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Modeling and Optimization of the TV Assembling Line Using Arena Simulation Software

Gonfa Angasu Benti[1*], Dr. Balkeshwar Singh[2]

[1]Lecturer, Department of Mechanical Engineering, Institute of Technology Ambo University, Ethiopia
[2]Professor, Department of Mechanical Design & Manufacturing Engineering School of Mechanical, Chemical & Materials Engineering Adama Science & Technology University, Adama City, Ethiopia

***Corresponding author:** Gonfa Angasu Benti
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Abstract **Original Research Article**

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.
Keywords: modeling, production/assembly line, simulation and optimization.

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. 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 TV32″ 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).

Production processes and layout of TV assembly line.

In the office and house hold equipment workshop the TV 32" is assembled step by step as shown in the table 1.

Table-1: The sequential activities and operation of the TV32" assembly line

Assembly operation stations	Activities to be performed	Abbreviations of the operation
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 cable HT cable	OP6
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

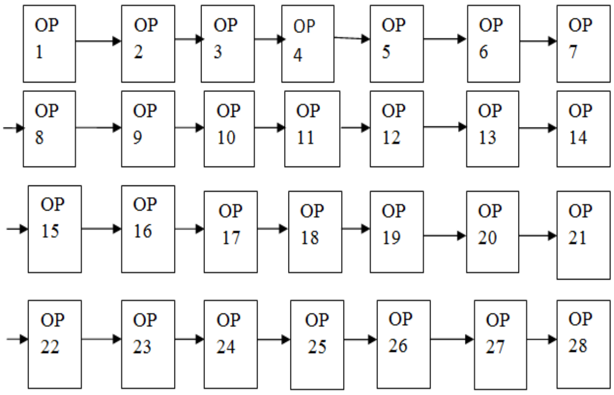

Fig-1: The flow diagram of the TV assembly line.

This data has been taken from Hi-Tech Engineering Industry house hold equipment department 2018.The average actual daily production, volume; unit cost and price have been given in the table 2.

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.

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. The data collection includes the following parameters which can influence and can be used in measuring of the performance of the manufacturing process are:

Table-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 = 28,2000	2000*141 = 28,2000	2000*141 = 28,2000

(i) Total number of tasks; (ii) Processing times of each task; (iii) Transfer time of WIP between stations; (iv) Priorities between processes (v) Arrival frequencies of entities or time between arrivals; (vi) Number of workers for each task; (vii) Layout of production/assembly line: (viii) Working hours; (ix) Production output; (x) Number of rework; (xi) unscheduled stop

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

Literature Review

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 research paper 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:
(i) Number and type of machines for a particular objective; (ii) Throughput analysis; (iii) Time-in-system analysis; (iv) Bottleneck analysis; (v) 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 paper is throughput which is related with work in process (WIP), cycle time 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.

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 inapplicable 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:

(i) Active period method; (ii) Turning point method; (iii) Arrow based method; (v) 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 authors tried to present a process that is less affected by data error. They 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: (i) the answers needed from the simulation, (ii) the products that are being made on the shop floor, (iii) new production processes or characteristics of the current production processes, and (iv)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;
- 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.

Data collection process and methods to develop simulation model

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. Based on this, the number of tasks on the assembly line is determined and the processing time for each task is collected and tabulated. 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. 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 as shown in the appendix figure 2 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 appendix table 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.

From the appendix table 3, 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.

- **Processing times of each task**: The appendix table 4 illustrates the processing time for each task on the assembly line recorded using stop watch.

- **Priorities between processes and the number of workers on each work station on the assembly line:** As described in the appendix table 5, 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.

- **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 6. 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-6: 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

- **Unscheduled stop**: As indicated in the table 7 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-7: 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

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. In 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.

Table-8: Arrival frequencies of entities or time between arrivals of entities to enter 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)

The following arrival time is recorded using stop watch on the assembly/production line for 14 entities as shown in the table 9.

Table-9: Recorded entities arrival and inter-arrival time/time between arrivals

Part number	Arrival time(Sec)	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

Arena 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.

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

The data collected in table 8 is used to decide entity arrival distributions expression using arena input analyzer is as follows.

From the appendix figure 3, 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.

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 8 above using arena input analyzer and the result of each work station/operation service or processing time is illustrated in the table 9 below. Table 9: Input analyzer result of processing time distribution function of each operation on the assembly-line.

Simulation model development

By using the above collected data as input in table 9 for each operation of the assembly line, the existing system model is developed by Arena software as shown in appendix figure 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. 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].

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 10 shows the average output and standard deviation for ten replications of TV assembly lines. Considering the first 10 replications we have the following:

Table-10: 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

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

$$Standard\ error = \left\{t_{1-\frac{\propto}{2},(n-1)}\right\} * \frac{s}{\sqrt{n}} --- (Eq. 1)$$

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 eq. (1). Considering a 95% confidence level the value of t can be read from t probability distribution table.
Hence: $t_{(\text{at } 95\%,9)}=2.262$.

$$Half\ width\ for\ assembly\ line(h_0) = \left\{t_{1-\frac{\propto}{2},(n-1)}\right\} * \frac{s}{\sqrt{n}} = \frac{2.262 * 2.4}{\sqrt{10}} = 1.72$$

Therefore, the percentage error for the assembly line

$$= \frac{(6.5 + 1.72)}{6.5} = 0.01264\%$$

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 then the number of replication for the line became:

$$n \cong z^2_{\left(1-\frac{\propto}{2}\right)} * \frac{s^2}{h^2} --- (Eq. 2)$$

$n = (1.96)^2 * (2.4)^2/(1.7)^2 = 8.64 \approx 9$ replications (assembly line first approx.)
From equation (2), approximate equation is

$$n \cong n_0 * \frac{h_0^2}{h^2} --- (Eq. 3)$$

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

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

Verification of existing simulation model

Verification indicates that the practitioner has included all of the intended components in the model and that the model is actually able to run. Sometimes, model verification confuse with model validation. Verification is the continuous process of insuring that the model operates as intended, whereas 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. 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.

Validation of existing simulation model

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.

RESULTS ANALYSIS

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.

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 11 and simulation of existing manufacturing system has shown in figure 3.5.

Table-11: 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	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%

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 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; 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:

(i) 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.

- There are under capacity utilization (idleness) at different workstations.
- Low production output with respect to the installed capacity.
- 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.
- Large amount of work in process is available at work stations 1 and 7 of the assembly line.
- There are large number of reworks due to ineffectiveness/ luck of operators' skill.

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:

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

Table-12: The performance measurement of the identified bottle neck workstations on the assembly line

S. No	Bottleneck stations	Resource (Manpower)	Scheduled capacity	Capacity utilization	Average Number of busy resources	Added Resources (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			13

Table-13: 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	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 %

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

Table-14: 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 bracket	Fix power board bracket	22	
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 connect to board	93	93
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 serial number	Warranty & manual, remote control register serial number	40	
26	Covering screen cover	Covering screen cover	15	72
27	Put safety bush	Put safety bush	16	
28	Packed by cartoon	Packed by cartoon	41	

Table-15: Performance measured for scnario-2

S. No.	Response parameter	Model-2
1	WIP	64
2	Number of output/production	18
3	Waiting time	781.28
4	Scheduled utilization	Indicated on appendix
5	VA time	1501.59
6	Average Capacity =capacity utilization/installed or scheduled capacity	90/139=64.75%
7	No. of 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%

(ii) Minimizing unscheduled stop (scenario-3)

Table-16: 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-	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.

Table-17: Performance measured for scenario-3

S. No.	Response parameter	Model-3
1	WIP	68
2	Number of output/production	7
3	Waiting time	712.75
4	Scheduled utilization	Indicated on appendix
5	VA time	1519.83
6	Average Capacity =capacity utilization/installed or scheduled capacity	51/139=36.69%
7	No. of Rework	51
8	Total output /total production volume	42
9	Total time	2232.58
10	No. operators	28

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

Combinations of scenarios 1&3

Combining scenarios 1&3 we have the following results:

Table-18: Performance measured for scenario-4

S. No.	Response parameter	Combination of Model 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 %

Appendix

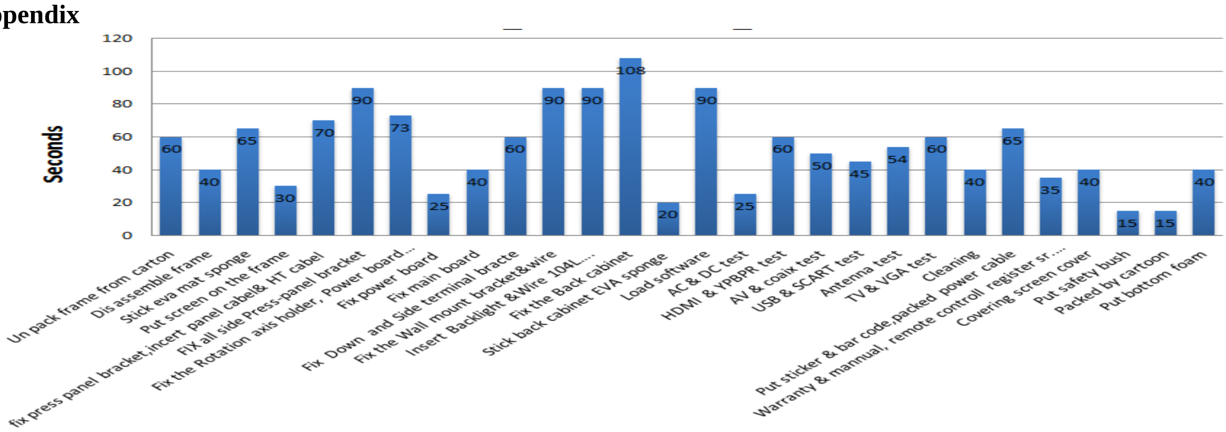

Fig-2: Time utilization at each workstation of current assembly line

Table-19: Daily actual production volume of the TV32" product

Month	Daily actual production volume																									Average
/Date	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

Table-20: 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	42	45	40	41

Table-21: 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	14	15
Packed by cartoon	2	27	40	38	43	36	42	43	43	41	37	39	40	40	41

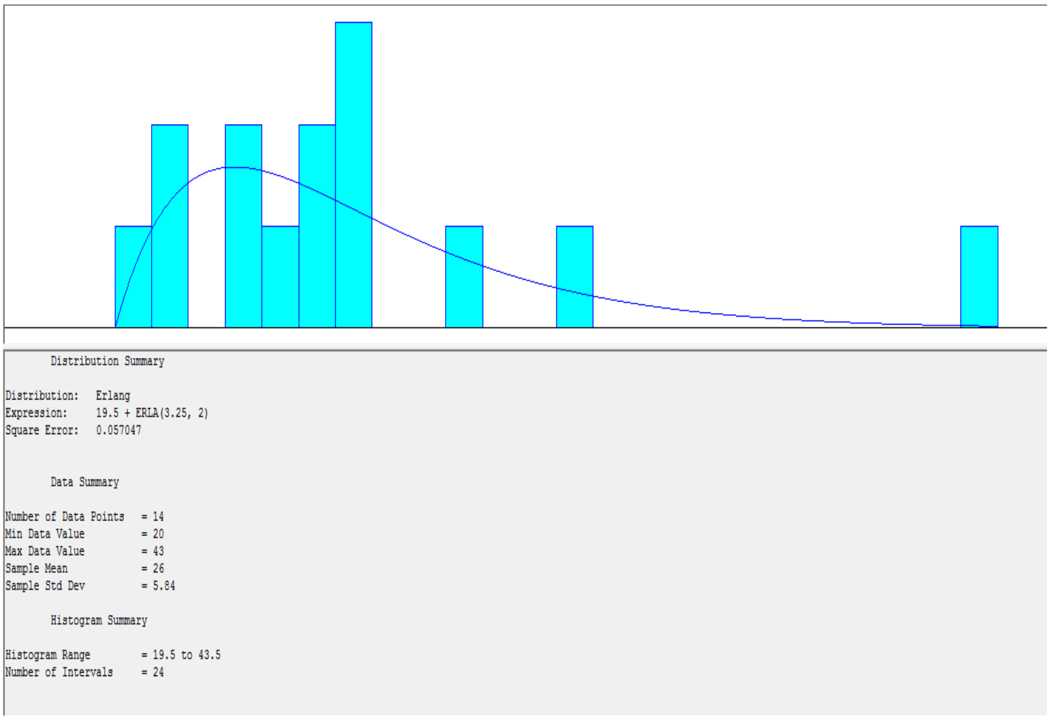

Fig-3: The histogram showing spare part arrival distribution

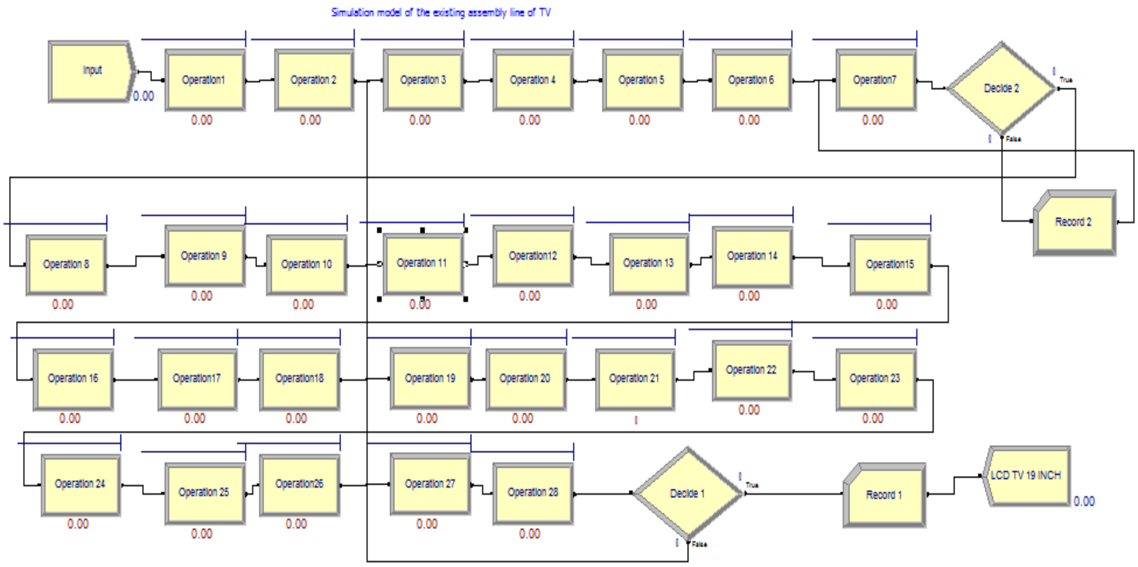

Fig-4: The simulation model of the existing system

Table-12: 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& 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	high	low	low	low	low
	Customer demand	Low	High	moderate	High	Highest
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

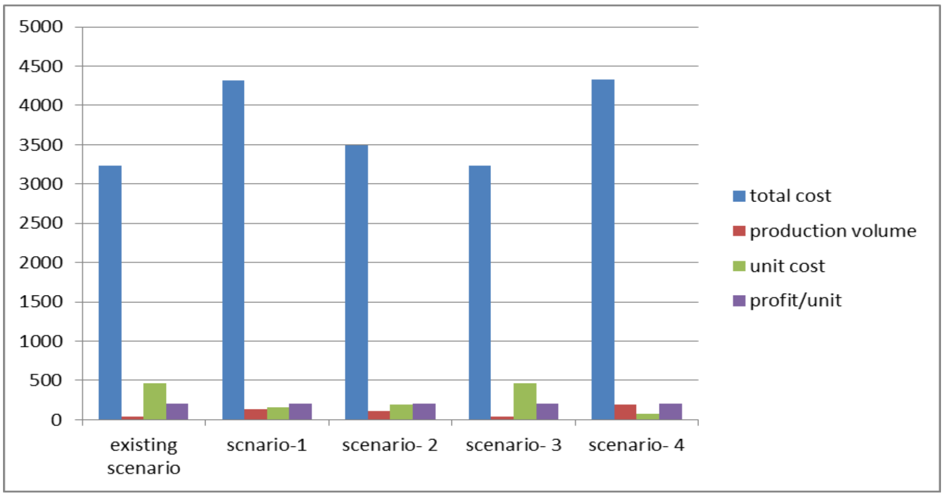

Fig-5: Comparison of different scenarios in terms of different performance indicating parameters

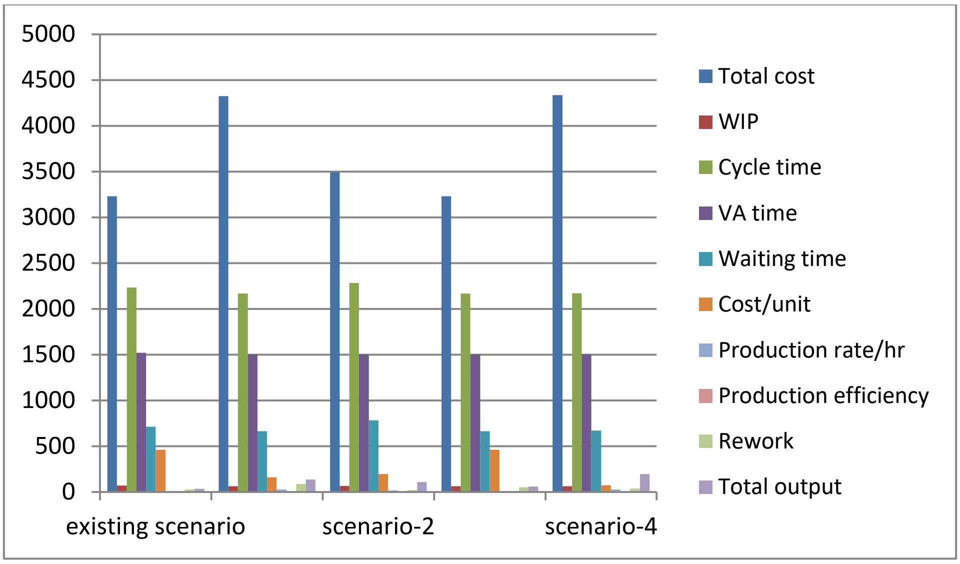

Fig-6: Comparison of different scenarios in terms of cost, profit and production volume

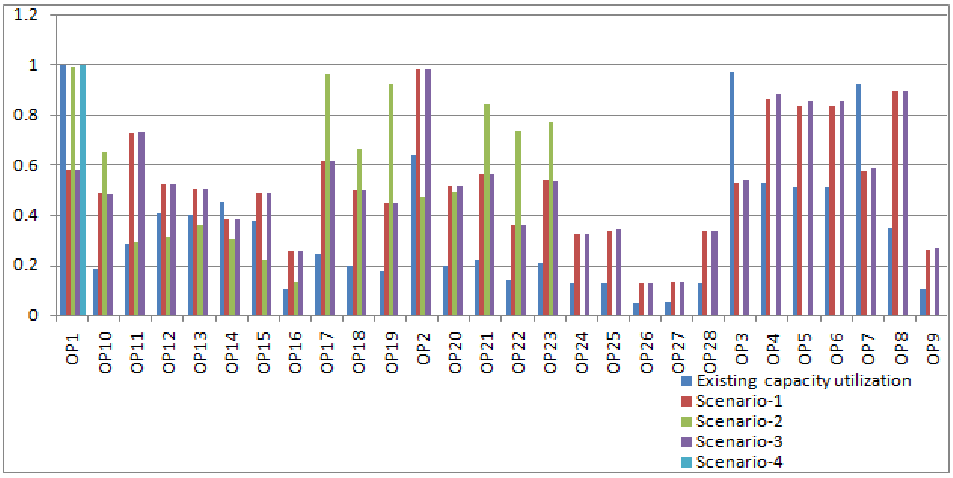

Fig-7: Scheduled capacity utilization of different scenarios

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 %

Comparison of different alternative scenarios' performance results

Appendix table 19 shows comparison of the above scenarios of the production line. Appendix figure 5 shows 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. Appendix figure 6 shows comparison of different scenarios in terms of cost, profit and production volume. Appendix figure 7 shows scheduled capacity utilization of different scenarios.

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.

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.

(i) The output increases from 35 to197 per shift, and
(ii) Profit increase from 35*200=7000 ETB to 197*200=39,400 ETB per shift, if the fourth alternative will be applied.
(iii) 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.

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