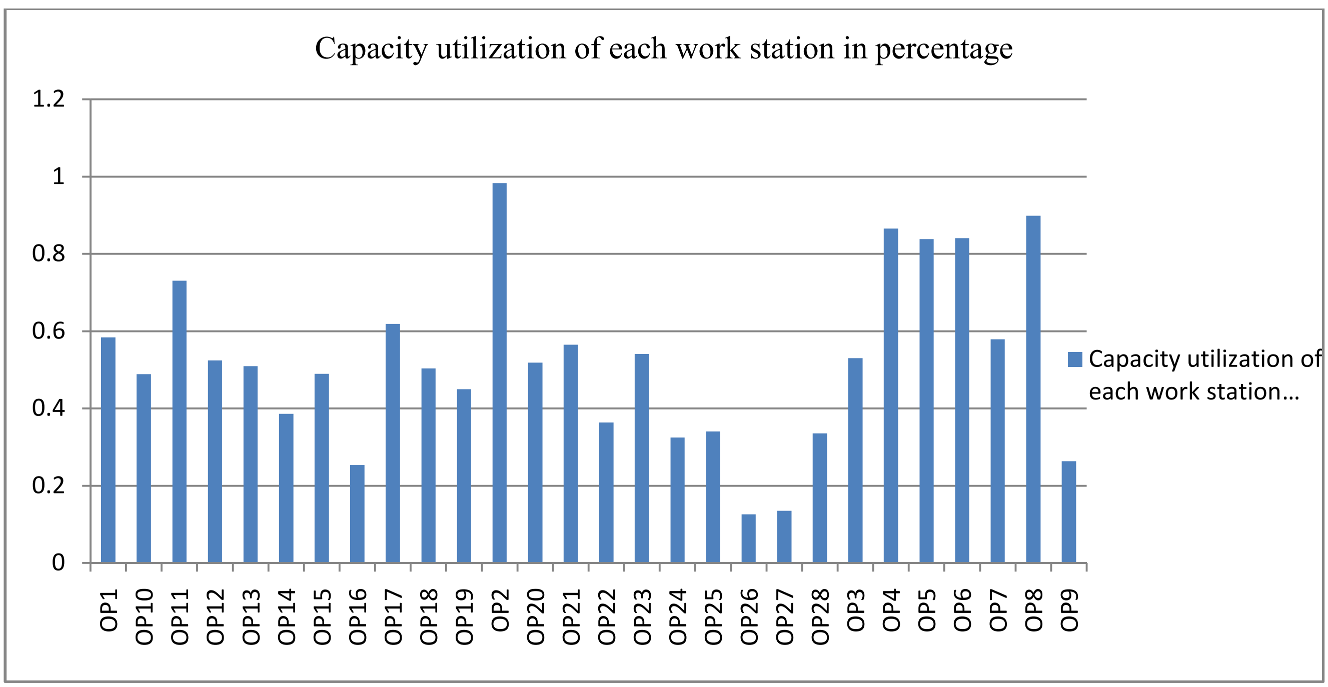

Figure 5.2: Capacity utilization of simulation model of the first scenario.

(ii) Merging similar operations with low resource utilization together and assign to one worker (Scenario 2)

In other hand, some stations with similar and consecutive operations have low capacity utilization. However, these operations can be merged together and assigned to only one worker. Consecutive similar operations that can be merged together are listed in the following table. When the work station is merged the works stations with long inter arrival and processing time is considered as the input for the merged station.

Table 5.3: Similar and consecutive operations with low capacity utilization that can be merged together for assembly line.

No.	Operation/workstation	Merged workstation	Existing data	Merging workstation with highly trained workers
1	Un pack frame from carton	Un pack frame from carton	60	100
2	Disassemble frame	Disassemble frame	40	
3	Stick eva mat sponge	Stick eva mat sponge	65	101
4	Put screen on the frame	Put screen on the frame	36	
5	Fix left & right press panel	Fix left & right press panel	35	71
6	Put sticker panel cable HT cable	Put sticker panel cable HT cable	36	
7	Fix EVA mat	Fix EVA mat	90	90
8	Fix boss bracket	Fix boss bracket	73	95
9	Fix power board	Fix power board	22	

	bracket	bracket		
10	Fix power board	Fix power board	41	102
11	Fix main board	Fix main board	61	
12	Fix up & down terminal	Fix up & down terminal	91	91
13	Insert panel & HT cable	Insert panel & HT cable	91	91
14	Insert speaker & power cable	Insert speaker & power cable	107	107
15	Fix back cabinet	Fix back cabinet	93	93
		Connect to board		
16	Load software	Load software	25	86
17	AC & DC test	AC & DC test	61	
18	HDMI & YPBPR test	HDMI & YPBPR test	51	97
19	AV &coax test	AV &coax test	46	
20	USB & SCART test	USB & SCART test	55	116
21	Antenna test	Antenna test	61	
22	TV & VGA test	TV & VGA test	40	101
23	Cleaning	Cleaning	61	
24	Put sticker & bar code,packed power cable	Put sticker & bar code, packed power cable	38	78
25	Warranty &manual, remote control register	Warranty & manual, remote control register	40	

	serial number	serial number		
26	Covering screen cover	Covering screen cover	15	
27	Put safety bush	Put safety bush	16	72
28	Packed by cartoon	Packed by cartoon	41	

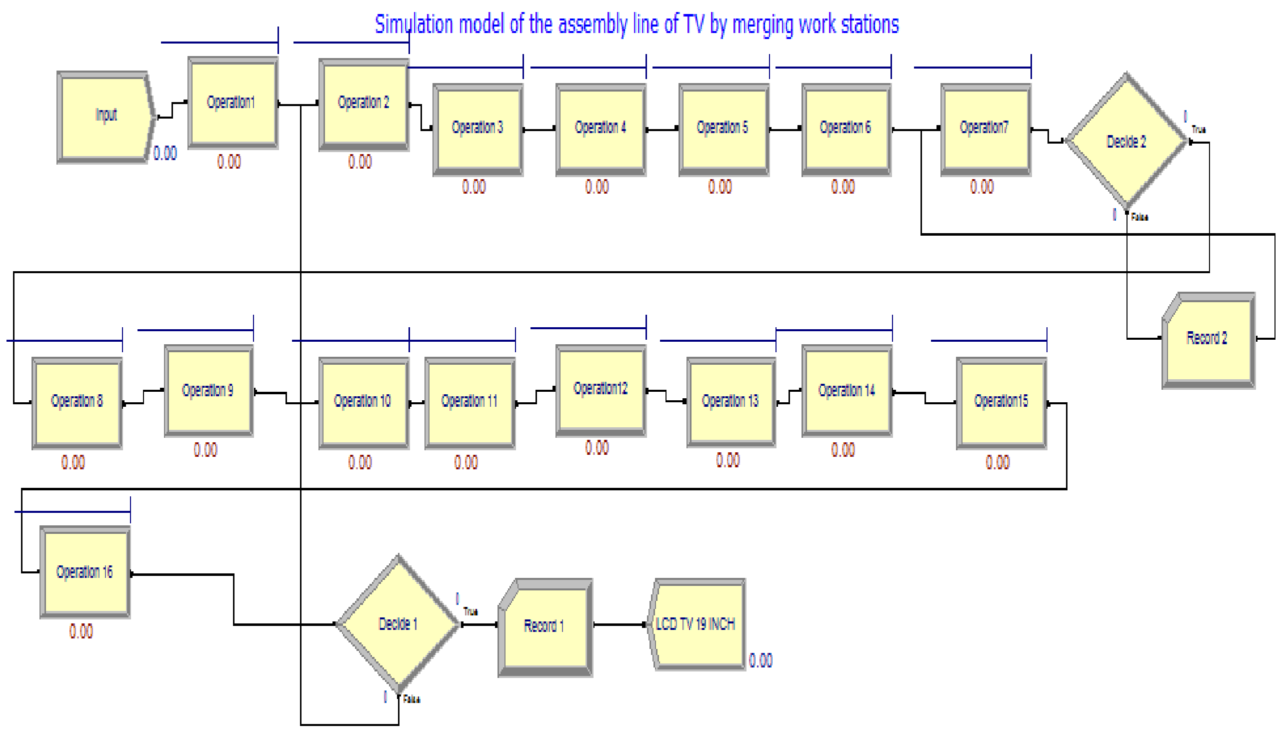

Figure 5.3: Simulation model of the assembly line of the second scenario/merging workstations.

Table 5.4: Performance measured for scnario-2

S. No.	**Response parameter**	**Model-2**
1	WIP	64
2	Number of output	18
3	Waiting time	781.28

4	Scheduled utilization	appendix
5	VA time	1501.59
6	Capacity utilization	90/139=64.75%
7	Rework	21
8	Total output /total production volume	108
9	Total time	2282.86
10	No. operators	28

Running the simulation model of the second scenarios for assembly line, we have the following performance measurement:

- Number of work stations=16
- Input= 139
- The number of workers of the line is= 16
- Line balance efficiency E_b=(1501.59)/(16*116) =80.90%
- Output(P)per 5 hour= 90
- Production rate (R_p) per hr=18
- Make span or work content time (T_{wc})= 1501.59
- Work in process(WIP) =65
- Production efficiency(E_p)=Output/Input= 90/139= 64.75%

Capacity utilization: the instantaneous capacity utilization for each station of the line is:

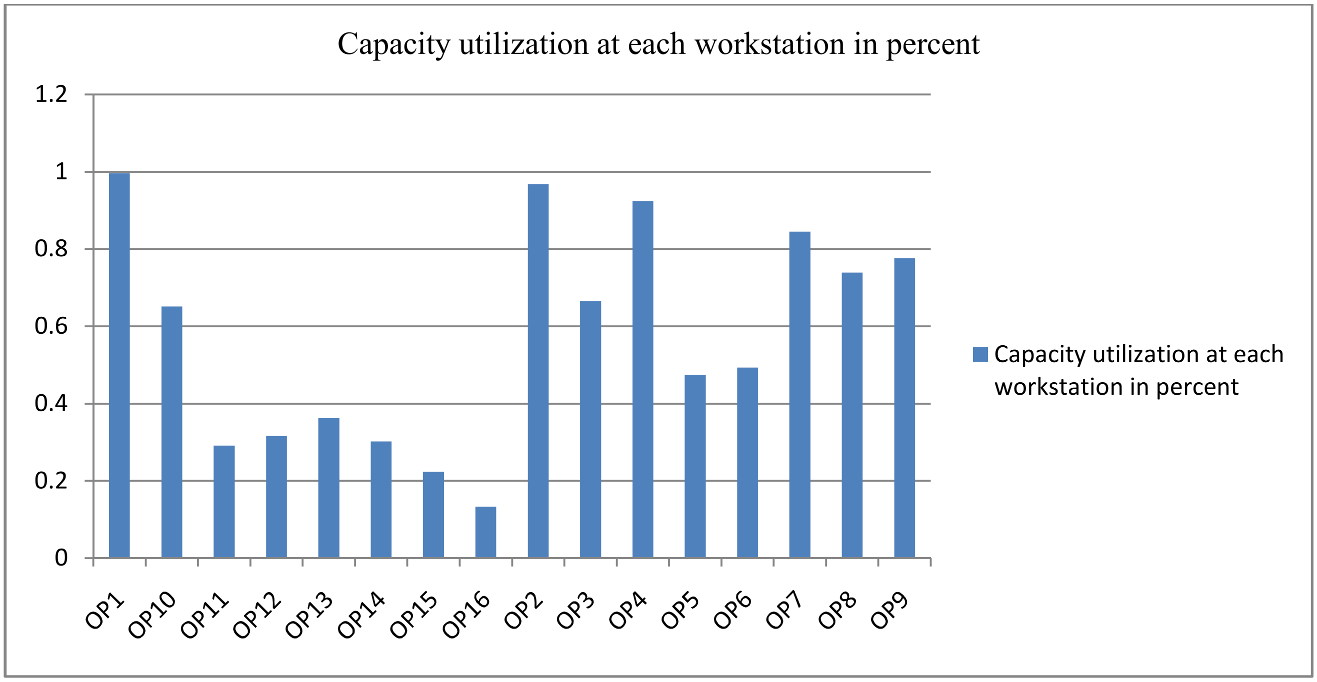

Figure 5.4: Capacity utilization of the assembly line in scenario-2.

(iii) Minimizing unscheduled stop (scenario-3)

Table5.5: Existing scheduled and actual stop of the production line

S.No.	break reason	Scheduled (hr)	Actual (hr)	Idle (min.)
1	entrance	8:00	8:40	40
2	Tea break	10:30-10:45	10:30-11:00	15
3	Lunch time	12:00-1:00	12:00-2:00	60
4	Tea break	3:30-3:45	3:30-4:00	15
5	Exit/stop	4:50	4:40	10
Productive time		7:20hr	5hr	
Schedule and actual deviation		40min.	3hr.	2:20hr

We can assume or avoid the schedule and actual deviation which is unproductive time (2:20hr).So that the output of the line will increase .we can develop the model for the assembly process from the existing system model by increasing the production time by 2:20hr.

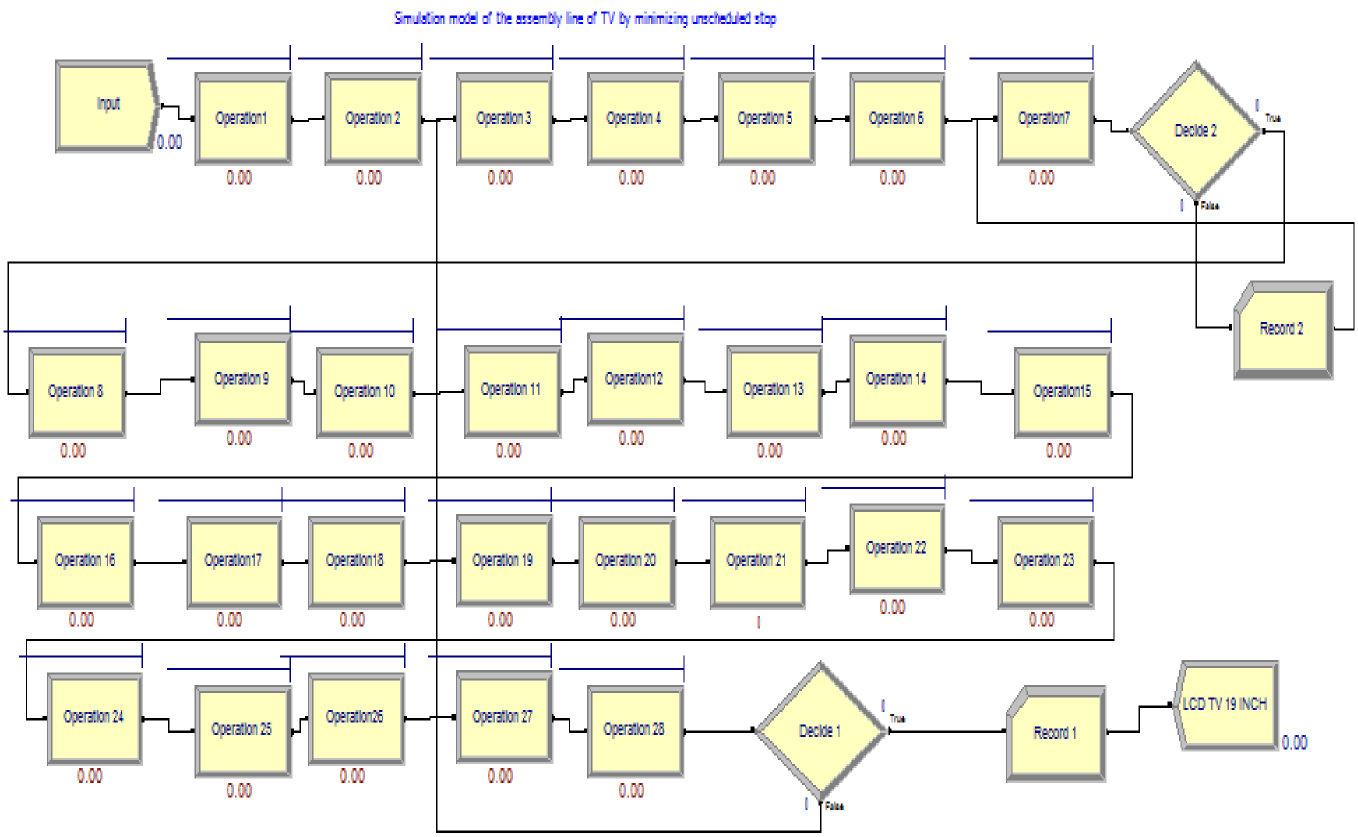

Figure5.5: Simulation model diagram of minimizing unproductive time (scenario-3).

Table 5.6: Performance measured for scenario-3

S. No.	Response parameter	Model-3
1	WIP	68
2	Number of output	7
3	Waiting time	712.75
4	Scheduled utilization	Indicated on appendix

5	VA and NVA time	1519.83
6	Capacity utilization	51/139=36.69%
7	Total output/production volume	51
8	No. Rework	42
9	Total time	2232.58
10	No. of operators	28

Individual who only work on the work station bring spare parts from the store as per the requirement.

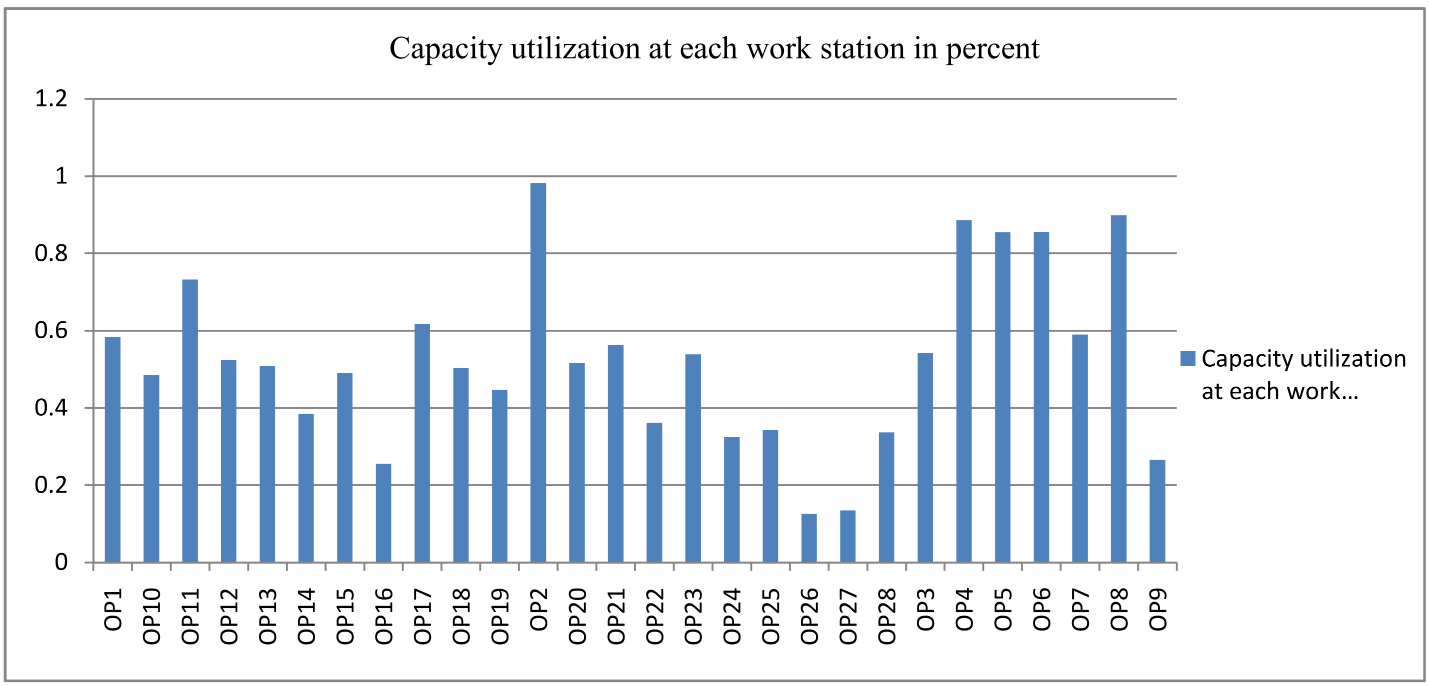

Figure 5.6: Capacity utilization of scenario/alternative-3.

(iv) Combinations of scenarios 1&3

Combining scenarios 1&3 we have the following results:

Table 5.7: Performance measured for scenario-4

S. No.	Response parameter	Combination of Models 1&3
1	WIP	62
2	Number of output	27
3	Waiting time	669.1
4	Scheduled utilization	Indicated on appendix
5	VA time	1501.22
6	Capacity utilization	Indicated on appendix
7	No. Rework	37
8	Total output	197
9	Production efficiency	197/(139+62)=98 %

The assembly line TV performance measurement:

- Number of workers is=41
- Input remain the same=139
- Production output is=27
- Average WIP is=62
- Production(R_p) rate is increased=27
- Make span or total work content time $T_{wc} = 2170.32$
- Production efficiency(E_p)is=197/(139+62)=98 %

5.5 Comparison of different alternative scenarios' performance results

Table 5.8: Comparison of the above scenarios of the production line

Parameters		**Existing scenario**	**Scenario-1** **Bottle neck with operator training**	**Scenario-2** **Merge &training**	**Scenario3 Unscheduled Stop(min. idle time) &training**	**Scenario-4** **Combination of 1 and 3**
Controls	No. operators	28	41	16	41	41
	workstation	28	28	16	28	28
	Operator skill	low	high	high	high	high
	Idle time	2:20	2:20	2:20	40min.	40min.
	No. input	139/3600s	139/3600s	139/3600s	139/3600s	139/3600s
	Inspectors	1	3	3	3	3
	Equipment sharing	high	low	low	low	low
	Scheduled stop	:40	40min.	40min.	40min.	40min.
	Motion /activity (NVA)	high	low	low	low	low
	Customer demand	Low	High	moderate	High	Highest

	satisfaction					
Response	Total cost	3231	4323	3491	3231	4333
	WIP	68	62.1463	65	62.1463	62
	Total output/3600s	7	27	18	7	27
	Cycle time	2232.58	2166.8	2282.86	2166.8	2170.32
	VA time	1519.83	1501.88	1501.59	1501.88	1501.22
	Waiting time	712.75	664.92	781.28	664.92	669.1
	Cost/unit	3231/7= 461.57	4323/27=160.1	3491/18=193.94	3231/7=461.57	14282.8/197 = 72
	Capacity utilization	35/139= 25.18%	135/139=97.12%	90/139=64.75%	58/139=41.73%	197/(139+62)=98 %
	Production rate/hr	7		18	7	27
	Production efficiency	35/139= 25.18%	135/139=97.12%	90/139=64.75%	58/139=41.73%	197/(139+62)=98 %
	Rework	26	86	21	51	37
	Total output/actual demand satisfied/shift	35	135	108	58	135+62=197

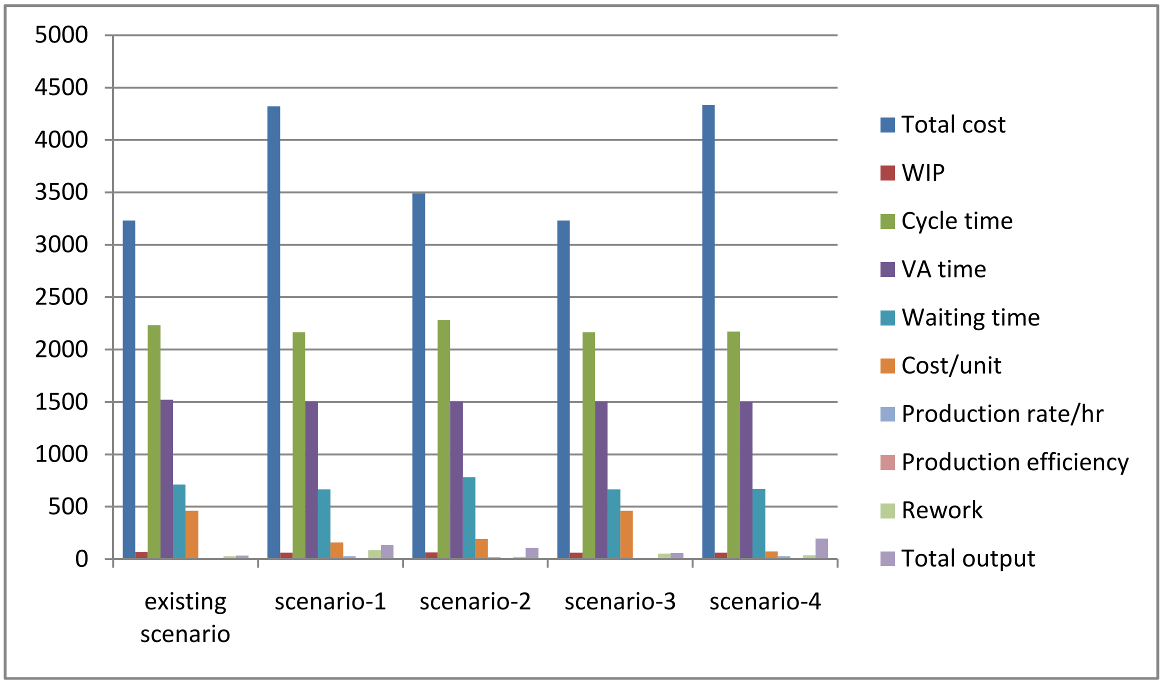

Figure 5.7: Comparison of different scenarios in terms of different performance indicating parameters.

Since the objective is minimizing cost with maximizing output the scenario-4 is the best strategy to follow.

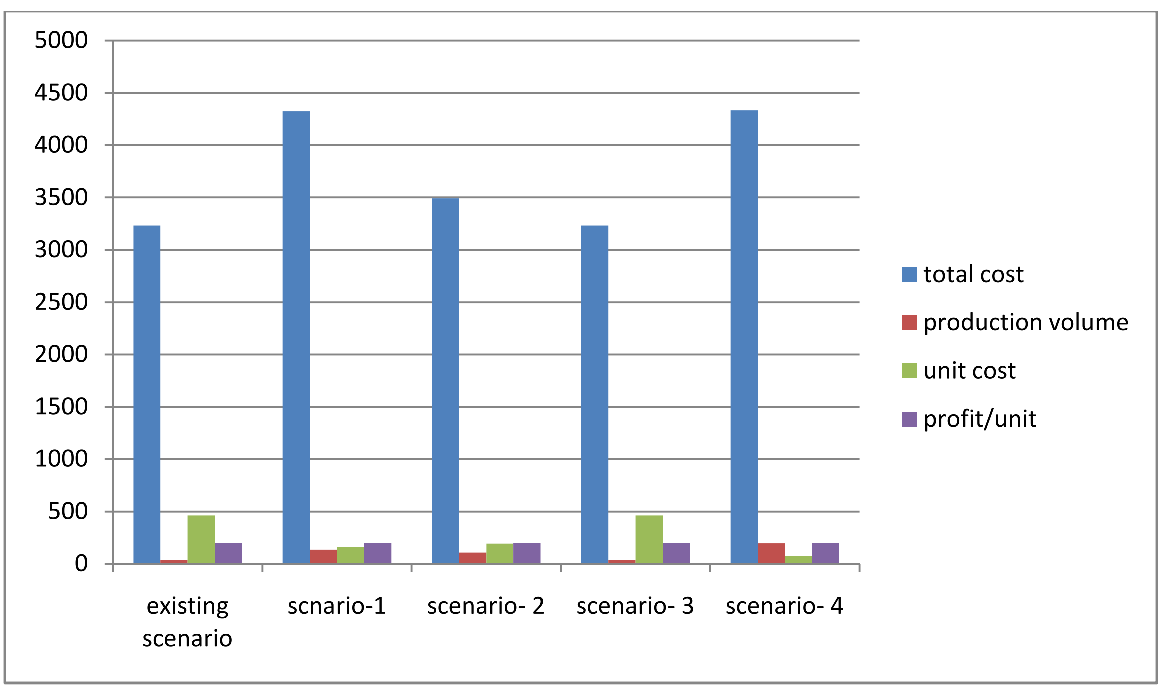

Figure 5.8: Comparison of different scenarios in terms of cost, profit and production volume.

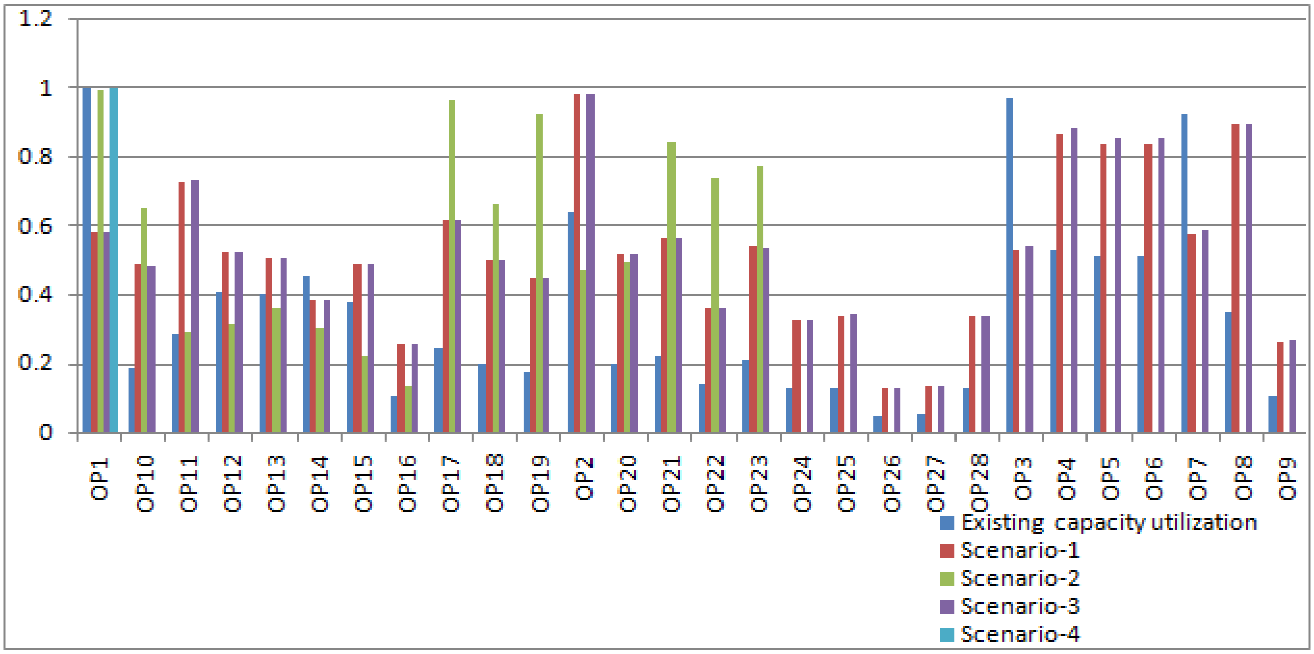

Figure 5.9: Scheduled capacity utilization of different scenarios.

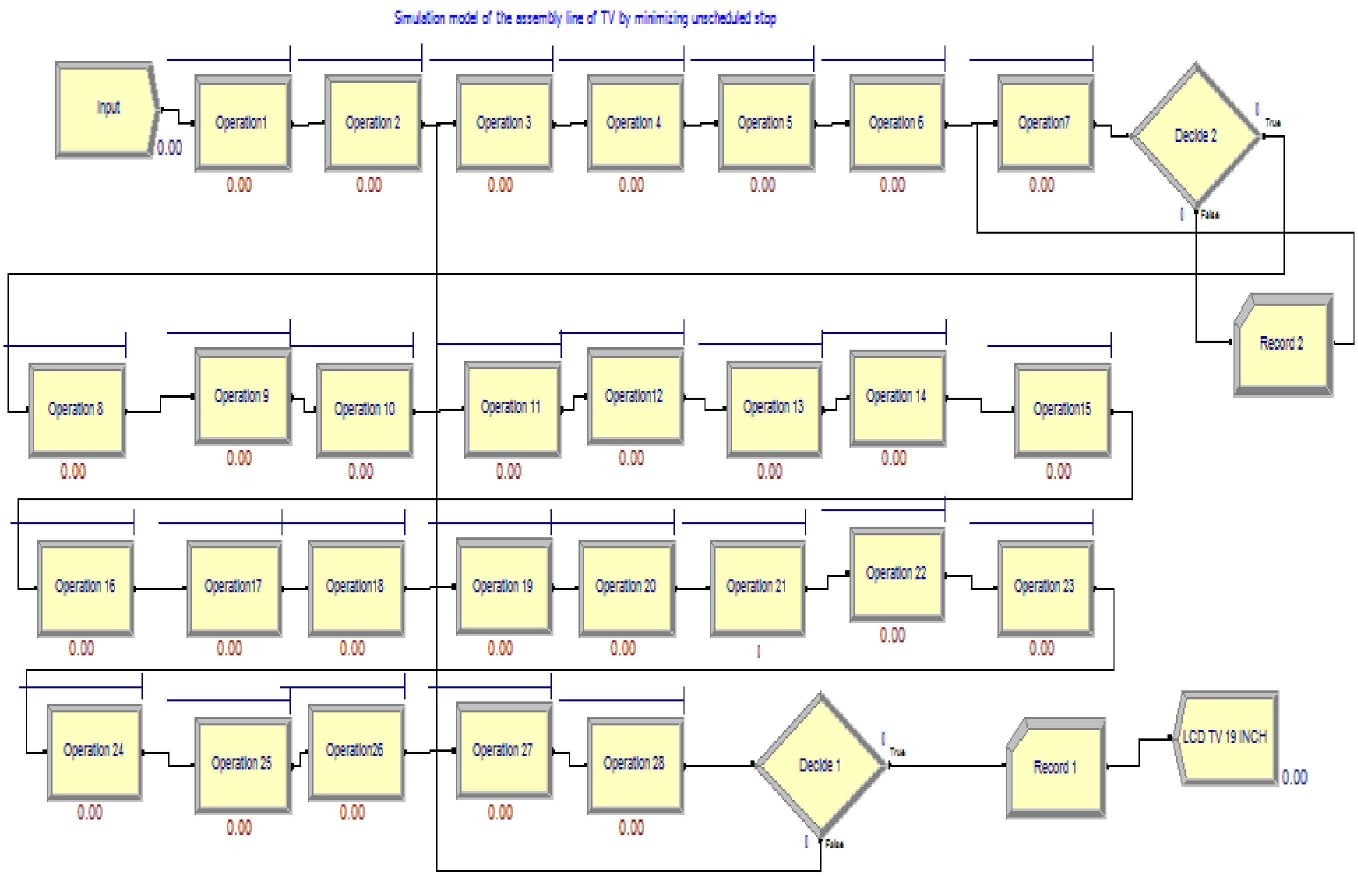

Figure5.10: Diagram of the simulation model of the improved assembly line.

The unit cost of the products for model-4 is the minimum and the amount of product produced per unit time is the maximum in model-4.

Therefore, model-4 is the best alternative to be practiced and implemented by the management to increase the output amount with minimum possible cost of production.
By choosing/ implementing model-4, 20numbers of additional products per hour will be produced. That means 160 additional products per shift will be obtained. The historical practical amount of profit per product is 200 ETB. This implies 20*200ETB =2000ETB per hour and 200ETB*160=32000 ETB per shift will be generated.

***

CHAPTER SIX: CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The goal of this study was achieved by measuring the performance of a TV assembly/production line. The production line was thoroughly analyzed and found to have bottlenecks that were causing congestions in the stations 1, 3, 7, 12, 13, 14 and 15 on the line. Simulation was used to analyze this bottleneck and resolve it, so simulation is the best tool that can be used in such a study because one can search for a good feasible solution without disrupting its operation.

The causes of the problems are insufficiency/luck of enough and skilled operators at some stations and wastage of unscheduled time of operators. The effect /varying of these control parameters are results/changes in the response parameters like inefficiency of the line, low production volume, high WIP, waiting time, low capacity utilization, high cycle time, which in turn influence the objective parameters total cost, production capacity and efficiency, and profit and cost per unit. To avoid and decrease these effect different alternatives scenarios are proposed and analyzed to select the one which appropriately meet the objectives.

- ✓ The output increases from 35 to197 per shift, and
- ✓ Profit increase from 35*200=7000 ETB to 197*200=39,400 ETB per shift, if the fourth alternative will be applied.
- ✓ The production efficiency increases from 35/139=25% to (27*7.33)/(139+62)=98.4%

This indicates production efficiency increased by 72.18%% if alternative-4 is considered. Increased by improving the number of operators at the stations with high WIP, the operators' skill and by minimizing the unscheduled idle time to increase the station utilization, which leads to increase in amount of production.

6.2 Recommendation

There is various type of solution that could be recommended to improve the performance of the production line. The recommendations of this study to enhance the production are:

- ✓ Add the number of operators at the stations with high WIP.
- ✓ The increase operators' skill level and
- ✓ Minimizing the unscheduled idle time

- ✓ Improve line balancing: to reduce operator's idle time or maximize operator utilization, and make work will flow smoothly.
- ✓ **Training for Line supervisors** on management skills and communication skill, Operation skill, workstation layout, movement and capacity study.
- ➢ This brings changes in managing and controlling the lines and will improve labor productivity.
- ✓ **Training to operators:** The factory must work on developing operator skill because production from an operator depends on his skill level to the task. A low skilled operator will consume higher resources (time) and give less output. As the skill level of the operators is increased through training lines output will improve. Training should be given only on specific tasks that will be performed by the operator.

Future work

- ✓ Developing Optimum simulation model program by integrating with scientific work station layout by including all the systems behavior and resources.

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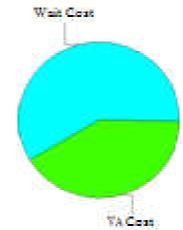
Appendices

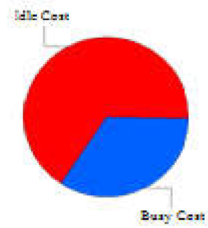
Appendix-AI: Existing system category overview simulation report.

Key Performance Indicators

All Entities	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	952
Wait Cost	1,360
Total Cost	2,312



All Resources	Average
Busy Cost	476 *
Idle Cost	919
Usage Cost	0
Total Cost	1,395



* *these costs are included in Entity Costs above.*

System	Average
Total Cost	3,231
Number Out	7

Average	HalfWidth	Average	Average	Value	Value
Entity1	17.27	1492.51	1566.72	1468.26	1753.94

NVATime			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	0.00	0.00	0.00	0.00	0.00

WaitTime			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	117.23	409.84	922.92	0.00	1616.92

TransferTime			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	0.00	0.00	0.00	0.00	0.00

OtherTime			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	0.00	0.00	0.00	0.00	0.00

TotalTime				Minimum	Maximum	
	Average	HalfWidth	Average	Average	Value	Value
E	2232.58	126.70	1902.35	2489.64	1488.65	3221.30
(						

VACost			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	0.48	91.4586	93.5200	90.7849	98.7206

NVA Cost			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	0.00	0.00	0.00	0.00	0.00

WaitCost			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1	1.63	5.6922	12.8183	0.00	22.4572

OtherCost			Minimum	Maximum	
Average	HalfWidth	Average	Average	Value	Value
Entity1 0.00	0.00	0.00	0.00	0.00	0.00

Appendix –AII: Existing system waiting time per entity

	Average	HalfWidth	Average	Average	Value	Value
Operation10	0.00	0.00	0.00	0.00	0.00	0.00
Operation 11	0.00	0.00	0.00	0.00	0.00	0.00
Operation13	0.8504	0.43	0.00	1.8990	0.00	9.2502
Operation14	9.3439	3.23	3.5208	14.5520	0.00	69.1665
Operation16	0.00	0.00	0.00	0.00	0.00	0.00
Operation19	0.00	0.00	0.00	0.00	0.00	0.00
Operation2	0.00	0.00	0.00	0.00	0.00	0.00
Operation20	0.00	0.00	0.00	0.00	0.00	0.00
Operation21	0.00	0.00	0.00	0.00	0.00	0.00
Operation22	0.00	0.00	0.00	0.00	0.00	0.00
Operation23	0.00	0.00	0.00	0.00	0.00	0.00
Operation24	0.00	0.00	0.00	0.00	0.00	0.00
Operation25	0.00	0.00	0.00	0.00	0.00	0.00
Operation27	0.00	0.00	0.00	0.00	0.00	0.00
Operation28	0.00	0.00	0.00	0.00	0.00	0.00
Operation3	153.99	37.52	82.6340	228.79	0.00	645.38
Operation4	0.00	0.00	0.00	0.00	0.00	0.00
Operation5	0.00	0.00	0.00	0.00	0.00	0.00
Operation6	0.00	0.00	0.00	0.00	0.00	0.00
Operation8	0.00	0.00	0.00	0.00	0.00	0.00
Operation9	0.00	0.00	0.00	0.00	0.00	0.00
Operation1	1010.81	20.50	967.41	1051.46	0.00	2087.77
Operation12	2.8745	1.15	0.2711	5.0275	0.00	25.7972
Operation15	0.1308	0.25	0.00	1.0938	0.00	13.4469
Operation17	0.00	0.00	0.00	0.00	0.00	0.00
Operation18	0.00	0.00	0.00	0.00	0.00	0.00
Operation26	0.00	0.00	0.00	0.00	0.00	0.00
Operation7	734.03	61.67	589.88	868.45	0.00	1686.64

Appendix-AIII: Existing system instantaneous capacity utilization

	Average	HalfWidth	Average	Average	Value	Value
OP1	1.0000	0.00	1.0000	1.0000	0.00	1.0000
OP10	0.1887	0.03	0.1156	0.2408	0.00	1.0000
OP11	0.2857	0.05	0.1698	0.3628	0.00	1.0000
OP12	0.4065	0.07	0.2505	0.5290	0.00	1.0000
OP13	0.3992	0.07	0.2523	0.5136	0.00	1.0000
OP14	0.4515	0.08	0.2957	0.5888	0.00	1.0000
OP15	0.3800	0.06	0.2512	0.5029	0.00	1.0000
OP16	0.1034	0.02	0.07333333	0.1353	0.00	1.0000
OP17	0.2424	0.04	0.1677	0.3193	0.00	1.0000
OP18	0.1974	0.03	0.1423	0.2664	0.00	1.0000
OP19	0.1775	0.03	0.1313	0.2447	0.00	1.0000
OP2	0.6395	0.00	0.6351	0.6448	0.00	1.0000
OP20	0.1990	0.03	0.1334	0.2617	0.00	1.0000
OP21	0.2192	0.04	0.1515	0.2962	0.00	1.0000
OP22	0.1399	0.03	0.0999	0.1854	0.00	1.0000
OP23	0.2073	0.04	0.1406	0.2886	0.00	1.0000
OP24	0.1265	0.02	0.08173103	0.1775	0.00	1.0000
OP25	0.1305	0.03	0.08971369	0.1872	0.00	1.0000
OP26	0.04896361	0.01	0.03017042	0.06911094	0.00	1.0000
OP27	0.05206676	0.01	0.03270568	0.07346380	0.00	1.0000
OP28	0.1269	0.03	0.07643189	0.1792	0.00	1.0000
OP3	0.9714	0.00	0.9693	0.9735	0.00	1.0000
OP4	0.5278	0.00	0.5211	0.5321	0.00	1.0000
OP5	0.5139	0.00	0.5100	0.5217	0.00	1.0000
OP6	0.5133	0.00	0.5030	0.5204	0.00	1.0000
OP7	0.9242	0.00	0.9217	0.9266	0.00	1.0000
OP8	0.3497	0.06	0.2010	0.4444	0.00	1.0000
OP9	0.1024	0.02	0.06028026	0.1292	0.00	1.0000

Appendix-AIV: Existing system number of busy resources

		Values	AcrossAll	Replications			
TV32							
Replications:	10	TimeUnits: Seconds					
Resource Usage Number Busy		Average	HalfWidth	Minimum Average	Maximum Average	Minimum Value	Maximum Value
OP1		1.0000	0.00	1.0000	1.0000	0.00	1.0000
OP10		0.1887	0.03	0.1156	0.2408	0.00	1.0000
OP11		0.2857	0.05	0.1698	0.3628	0.00	1.0000
OP12		0.4065	0.07	0.2505	0.5290	0.00	1.0000
OP13		0.3992	0.07	0.2523	0.5136	0.00	1.0000
OP14		0.4515	0.08	0.2957	0.5888	0.00	1.0000
OP15		0.3800	0.06	0.2512	0.5029	0.00	1.0000
OP16		0.1034	0.02	0.07333333	0.1353	0.00	1.0000
OP17		0.2424	0.04	0.1677	0.3193	0.00	1.0000
OP18		0.1974	0.03	0.1423	0.2664	0.00	1.0000
OP19		0.1775	0.03	0.1313	0.2447	0.00	1.0000
OP2		0.6395	0.00	0.6351	0.6448	0.00	1.0000
OP20		0.1990	0.03	0.1334	0.2617	0.00	1.0000
OP21		0.2192	0.04	0.1515	0.2962	0.00	1.0000
OP22		0.1399	0.03	0.0999	0.1854	0.00	1.0000
OP23		0.2073	0.04	0.1406	0.2886	0.00	1.0000
OP24		0.1265	0.02	0.08173103	0.1775	0.00	1.0000
OP25		0.1305	0.03	0.08971369	0.1872	0.00	1.0000
OP26		0.04896361	0.01	0.03017042	0.06911094	0.00	1.0000
OP27		0.05206676	0.01	0.03270568	0.07346380	0.00	1.0000
OP28		0.1269	0.03	0.07643189	0.1792	0.00	1.0000
OP3		0.9714	0.00	0.9693	0.9735	0.00	1.0000
OP4		0.5278	0.00	0.5211	0.5321	0.00	1.0000
OP5		0.5139	0.00	0.5100	0.5217	0.00	1.0000
OP6		0.5133	0.00	0.5030	0.5204	0.00	1.0000
OP7		0.9242	0.00	0.9217	0.9266	0.00	1.0000
OP8		0.3497	0.06	0.2010	0.4444	0.00	1.0000
OP9		0.1024	0.02	0.06028026	0.1292	0.00	1.0000

Appendix-AV: Existing system schedule utilization of resources at each stations

	Average	HalfWidth	Average	Average
OP1	1.0000	0.00	1.0000	1.0000
OP10	0.1887	0.03	0.1156	0.2408
OP11	0.2857	0.05	0.1698	0.3628
OP12	0.4065	0.07	0.2505	0.5290
OP13	0.3992	0.07	0.2523	0.5136
OP14	0.4515	0.08	0.2957	0.5888
OP15	0.3800	0.06	0.2512	0.5029
OP16	0.1034	0.02	0.07333333	0.1353
OP17	0.2424	0.04	0.1677	0.3193
OP18	0.1974	0.03	0.1423	0.2664
OP19	0.1775	0.03	0.1313	0.2447
OP2	0.6395	0.00	0.6351	0.6448
OP20	0.1990	0.03	0.1334	0.2617
OP21	0.2192	0.04	0.1515	0.2962
OP22	0.1399	0.03	0.0999	0.1854
OP23	0.2073	0.04	0.1406	0.2886
OP24	0.1265	0.02	0.08173103	0.1775
OP25	0.1305	0.03	0.08971369	0.1872
OP26	0.04896361	0.01	0.03017042	0.06911094
OP27	0.05206676	0.01	0.03270568	0.07346380
OP28	0.1269	0.03	0.07643189	0.1792
OP3	0.9714	0.00	0.9693	0.9735
OP4	0.5278	0.00	0.5211	0.5321
OP5	0.5139	0.00	0.5100	0.5217
OP6	0.5133	0.00	0.5030	0.5204
OP7	0.9242	0.00	0.9217	0.9266
OP8	0.3497	0.06	0.2010	0.4444
OP9	0.1024	0.02	0.06028026	0.1292

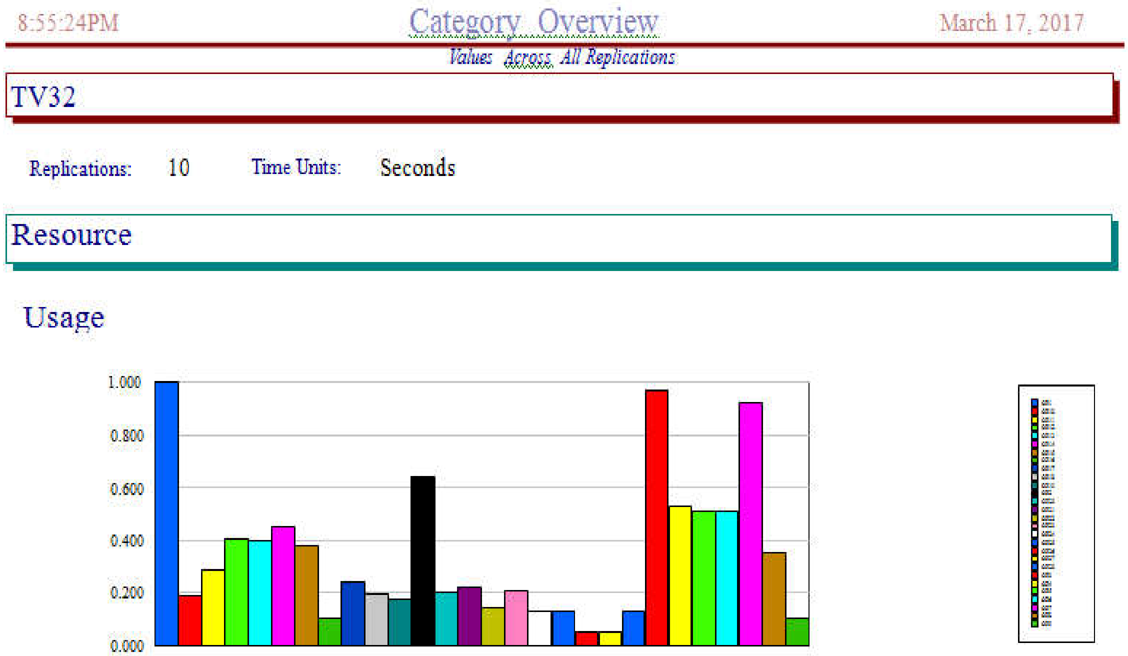


Fig- 4.1A Existing system schedule utilization of resources at each station.

Appendix-AVI: Existing system cost incur at each workstations

	Value	AcrossAll	Replications			
TV32						
Replicati n	s: 10	Time Units:	Seconds			
Resoure Cost BusyCos t			Average	HalfWidth	Minimum Average	Maxi mum Avera ge
OP1			49.5893	0.15	49.2445	49.8927
OP10			9.4245	1.51	5.7778	12.0411
OP11			14.1232	2.42	8.4916	17.9229
OP12			20.1421	3.62	12.5259	26.4484
OP13			19.5912	3.36	12.6146	25.3081
OP14			22.1474	3.68	14.7847	29.4395
OP15			18.8857	3.13	12.5624	24.6685
OP16			5.1181	0.78	3.6667	6.7639
OP17			11.9545	2.04	8.3737	15.9660
OP18			9.5840	1.58	7.1163	12.6309
OP19			8.8146	1.42	6.3781	12.2337
OP2			31.7060	0.20	31.3009	32.1040
OP20			9.8033	1.82	6.6718	12.9506
OP21			10.8398	2.02	7.5728	14.8076
OP22			6.9361	1.27	4.9925	9.2710
OP23			10.2527	1.96	6.5964	14.4290
OP24			6.3074	1.26	4.0866	8.8726
OP25			6.4067	1.37	3.9638	9.3621
OP26			2.4482	0.50	1.5085	3.4555
OP27			2.5809	0.54	1.6353	3.6309
OP28			6.3450	1.31	3.8216	8.9613
OP3			48.1033	0.24	47.6613	48.4987
OP4			26.3018	0.16	26.0575	26.6073
OP5			25.4838	0.12	25.2712	25.7420
OP6			25.6166	0.15	25.1487	25.8923
OP7			45.3580	0.26	44.8796	46.1531
OP8			17.2436	2.75	10.0490	22.2210
OP9			5.0925	0.83	3.0140	6.4624

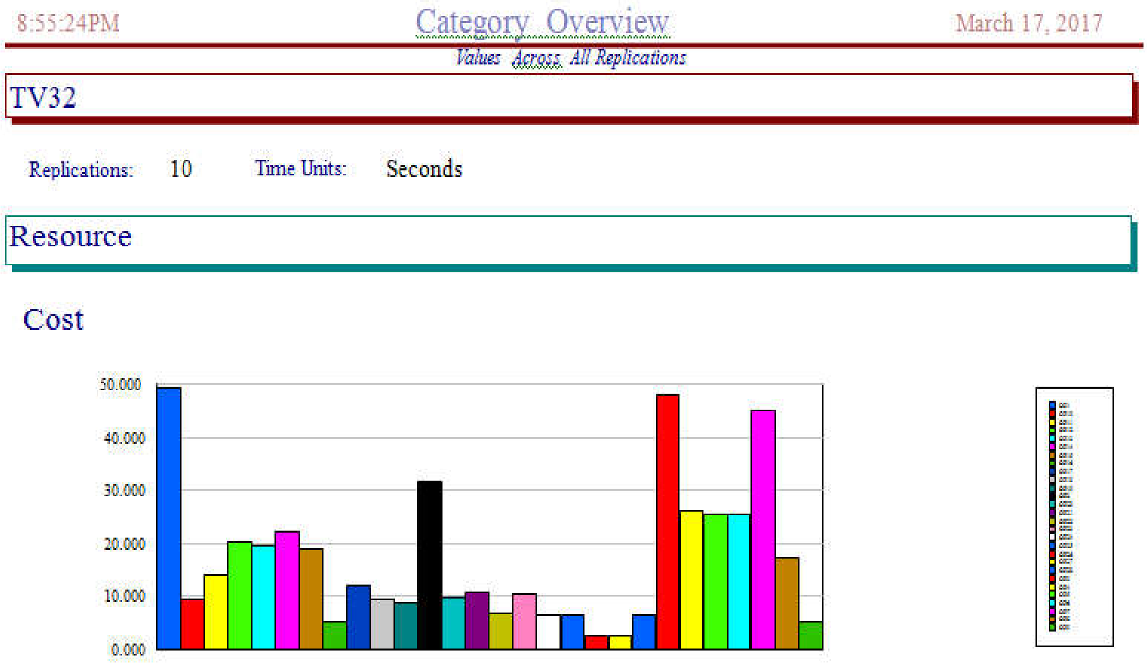


Fig-4.2A Existing system cost incur at each workstation

Appendix-BI: Altenative-1simulation model category overview report

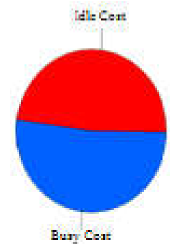
Key Performance Indicators

All Entities

	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	2,119
Wait Cost	1,225
Total Cost	3,344

All Resources

	Average
Busy Cost	1,060 *
Idle Cost	979
Usage Cost	0
Total Cost	2,038



* *these costs are included in Entity Costs above.*

System

	Average
Total Cost	4,323
Number Out	27

	Average	HalfWidth	Average	Average	Value	Value
Entity1		5.96	1492.09	1520.29	1449.19	1666.60
NVATime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		29.56	605.72	724.09	0.00	1457.47
TransferTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
OtherTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
TotalTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1	2166.80	29.48	2117.50	2229.87	1463.08	2932.04
Cost						
VACost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.17	91.4469	92.2303	90.2554	96.2945
NVA Cost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitCost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.41	8.4128	10.0569	0.00	20.2427
OtherCost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1 0.00		0.00	0.00	0.00	0.00	0.00

Transfer Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00

Total Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	100.95	0.42	100.25	101.88	90.6412	111.46

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Entity 1	139.00	1.43	136.00	142.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Entity 1	26.5000	1.03	24.0000	29.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	62.1463	0.88	60.3074	64.3084	0.00	117.00

Appendix-BII: Altenative-1waiting time per entity at each work stations

operations	Average	HalfWidth	Average	Average	Value	Value
Operation10	0.00	0.00	0.00	0.00	0.00	0.00
Operation 11	0.4862	0.21	0.2386	1.0308	0.00	15.0316
Operation13	0.00	0.00	0.00	0.00	0.00	0.00
Operation14	0.00	0.00	0.00	0.00	0.00	0.00
Operation16	0.06275509	0.09	0.00	0.3270	0.00	12.1008
Operation19	0.03699355	0.08	0.00	0.3699	0.00	7.9220
Operation2	607.02	19.05	575.77	663.45	0.00	1311.71
Operation20	0.6099	0.24	0.05051549	1.1804	0.00	20.6861
Operation21	1.8910	0.59	0.3599	2.9143	0.00	32.7563
Operation22	0.00	0.00	0.00	0.00	0.00	0.00
Operation23	1.2450	0.38	0.3439	2.0834	0.00	20.4319
Operation24	0.00	0.00	0.00	0.00	0.00	0.00
Operation25	0.00	0.00	0.00	0.00	0.00	0.00
Operation27	0.00	0.00	0.00	0.00	0.00	0.00
Operation28	0.02102760	0.03	0.00	0.1452	0.00	4.3573
Operation3	0.00	0.00	0.00	0.00	0.00	0.00
Operation4	0.4108	0.13	0.1749	0.7813	0.00	12.4719
Operation5	0.3223	0.10	0.1754	0.6775	0.00	7.2947
Operation6	0.5295	0.16	0.2910	0.9061	0.00	10.4496
Operation8	706.94	11.25	684.74	733.35	0.00	1462.94
Operation9	0.00	0.00	0.00	0.00	0.00	0.00
Operation1	0.00	0.00	0.00	0.00	0.00	0.00
Operation12	0.00	0.00	0.00	0.00	0.00	0.00
Operation15	0.04667567	0.07	0.00	0.2793	0.00	10.3345
Operation17	3.3632	0.79	1.5364	4.8640	0.00	40.4966
Operation18	0.00602041	0.01	0.00	0.04046174	0.00	1.4162
Operation26	0.00	0.00	0.00	0.00	0.00	0.00
Operation7	0.2116	0.24	0.00	0.9607	0.00	26.9580

Appendix-BIII: Altenative-1 Instantaneous capacity utilization

	Average	Half Width	Average	Average	Value	Value
OP1	0.5837	0.01	0.5708	0.5973	0.00	1.0000
OP10	0.4882	0.01	0.4696	0.5089	0.00	1.0000
OP11	0.7307	0.01	0.7096	0.7458	0.00	1.0000
OP12	0.5240	0.00	0.5166	0.5301	0.00	1.0000
OP13	0.5093	0.00	0.5009	0.5147	0.00	1.0000
OP14	0.3862	0.00	0.3797	0.3904	0.00	0.6667
OP15	0.4896	0.01	0.4751	0.5005	0.00	1.0000
OP16	0.2535	0.00	0.2475	0.2617	0.00	1.0000
OP17	0.6184	0.00	0.6066	0.6243	0.00	1.0000
OP18	0.5032	0.01	0.4843	0.5131	0.00	1.0000
OP19	0.4500	0.01	0.4272	0.4667	0.00	1.0000
OP2	0.9827	0.00	0.9813	0.9842	0.00	1.0000
OP20	0.5181	0.00	0.5084	0.5268	0.00	1.0000
OP21	0.5644	0.01	0.5484	0.5749	0.00	1.0000
OP22	0.3632	0.01	0.3538	0.3760	0.00	1.0000
OP23	0.5409	0.00	0.5354	0.5498	0.00	1.0000
OP24	0.3249	0.00	0.3203	0.3312	0.00	1.0000
OP25	0.3403	0.00	0.3333	0.3526	0.00	1.0000
OP26	0.1258	0.00	0.1195	0.1296	0.00	1.0000
OP27	0.1347	0.00	0.1246	0.1438	0.00	1.0000
OP28	0.3357	0.00	0.3239	0.3443	0.00	1.0000
OP3	0.5299	0.00	0.5228	0.5334	0.00	0.6667
OP4	0.8653	0.00	0.8578	0.8739	0.00	1.0000
OP5	0.8378	0.00	0.8327	0.8484	0.00	1.0000
OP6	0.8403	0.00	0.8285	0.8483	0.00	1.0000
OP7	0.5791	0.02	0.5378	0.6192	0.00	1.0000
OP8	0.8985	0.00	0.8858	0.9040	0.00	1.0000
OP9	0.2637	0.00	0.2560	0.2743	0.00	1.0000

Appendix-BIV: Altenative-1 Busy number of resource at each workstation

			Values	*AcrossAll*	*Replications*			
TV19								
Replicats:	10	TimeUnits:	Seconds					
Resoue c Usag	sy		Average	HalfWidth	Minimum Average	Maxim um Aver	Minimum Value	Maximum Value
OP1			2.3350	0.02	2.283	2.3892	0.00	4.0000
OP10			0.4882	0.01	0.469	0.5089	0.00	1.0000
OP11			0.7307	0.01	0.709	0.7458	0.00	1.0000
OP12			1.0480	0.01	1.033	1.0603	0.00	2.0000
OP13			1.0185	0.01	1.001	1.0293	0.00	2.0000
OP14			1.1586	0.01	1.139	1.1713	0.00	2.0000
OP15			0.9792	0.01	0.950	1.0010	0.00	2.0000
OP16			0.2535	0.00	0.247	0.2617	0.00	1.0000
OP17			0.6184	0.00	0.606	0.6243	0.00	1.0000
OP18			0.5032	0.01	0.484	0.5131	0.00	1.0000
OP19			0.4500	0.01	0.427	0.4667	0.00	1.0000
OP2			0.9827	0.00	0.981	0.9842	0.00	1.0000
OP20			0.5181	0.00	0.508	0.5268	0.00	1.0000
OP21			0.5644	0.01	0.548	0.5749	0.00	1.0000
OP22			0.3632	0.01	0.353	0.3760	0.00	1.0000
OP23			0.5409	0.00	0.535	0.5498	0.00	1.0000
OP24			0.3249	0.00	0.320	0.3312	0.00	1.0000
OP25			0.3403	0.00	0.333	0.3526	0.00	1.0000
OP26			0.1258	0.00	0.119	0.1296	0.00	1.0000
OP27			0.1347	0.00	0.124	0.1438	0.00	1.0000
OP28			0.3357	0.00	0.323	0.3443	0.00	1.0000
OP3			1.5897	0.01	1.568	1.6003	0.00	2.0000
OP4			0.8653	0.00	0.857	0.8739	0.00	1.0000
OP5			0.8378	0.00	0.832	0.8484	0.00	1.0000
OP6			0.8403	0.00	0.828	0.8483	0.00	1.0000
OP7			2.3165	0.06	2.151	2.4767	0.00	4.0000
OP8			0.8985	0.00	0.885	0.9040	0.00	1.0000
OP9			0.2637	0.00	0.256	0.2743	0.00	1.0000

Appendix-BV:Altenative-1 Schedule resource utilization at each station

	Average	HalfWidth	Average	Average
OP1	0.5837	0.01	0.5708	0.5973
OP10	0.4882	0.01	0.4696	0.5089
OP11	0.7307	0.01	0.7096	0.7458
OP12	0.5240	0.00	0.5166	0.5301
OP13	0.5093	0.00	0.5009	0.5147
OP14	0.3862	0.00	0.3797	0.3904
OP15	0.4896	0.01	0.4751	0.5005
OP16	0.2535	0.00	0.2475	0.2617
OP17	0.6184	0.00	0.6066	0.6243
OP18	0.5032	0.01	0.4843	0.5131
OP19	0.4500	0.01	0.4272	0.4667
OP2	0.9827	0.00	0.9813	0.9842
OP20	0.5181	0.00	0.5084	0.5268
OP21	0.5644	0.01	0.5484	0.5749
OP22	0.3632	0.01	0.3538	0.3760
OP23	0.5409	0.00	0.5354	0.5498
OP24	0.3249	0.00	0.3203	0.3312
OP25	0.3403	0.00	0.3333	0.3526
OP26	0.1258	0.00	0.1195	0.1296
OP27	0.1347	0.00	0.1246	0.1438
OP28	0.3357	0.00	0.3239	0.3443
OP3	0.5299	0.00	0.5228	0.5334
OP4	0.8653	0.00	0.8578	0.8739
OP5	0.8378	0.00	0.8327	0.8484
OP6	0.8403	0.00	0.8285	0.8483
OP7	0.5791	0.02	0.5378	0.6192
OP8	0.8985	0.00	0.8858	0.9040
OP9	0.2637	0.00	0.2560	0.2743

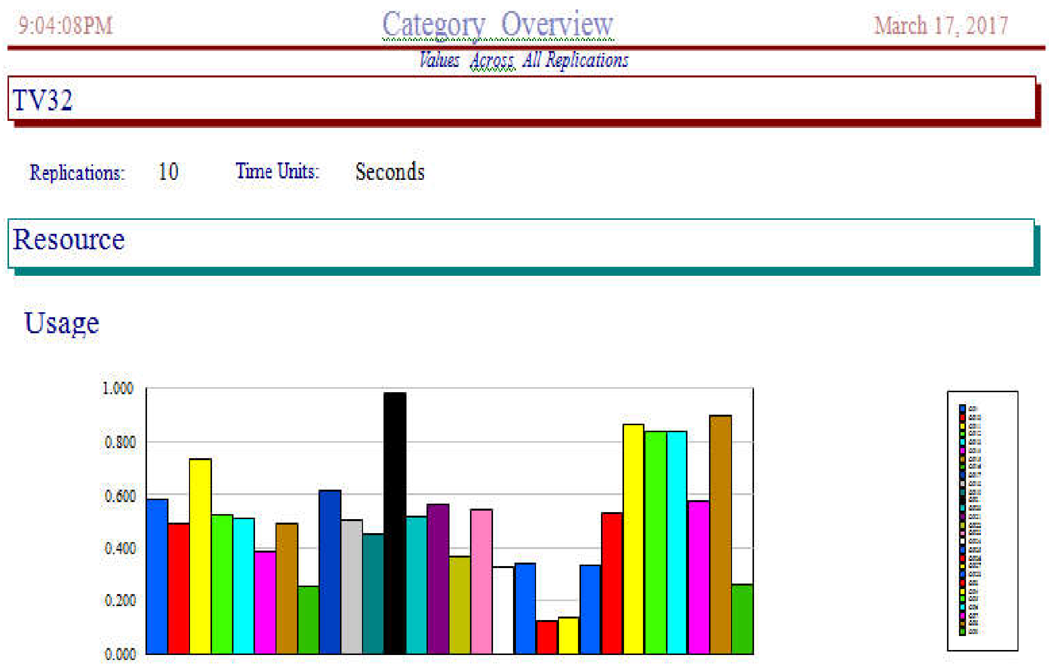


Fig-4.1B Alternative-1 scheduled resource utilization at each workstation

Appendix-BVI:Altenative-1 cost incur to work station

			Values	AcrossAll	Replications	
TV32						
Replications:	10	TimeUnits:	Seconds			
Resource Cost IdleCost			Average	HalfWidth	Minimum Average	M a
OP1			83.2514	1.09	80.5387	85.8482
OP10			25.5900	0.40	24.5541	26.5207
OP11			13.4653	0.42	12.7101	14.5220
OP12			47.6022	0.32	46.9850	48.3412
OP13			49.0749	0.26	48.5349	49.9083
OP14			92.0690	0.40	91.4366	93.0513
OP15			51.0384	0.52	49.9501	52.4889
OP16			37.3250	0.18	36.9167	37.6250
OP17			19.0795	0.18	18.7844	19.6702
OP18			24.8383	0.30	24.3454	25.7870
OP19			27.5009	0.44	26.6666	28.6390
OP2			0.8648	0.04	0.7909	0.9371
OP20			24.0961	0.21	23.6620	24.5819
OP21			21.7818	0.30	21.2566	22.5802
OP22			31.8406	0.26	31.1991	32.3124
OP23			22.9564	0.16	22.5118	23.2299
OP24			33.7560	0.15	33.4408	33.9843
OP25			32.9868	0.23	32.3707	33.3351
OP26			43.7105	0.12	43.5184	44.0265
OP27			43.2626	0.19	42.8112	43.7688
OP28			33.2157	0.23	32.7832	33.8058
OP3			70.5136	0.37	69.9856	71.5805
OP4			6.7336	0.21	6.3030	7.1108
OP5			8.1106	0.20	7.5783	8.3645
OP6			7.9838	0.21	7.5848	8.5730
OP7			84.1774	3.10	76.1636	92.4320
OP8			5.0734	0.18	4.8001	5.7088
OP9			36.8129	0.18	36.2826	37.1975

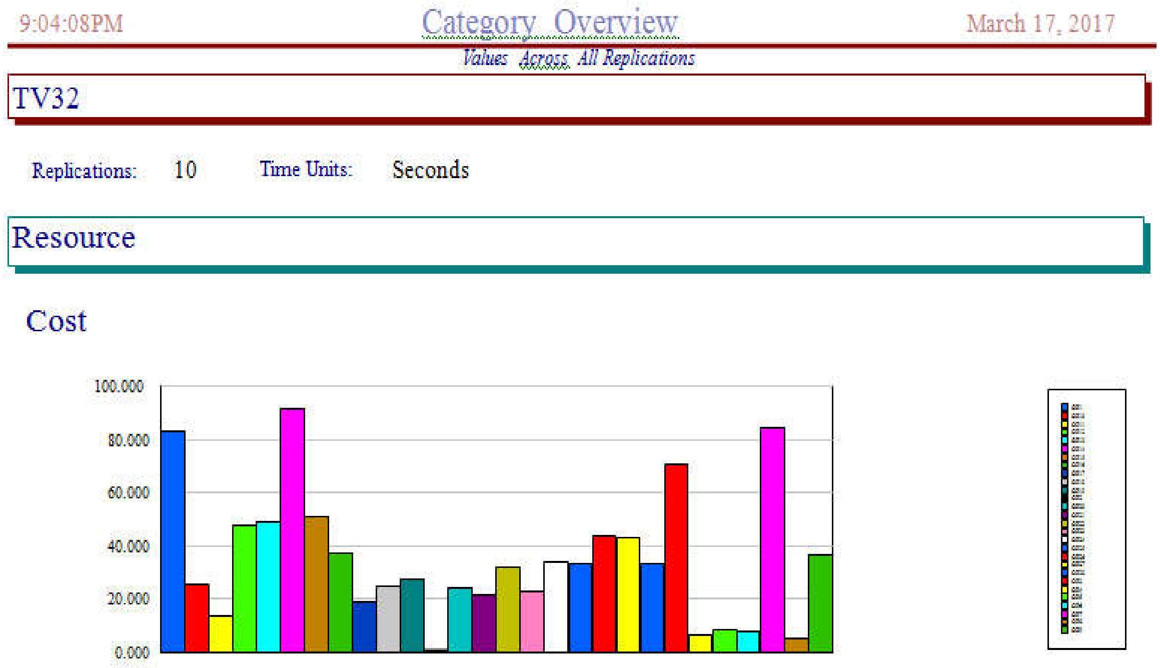


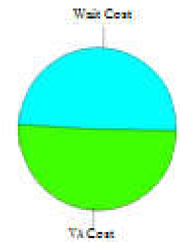
Fig-4.2B Altenative-1 cost incur to work station.

Appendix-CI: Alternative-2 simulation model category overview report

Key Performance Indicators

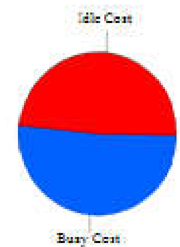
All Entities

	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	1,427
Wait Cost	1,390
Total Cost	2,817



All Resources

	Average
Busy Cost	713 *
Idle Cost	674
Usage Cost	0
Total Cost	1,387



* these costs are included in Entity Costs above.

System

	Average
Total Cost	3,491
Number Out	18

	Average	HalfWidth	Average	Average	Value	Value
Entity1		3.25	1495.55	1508.06	1491.00	1673.00
NVATime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		39.29	733.82	880.68	0.00	1599.24
TransferTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
OtherTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
TotalTime				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1	2282.86	40.45	2236.46	2382.91	1491.00	3090.24
Cost						
VACost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.09	91.5431	91.8906	91.4167	96.4722
NVA Cost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitCost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.55	10.1919	12.2316	0.00	22.2117
OtherCost				Minimum	Maximum	Minimum
	Average	HalfWidth	Average	Average	Value	Value
Entity1 0.00		0.00	0.00	0.00	0.00	0.00

Transfer Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00

Total Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	102.56	0.58	101.88	104.02	91.4167	114.49

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Entity 1	139.30	2.08	136.00	146.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Entity 1	17.5000	1.08	15.0000	20.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	64.6337	0.90	63.2132	66.8225	0.00	130.00

Appendix-CII: Alternative-2 waiting time of entity at each workstation

Wait Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Operation 10	0.00	0.00	0.00	0.00	0.00	0.00
Operation 11	0.00	0.00	0.00	0.00	0.00	0.00
Operation 13	0.00	0.00	0.00	0.00	0.00	0.00
Operation 14	0.00	0.00	0.00	0.00	0.00	0.00
Operation 16	0.00	0.00	0.00	0.00	0.00	0.00
Operation 2	44.3552	12.72	16.5000	73.1564	0.00	233.00
Operation 3	0.00	0.00	0.00	0.00	0.00	0.00
Operation 4	702.60	1.74	697.14	705.27	0.00	1410.54
Operation 5	0.00	0.00	0.00	0.00	0.00	0.00
Operation 6	0.00	0.00	0.00	0.00	0.00	0.00
Operation 8	0.00	0.00	0.00	0.00	0.00	0.00
Operation 9	89.9927	17.97	58.6400	140.50	0.00	309.00
Operation1	825.70	7.05	814.67	848.68	0.00	1718.82
Operation12	0.00	0.00	0.00	0.00	0.00	0.00
Operation15	0.00	0.00	0.00	0.00	0.00	0.00
Operation7	159.07	35.75	75.6970	216.36	0.00	455.00

Appendix-CIII: Alternative-2 Instantaneous capacity utilization

	Average	HalfWidth	Average	Average	Value	Value
OP1	0.9961	0.00	0.9946	0.9969	0.00	1.0000
OP10	0.6512	0.01	0.6200	0.6672	0.00	1.0000
OP11	0.2910	0.01	0.2761	0.2986	0.00	0.5000
OP12	0.3162	0.01	0.3007	0.3240	0.00	0.5000
OP13	0.3627	0.01	0.3440	0.3726	0.00	1.0000
OP14	0.3018	0.01	0.2850	0.3094	0.00	0.5000
OP15	0.2237	0.00	0.2111	0.2292	0.00	0.5000
OP16	0.1334	0.00	0.1262	0.1371	0.00	0.3333
OP2	0.9684	0.00	0.9668	0.9691	0.00	1.0000
OP3	0.6653	0.00	0.6638	0.6660	0.00	1.0000
OP4	0.9244	0.00	0.9244	0.9244	0.00	1.0000
OP5	0.4740	0.00	0.4740	0.4740	0.00	1.0000
OP6	0.4932	0.00	0.4932	0.4932	0.00	1.0000
OP7	0.8447	0.00	0.8447	0.8447	0.00	1.0000
OP8	0.7390	0.02	0.6825	0.7836	0.00	1.0000
OP9	0.7763	0.01	0.7419	0.7942	0.00	1.0000

Number Busy			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
OP1	1.9923	0.00	1.9892	1.9938	0.00	2.0000
OP10	0.6512	0.01	0.6200	0.6672	0.00	1.0000
OP11	0.5821	0.01	0.5522	0.5972	0.00	1.0000
OP12	0.6324	0.01	0.6014	0.6481	0.00	1.0000
OP13	0.7254	0.02	0.6881	0.7453	0.00	2.0000
OP14	0.6035	0.01	0.5700	0.6189	0.00	1.0000
OP15	0.4473	0.01	0.4222	0.4583	0.00	1.0000
OP16	0.4001	0.01	0.3786	0.4114	0.00	1.0000
OP2	1.9367	0.00	1.9337	1.9382	0.00	2.0000
OP3	1.3306	0.00	1.3276	1.3321	0.00	2.0000
OP4	0.9244	0.00	0.9244	0.9244	0.00	1.0000
OP5	0.9481	0.00	0.9481	0.9481	0.00	2.0000
OP6	0.9864	0.00	0.9864	0.9864	0.00	2.0000
OP7	0.8447	0.00	0.8447	0.8447	0.00	1.0000
OP8	0.7390	0.02	0.6825	0.7836	0.00	1.0000
OP9	0.7763	0.01	0.7419	0.7942	0.00	1.0000

Appendix-CIV: Alternative-2 schedule utilization of resources at each workstation.

TV19

Replications: 10 Time Units: Seconds

Resource

Usage

Scheduled Utilization

	Average	Half Width	Minimum Average	Maximum Average
OP1	0.9961	0.00	0.9946	0.9969
OP10	0.6512	0.01	0.6200	0.6672
OP11	0.2910	0.01	0.2761	0.2986
OP12	0.3162	0.01	0.3007	0.3240
OP13	0.3627	0.01	0.3440	0.3726
OP14	0.3018	0.01	0.2850	0.3094
OP15	0.2237	0.00	0.2111	0.2292
OP16	0.1334	0.00	0.1262	0.1371
OP2	0.9684	0.00	0.9668	0.9691
OP3	0.6653	0.00	0.6638	0.6660
OP4	0.9244	0.00	0.9244	0.9244
OP5	0.4740	0.00	0.4740	0.4740
OP6	0.4932	0.00	0.4932	0.4932
OP7	0.8447	0.00	0.8447	0.8447
OP8	0.7390	0.02	0.6825	0.7836
OP9	0.7763	0.01	0.7419	0.7942

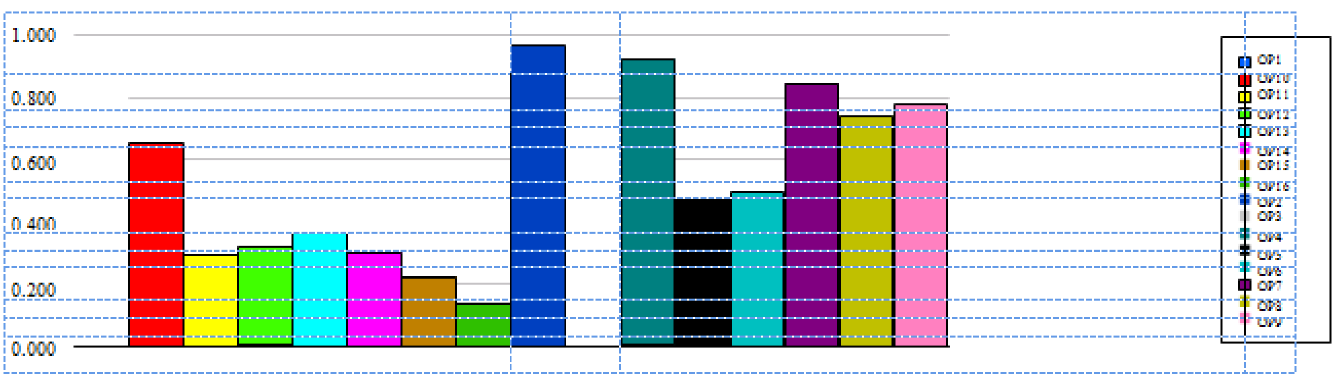


Fig-5.1C Alternative-2 schedule utilization of resources at each workstation.

Appendix-DI: Alternative-4 simulation model category overview report

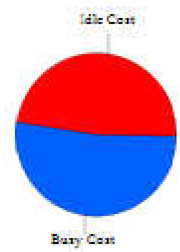
Key Performance Indicators

All Entities

	Average
Non-Value Added Cost	0
Other Cost	0
Transfer Cost	0
Value Added Cost	2,132
Wait Cost	1,229
Total Cost	3,361

All Resources

	Average
Busy Cost	1,066 *
Idle Cost	972
Usage Cost	0
Total Cost	2,038



* *these costs are included in Entity Costs above.*

System

	Average
Total Cost	4,333
Number Out	27

	Average	HalfWidth	Average	Average	Value	Value
Entity1		4.62	1491.66	1512.58	1435.99	1671.96
NVATime			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitTime			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		24.71	603.26	713.88	0.00	1407.41
TransferTime			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
OtherTime			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
TotalTime			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1	2170.32	24.64	2115.84	2219.64	1463.08	2866.27
Cost						
VACost			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.13	91.4351	92.0160	89.8886	96.4435
NVA Cost			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00
WaitCost			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.34	8.3786	9.9150	0.00	19.5473
OtherCost			Minimum	Maximum	Minimum	
	Average	HalfWidth	Average	Average	Value	Value
Entity1		0.00	0.00	0.00	0.00	0.00

Transfer Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	0.00	0.00	0.00	0.00	0.00	0.00

Total Cost	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	100.99	0.35	100.39	101.74	90.6412	111.59

Other

Number In	Average	Half Width	Minimum Average	Maximum Average
Entity 1	139.10	1.19	136.00	141.00

Number Out	Average	Half Width	Minimum Average	Maximum Average
Entity 1	27.0000	0.95	25.0000	29.0000

WIP	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Entity 1	62.0070	0.72	60.4761	63.8887	0.00	115.00

Appendix-DII: Alternative-4 waiting time per entity at each work stations

	Average	HalfWidth	Average	Average	Value	Value
Operation10	0.00	0.00	0.00	0.00	0.00	0.00
Operation 11	0.4816	0.13	0.2490	0.6987	0.00	15.0316
Operation13	0.00	0.00	0.00	0.00	0.00	0.00
Operation14	0.00	0.00	0.00	0.00	0.00	0.00
Operation16	0.03278222	0.07	0.00	0.3278	0.00	11.8016
Operation19	0.02840165	0.04	0.00	0.1436	0.00	5.0257
Operation2	601.70	18.45	575.77	663.47	0.00	1306.45
Operation20	0.6488	0.29	0.0976	1.4918	0.00	20.6861
Operation21	1.7322	0.50	0.9030	2.9947	0.00	18.2468
Operation22	0.00	0.00	0.00	0.00	0.00	0.00
Operation23	1.4610	0.54	0.6023	2.7710	0.00	21.9398
Operation24	0.00	0.00	0.00	0.00	0.00	0.00
Operation25	0.00	0.00	0.00	0.00	0.00	0.00
Operation27	0.00	0.00	0.00	0.00	0.00	0.00
Operation28	0.01502500	0.03	0.00	0.1503	0.00	4.3573
Operation3	0.00	0.00	0.00	0.00	0.00	0.00
Operation4	5.5836	3.01	0.3721	14.3961	0.00	85.2814
Operation5	0.6609	0.26	0.1754	1.1571	0.00	12.3651
Operation6	0.9347	0.42	0.3117	2.1138	0.00	12.1709
Operation8	710.04	11.59	694.55	746.48	0.00	1470.67
Operation9	0.00	0.00	0.00	0.00	0.00	0.00
Operation1	0.00	0.00	0.00	0.00	0.00	0.00
Operation12	0.00	0.00	0.00	0.00	0.00	0.00
Operation15	0.00	0.00	0.00	0.00	0.00	0.00
Operation17	3.4999	1.21	0.9574	5.5654	0.00	34.3594
Operation18	0.00545132	0.01	0.00	0.03477075	0.00	1.2170
Operation26	0.00	0.00	0.00	0.00	0.00	0.00
Operation7	0.2062	0.29	0.00	1.1082	0.00	26.9580

Appendix-DIII: Alternative-4 Instantaneous capacity utilization at each work stations

	Average	HalfWidth	Average	Average	Value	Value
OP1	0.5838	0.00	0.5715	0.5951	0.00	1.0000
OP10	0.4846	0.01	0.4714	0.4951	0.00	1.0000
OP11	0.7325	0.01	0.7167	0.7544	0.00	1.0000
OP12	0.5236	0.00	0.5183	0.5295	0.00	1.0000
OP13	0.5089	0.00	0.5033	0.5122	0.00	1.0000
OP14	0.3851	0.00	0.3809	0.3904	0.00	0.6667
OP15	0.4901	0.00	0.4846	0.4931	0.00	1.0000
OP16	0.2555	0.00	0.2458	0.2653	0.00	1.0000
OP17	0.6170	0.00	0.6033	0.6253	0.00	1.0000
OP18	0.5037	0.00	0.4933	0.5108	0.00	1.0000
OP19	0.4467	0.01	0.4266	0.4607	0.00	1.0000
OP2	0.9827	0.00	0.9813	0.9842	0.00	1.0000
OP20	0.5168	0.01	0.5025	0.5327	0.00	1.0000
OP21	0.5629	0.00	0.5539	0.5725	0.00	1.0000
OP22	0.3619	0.00	0.3556	0.3667	0.00	1.0000
OP23	0.5384	0.00	0.5288	0.5446	0.00	1.0000
OP24	0.3247	0.00	0.3165	0.3329	0.00	1.0000
OP25	0.3426	0.00	0.3331	0.3515	0.00	1.0000
OP26	0.1262	0.00	0.1244	0.1293	0.00	1.0000
OP27	0.1353	0.00	0.1313	0.1409	0.00	1.0000
OP28	0.3369	0.00	0.3298	0.3424	0.00	1.0000
OP3	0.5430	0.01	0.5298	0.5544	0.00	1.0000
OP4	0.8861	0.01	0.8683	0.9028	0.00	1.0000
OP5	0.8552	0.01	0.8344	0.8764	0.00	1.0000
OP6	0.8558	0.01	0.8380	0.8708	0.00	1.0000
OP7	0.5901	0.02	0.5500	0.6348	0.00	1.0000
OP8	0.8985	0.00	0.8858	0.9040	0.00	1.0000
OP9	0.2659	0.00	0.2609	0.2734	0.00	1.0000

Appendix-DIV: Alternative-4 number of busy resources at each work stations

			Values	AcrossAll	Replications			
TV19								
Replications:	10	Time Units:	Seconds					
Resource Usage Number Busy			Average	HalfWidth	Minimum Average	Maximum Average	Minimum Value	Maximum Value
OP1			2.3352	0.02	2.286	2.3802	0.00	4.0000
OP10			0.4846	0.01	0.471	0.4951	0.00	1.0000
OP11			0.7325	0.01	0.716	0.7544	0.00	1.0000
OP12			1.0471	0.00	1.036	1.0589	0.00	2.0000
OP13			1.0178	0.00	1.006	1.0244	0.00	2.0000
OP14			1.1552	0.01	1.142	1.1713	0.00	2.0000
OP15			0.9801	0.00	0.969	0.9862	0.00	2.0000
OP16			0.2555	0.00	0.245	0.2653	0.00	1.0000
OP17			0.6170	0.00	0.603	0.6253	0.00	1.0000
OP18			0.5037	0.00	0.493	0.5108	0.00	1.0000
OP19			0.4467	0.01	0.426	0.4607	0.00	1.0000
OP2			0.9827	0.00	0.981	0.9842	0.00	1.0000
OP20			0.5168	0.01	0.502	0.5327	0.00	1.0000
OP21			0.5629	0.00	0.553	0.5725	0.00	1.0000
OP22			0.3619	0.00	0.355	0.3667	0.00	1.0000
OP23			0.5384	0.00	0.528	0.5446	0.00	1.0000
OP24			0.3247	0.00	0.316	0.3329	0.00	1.0000
OP25			0.3426	0.00	0.333	0.3515	0.00	1.0000
OP26			0.1262	0.00	0.124	0.1293	0.00	1.0000
OP27			0.1353	0.00	0.131	0.1409	0.00	1.0000
OP28			0.3369	0.00	0.329	0.3424	0.00	1.0000
OP3			1.6290	0.02	1.589	1.6631	0.00	3.0000
OP4			0.8861	0.01	0.868	0.9028	0.00	1.0000
OP5			0.8552	0.01	0.834	0.8764	0.00	1.0000
OP6			0.8558	0.01	0.838	0.8708	0.00	1.0000
OP7			2.3606	0.08	2.199	2.5393	0.00	4.0000
OP8			0.8985	0.00	0.885	0.9040	0.00	1.0000
OP9			0.2659	0.00	0.260	0.2734	0.00	1.0000

Appendix-DV: Alternative-4 schedule resource utilization at each work stations.

	Average	HalfWidth	Average	Average
OP1	0.5838	0.00	0.5715	0.5951
OP10	0.4846	0.01	0.4714	0.4951
OP11	0.7325	0.01	0.7167	0.7544
OP12	0.5236	0.00	0.5183	0.5295
OP13	0.5089	0.00	0.5033	0.5122
OP14	0.3851	0.00	0.3809	0.3904
OP15	0.4901	0.00	0.4846	0.4931
OP16	0.2555	0.00	0.2458	0.2653
OP17	0.6170	0.00	0.6033	0.6253
OP18	0.5037	0.00	0.4933	0.5108
OP19	0.4467	0.01	0.4266	0.4607
OP2	0.9827	0.00	0.9813	0.9842
OP20	0.5168	0.01	0.5025	0.5327
OP21	0.5629	0.00	0.5539	0.5725
OP22	0.3619	0.00	0.3556	0.3667
OP23	0.5384	0.00	0.5288	0.5446
OP24	0.3247	0.00	0.3165	0.3329
OP25	0.3426	0.00	0.3331	0.3515
OP26	0.1262	0.00	0.1244	0.1293
OP27	0.1353	0.00	0.1313	0.1409
OP28	0.3369	0.00	0.3298	0.3424
OP3	0.5430	0.01	0.5298	0.5544
OP4	0.8861	0.01	0.8683	0.9028
OP5	0.8552	0.01	0.8344	0.8764
OP6	0.8558	0.01	0.8380	0.8708
OP7	0.5901	0.02	0.5500	0.6348
OP8	0.8985	0.00	0.8858	0.9040
OP9	0.2659	0.00	0.2609	0.2734

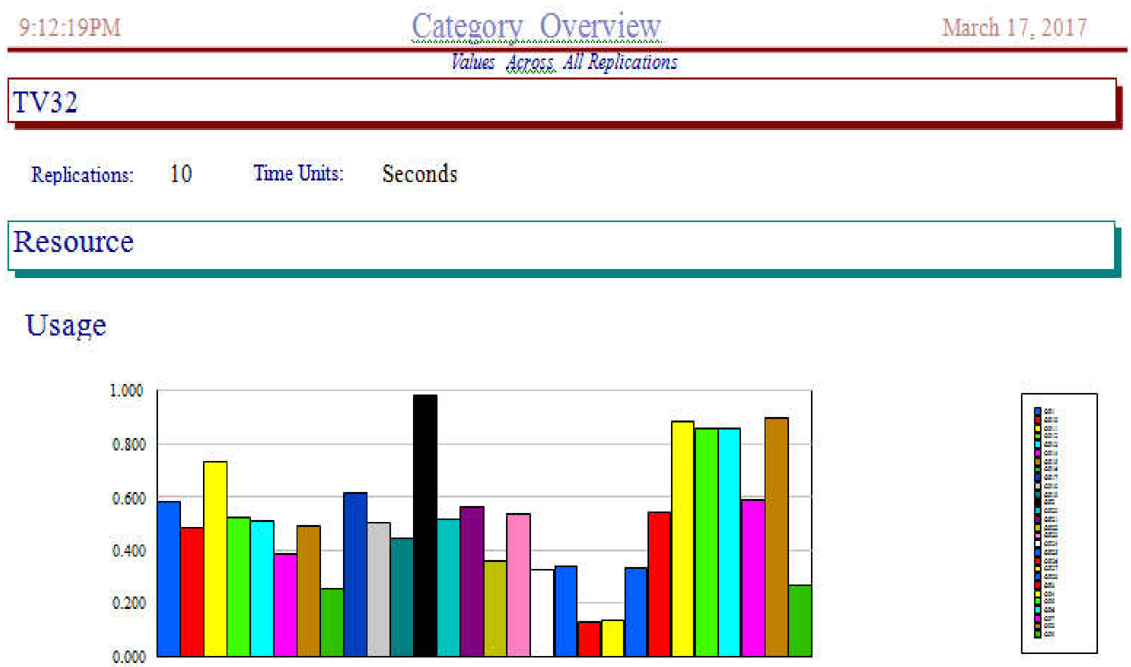


Fig-5.1D Alternative-4 schedule resource utilization at each work stations.

Appendix-DVI: Alternative-4 cost incur at each work stations

			Value	AcrossAll	Replications	
TV32						
Replications:	10	TimeUnits:	Seconds			
Resource Cost IdleCost			Average	HalfWidth	Minimum Average	M
OP1			83.2385	0.98	80.9883	85.6949
OP10			25.7692	0.26	25.2470	26.4320
OP11			13.3733	0.44	12.2780	14.1642
OP12			47.6447	0.24	47.0542	48.1720
OP13			49.1084	0.18	48.7789	49.6735
OP14			92.2405	0.33	91.4366	92.8602
OP15			50.9944	0.20	50.6905	51.5448
OP16			37.2231	0.24	36.7361	37.7083
OP17			19.1490	0.25	18.7344	19.8337
OP18			24.8147	0.20	24.4619	25.3344
OP19			27.6643	0.32	26.9664	28.6689
OP2			0.8648	0.04	0.7909	0.9371
OP20			24.1594	0.33	23.3645	24.8732
OP21			21.8545	0.23	21.3731	22.3064
OP22			31.9075	0.13	31.6674	32.2217
OP23			23.0779	0.21	22.7675	23.5623
OP24			33.7656	0.18	33.3536	34.1740
OP25			32.8716	0.19	32.4271	33.3449
OP26			43.6883	0.05	43.5326	43.7781
OP27			43.2370	0.12	42.9526	43.4358
OP28			33.1575	0.14	32.8787	33.5111
OP3			68.5502	0.92	66.8473	70.5314
OP4			5.6939	0.43	4.8615	6.5873
OP5			7.2398	0.47	6.1788	8.2818
OP6			7.2111	0.39	6.4591	8.0999
OP7			81.9701	4.06	73.0339	90.0086
OP8			5.0734	0.18	4.8001	5.7088
OP9			36.7062	0.16	36.3305	36.9542

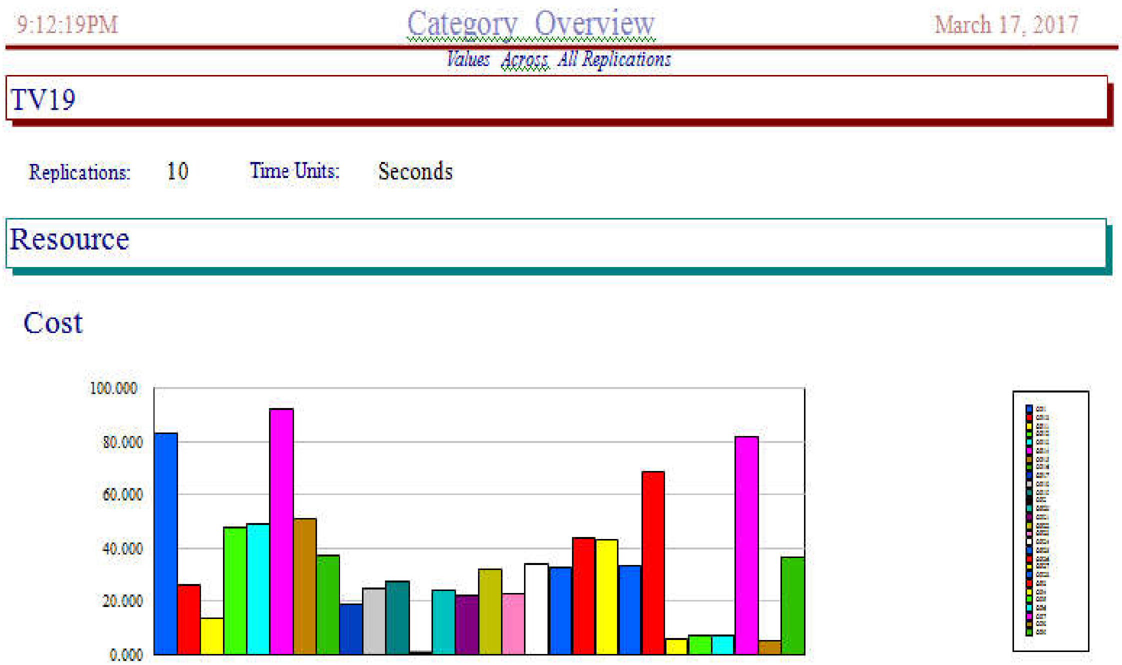


Fig-5.2D Alternative-4 cost incur at each work stations.

Appendix-DVII : "t" probability distribution table

df	t0.100	t0.050	t0.025	t0.010	t0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	**1.372**	**1.812**	**2.228**	**2.764**	**3.169**
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
30	1.310	1.697	2.042	2.457	2.750
40	1.303	1.684	2.021	2.423	2.704
60	1.296	1.671	2.000	2.390	2.660
120	1.289	1.658	1.980	2.358	2.617

Appendix-DVIII: Standard normal probability distribution table (z-table)

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964