Journal of Engineering, Project, and Production Management
2019, 9(2), 132-141

# Comparative Analysis of Analytical and Discrete-Event Simulation Models of Assembly Line Systems

Melkamu Ambelu Biazen[1] and Sisay Geremew Gebeyehu[2]
[1]Lecturer, School of Mechanical and Industrial Engineering, Dire Dawa Institute of Technology, Dire Dawa University, Ethiopia. E-mail: melkamu231@gmail.com
[2]Assistant Professor, Faculty of Mechanical and Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia. E-mail: sisayg78@gmail.com (corresponding author).

Production Management
Received December 11, 2018; received revisions May 22, 2019; May 28, 2019; accepted June 23, 2019
Available online July 14, 2019

**Abstract:** System-wide performance analysis of manufacturing setup helps a company to stay competitive. This can be done by selecting appropriate performance analysis tool which can save time and effort. As a problem assembly line systems are difficult to completely model and analyze using either of analytical or discrete-event simulation (DES) models. The main objective of this study is to analyze the distinct modeling capabilities of analytical modeling approach and DES approach so as to take their respective primacy for analysis of particular pertinent parameters suitable for Tana Communication (TC assembly line). Both analytical and discrete-event simulation models are developed for TC production process using decomposition approach and AnyLogic software. The results from the two models for work in process, queue cycle time, cycle time and resource utilization have high degree of agreement. By making reassignment of operators from the idle stage to the bottleneck stage the system waiting time and work in process is reduced by 12% and 13% respectively from the proposed model.

**Keywords:** Analytical model, discrete-event simulation, modeling, pertinent parameters.



DOI 10.2478/jeppm-2019-0015

## 1. Introduction

As it is mentioned by Ingemansson and Bolmsjo (2004), manufacturing industry, which many other business rely on, is the pivot for a country's economy, especially for those countries in a stage of transformation like Ethiopia. Since all other sectors of a country's economy rely on manufacturing outputs, without competitive manufacturing companies, the sustainable development of the country can be put in question. Among these manufacturing systems, assembly line manufacturing system is one of the most important concerned system to be studied as a discrete type manufacturing system. Improving a system-wide efficiency and effectiveness of these manufacturing set up helps a company to stay competitive. This can be done by selecting appropriate performance analysis tool which can save time and money. Among them, the most important way to scientifically study the behavior of assembly line systems is modeling. Modeling is representation of a real system in another medium, usually in a simplified form. The typical types of modeling approaches that are used for modeling of discrete manufacturing systems or assembly line systems are:-physical, analytical and simulation models. Physical model is a smaller or a larger copy of an object. It is helpful for visualization of an object. An analytical model is a mathematical expression of a system to understand the behavior of the system and also to examine the pertinent parameter relationships. Whereas simulation is the process of examining the behavior for the simplified system by taking its characteristics in conjunction with its make up. On the other hand, Discrete-Event Simulation (DES) by definition is an operation, or technique, that studies events that change at separate and countable points in time, within some type of system. Based on the above premises in respect to understand the behaviors of the system, analytical and simulation modeling approaches are the most powerful tool in modeling of the assembly line manufacturing system as compared to physical modeling approach.

Analytical and simulation modeling in a combined way to help the behavior of manufacturing system in an optimum cost, time and effort. This study targets on taking advantages of DES and analytical modeling approaches since physical modeling approach has less to do with studying the behavior of assembly line system. As it is stated earlier, analytical modeling approach is the cornerstone to modeling and analysis of manufacturing and production systems due to its ability to quickly evaluate potential alternatives (rapid scenario analysis). Pertinent factors must be identified while secondary factors will generally be ignored. On the other hand, DES has the ability to show the real behavior of the system via the model by taking into considerations the events, event lists, state variables, parameters, and their interaction in real terms. In both cases, one lacks the strength of the other; hence, this study has been initiated to devise an improved assembly line system modeling approach based on the modeling power of these two core modeling approaches.

Since most of Ethiopian manufacturing companies have no good method of doing things, they faced a great challenge when competing in the international market. Most of the previous researches done on modeling of a manufacturing system are either discrete-event simulation or analytical model for a particular system. In reality, however, assembly line systems are difficult to completely model and analyze using only either of these modeling approaches where Tana Communication Private Limited Company (TCPLC) is not different. As like of the other manufacturing companies in Ethiopia, especially as those assembly line industries, the case company has no better way of performance analysis mechanism. During the preliminary observation and visit of the company to identify the existing performance analysis tool within the case company, the company did not yet use any scientific production process modeling tool. Due to this condition, the company couldn't identify its production process (assembly line) pertinent parameters and take any remedial action on the bottleneck of the production process stage. Thus, this study intends to introduce a new and comprehensive assembly line modeling approach which takes the representation power of analytical modeling and experimentation power of DES into consideration for bringing to improve simulation approach for the betterment of TCPLC.

Therefore, the main objective of this study is to analyze the distinct modeling capabilities of analytical modeling and DES approaches so as to take their respective primacy for analysis of particular pertinent parameters suitable for Tana Communication assembly line industries. Specifically it intends to:

- Critically examine the distinct natures or capabilities of analytical modeling and discrete-event simulation modeling;

- Investigate the distinct results from analytical model and discrete-event simulation models;

- Analyze the bottleneck production process stages of TC assembly line by using modeling capability of both analytical and Discrete-Event simulation model;

- Propose suitable modeling approach to analyze particular pertinent parameters.

## 2. Research Methodology

This study uses different approaches by identifying their contribution toward the best achievement of the anticipated results. The relevant data will be collected from flow process manual and production process manual. Data has been also collected using stopwatch to record operational time of each process besides direct observation on site visit to enable the investigator to keep tracking the responses. The method of this study investigates the analytical and discrete-event simulation modeling approach and system behavior representation mechanism of a manufacturing system. Based on the collected data, the manufacturing system is modeled and its pertinent parametric behavior is analyzed and this helps to improve its production system.

### 2.1. Data Collection

For the successful completion of this study, two main types of data sources are used. These are secondary data and primary data sources. Secondary data sources are books, journal articles, magazines, production process manual of TCPLC and recorded videos. In this case, books, journal articles and magazines can be used to get information about the general theoretical aspects and application of the two modeling approaches and recorded video used to getting full information about the discrete-event simulation analysis tool called any logic software. On the other hand, primary data sources include unstructured interview, site observation, and operational time recording using stopwatch was performed. The site observation and operational time recording used to get information about the manufacturing system parameter relationship, production rate, company performance and the causes of ineffectiveness of the company. Site observation and unstructured interview help to analyze production flow and to identify the production stage. The recorded data from the production manual is designed to provide background information about the case company regarding to the previous production capacity, its effectiveness, utilization rate and its production parameter relationship representation mechanism. In addition to this, the following types of data element are obtained from the site observation and direct recording during operation.

### 2.2. Case Company

Tana Communication is the only mobile phone producing company in Bahir Dar city. Tana Communication PLC was established in 2008 with initial capital of birr 100 million to enhance comprehensive national economic development. It produces different types of products as shown in Fig. 1.

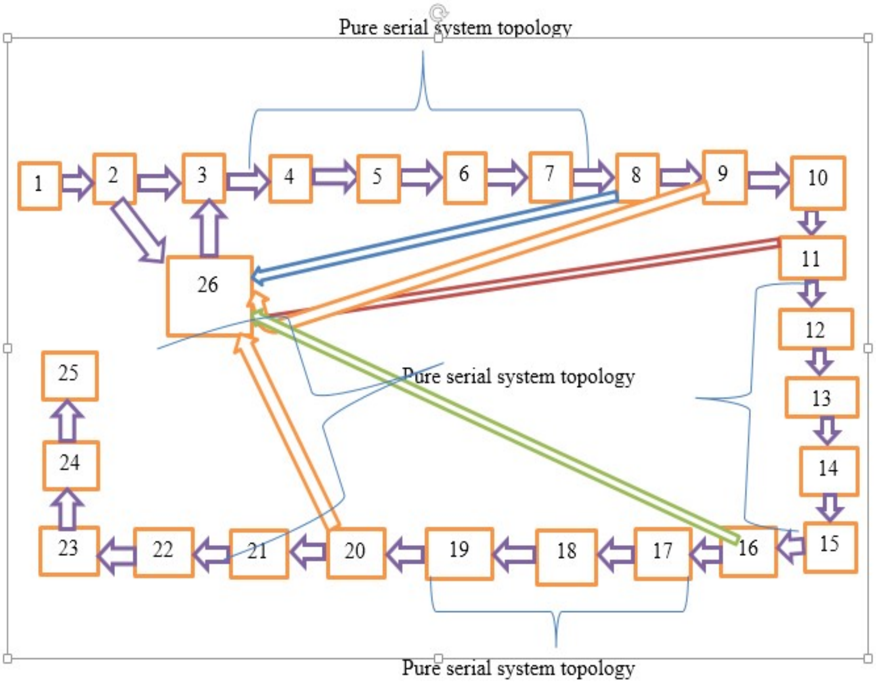


**Fig. 1.** Case company production process and its system

For ease understanding the numbers within the box in the above figure represents each subsequent workstations of the factory and their symbolic representation is expressed as follows.

1 = Raw Material Storage

2 = Inspect and Stick Water Proof

3 = Soldering Speaker

4 = Soldering Microphone

5 = Build in Speaker Bracket

6 = Assemble Middle Cover

7 = Front and Back Cover Assemble

8 = Pre-Function Test

9 = Checking Network Strength

10 = IMEI Loading

11 = Final Function Test

12 = Folding Gift box and input user manual

13 = Testing Travel charger

14 = Scanning, printing, painting the level of gift box

15 = Placing charger and earphone in the gift box

16 = Final appearance check

17 = Fix front and back cover with screws

18 = Attach CAM lens and CAM lens film

19 = Attach fraud prevention

20 = Check IMEI

21 = Install Phone in PE bag and put in the gift box

22 = Product Packaging cartoon preparation

23 = Closing packaging box

24 = Final Product Quality Control Unit

25 = Final Product Storage

26 = Line Maintenance

### 2.3. Types of Data Required

**Raw (effective) process time ($t_e$)**: The net (effective) time a system needs to process an item. This is measured by a stopwatch. This data is required to get each operational time of TC's Production process stage. The data is collected for 14 continuous working days within a day shift period due to the difficulty to collect data in other shift period. For each production process stage 60 recorded times were taken and the probabilistic distribution of each production process stage's recorded times is analyzed using arena input analyzer software.

**Throughput ($\partial$)**: The number of items per time-unit leaving the system measured by number. This data is necessary for the validation of the model output with the actual output.

**Flow time ($\varphi$)**: The time it takes for an item to travel through the system. This data is measured by using a stopwatch. The necessity of this data is that to know the conveyor speed and the actual speeds of the server.

### 2.4. Tools and Techniques of the Study

The major tools and techniques used in this study include but not limited to:

**i. AnyLogic software:** this is a multi-method simulation modeling tool. It gains its name called AnyLogic because it supported all the three well known modeling approaches; System dynamics, Discrete-event simulation and Agent based simulation. Hence this software is used for modeling of discrete event modeling approach for this study.

**ii. Mathematical equations:** In order to properly analyze the manufacturing systems of the case company in analytical model, the mathematical equations like little's law and other equations is used for the analysis of the pertinent factors of the manufacturing system. As it is mentioned by (Curry and Feldman, 2011) cycle time and work in process (WIP) are the two vital manufacturing system performance measurement parameters which are the influential factor for the productivity improvement of the company.

**iii. Stopwatch:** is used for the purpose of recording elapsed time for the operation of particular activity in the production process during the operation of the company.

**iv. Arena input analyzer:** is useful for the analysis of the collected raw data which can change each recorded data to fitted distribution.

## 3. Model Development

In this part, first the main concerned products, which their production line is going to be modeled, are mentioned in the model formulation part of this study. These are the products produced during the time interval of data collection for this study. This is due to the need of primary data for this study. As a result of this, it is a good conclusion to select these products. The following data are gathered after the critical (necessary) products are selected:

- Type and number of resources required for the production of each product at each production stage;

- The production process of the selected product is identified;

- After these data are collected the following time measurement is taken place;

- Raw (effective) time of each operation;

- Inter arrival time;

- Transfer times of agents between each station are measured using stop watch.

These raw collected data cannot be used directly for both analytical and simulation approach, rather it is an important approach to change these raw data into useable form.

### 3.1. Analytical Model

Analytical model development for a manufacturing system is performed based on the production route's topology. Hence, as it is shown in the production process of TC, the case company's manufacturing system is characterized by an infinite capacity multi-server workstation with a factory that has both purely serial from some point to another point and a non-serial system topology at some portion of the production process. In addition to this, in the methodology part of this study, it is mentioned that the selected pertinent manufacturing system parameter are cycle time, work in process, utilization and throughput. With regard to this as it is expressed by (Curry and Feldman, 2011) the kingman diffusion approximation extended for a multi-server system is used as an analytical model of this manuacturing system of the branching and merging stream part. Hence the mathematical (analytical) model for the mean queue cycle time and mean cycle time for the branching and merging section of this study is expressed in Eq. (1) and (2).

$$CTq\langle G|G|C\rangle = \left(\frac{C^2a+C^2s}{2}\right) \times \left(\frac{U^{\sqrt{2Ci+2}-1}}{Ci*(1-U)}\right) \times E[Ts(i)] \tag{1}$$

$$CTs = CTq\langle G|G|C\rangle + E[Ts] \tag{2}$$

where:

$2C + 2 = (K+1)^2$;

$L^2 = C_i$;

$C^2_a$ = squared coefficient of arrival stream to each operation;

$u = \lambda E[Ts]/_C$ *is server* Utilization

$E[T_s]$= Random variable denoting service times of operation.

$C^2_s$ = squared coefficient of variation of service time for each workstation.

C = number of servers in each workstation (process).

**λ** = mean arrival rate to the target workstation which is the reciprocal of the mean inter arrival time.

Based on this analytical model, the input parameters for cycle time are squared coefficient of variation of arrival time, squared coefficient variation of service time, workstation utilization, number of server and arrival rate for each station. Consequently, to find the arrival rate and squared coefficient of variation of arrival time for the branching and merging stream part of the production process, the general network model is used. As a result of this, the following mathematical model is helpful to obtain these parameters for the subsequent stations.

$$\lambda i = \gamma i + \sum_{k=1}^{n} (Pki\lambda k) \text{ For i = 1, -----, n...5}$$

where:

**λ**i = mean arrival rate to the target workstation

***γ***i = external source arrival rate to the target workstation

Pki = probability of jobs routed from k workstation to the target workstation i.

This mathematical formula is used to obtain the mean arrival rate for the branching and merging part of the production system. In addition to the arrival rate, squared coefficient variation of arrival process is the crucial input component to obtain cycle time of a workstation. With respect to this, the following analytical formula is taken to compute squared coefficient of variation of arrival process using Eq. (3).

$$C^2a(j) = \frac{\gamma j}{\lambda j}C^2a(0,j) + \sum_{k=1}^{n} \frac{\lambda k Pk,j}{\lambda j}\left[Pk,j(1 - U^2k)C^2a(k) + Pk,jU^2k\left(\frac{C^2s(k)+\sqrt{Ck}-1}{\sqrt{ck}}\right) + 1 - Pk,j\right] \tag{3}$$

where:

$C^2a(j)$ = squared coefficient variation of arrival process at workstation j

Pk,j = Probability of jobs routed from k workstation to the target workstation j.

$C^2s(k)$ = squared coefficient of variation of service process at workstation k.

Ck = number of server at workstation k.

Uk = utilization of workstation k.

Since the production process of the case company is experienced by both purely serial system topology and merging and branching system topology, another analytical model should be developed for a pure serial system topology portion of the production processes of the case company. As it is expressed by (Curry and Feldman, 2011), the mean cycle time and departure process for an infinite capacity workstation with C servers within a factory that has pure serial system topology are given in Eq. (4).

$$CT(i) = \left(\frac{C^2d(i-1)+C^2s(i)}{2}\right) \times \left(\frac{Ui^{\sqrt{2Ci+2}-1}}{Ci(1-ui)}\right) \times (E[Ts(i)]) + E[Ts(i)] \quad (4)$$

$$C^2d(i) = 1 + (1 - U^2i)(C^2d(i-1) - 1) + U^2i\frac{(C^2s(i) - 1)}{\sqrt{Ci}}$$

where:

$C^2d$ = squared coefficient of departure process

CT(i) = workstation cycle time

Ci = Number of server at workstation i.

Work in process (WIP) is another pertinent factor for the analysis of this manufacturing. With regard to this the calculation of this pertinent factor is possible with the aid of the following analytical formula Eq. (5).

$$WIPs = \sum_{i=1}^{n} WIPs = \sum_{i=1}^{n} \frac{CT(i)}{E[Ta(i)]} \quad (5)$$

After the built up of these models, the next step is numerical analysis of the pertinent parameters of the case company's manufacturing system.

### 3.2. Simulation Model

In this work we have used AnyLogic 7.2.0 Personal Learning Edition to simulation the case company existing working operational conditions. It consists of two basic building blocks called elements and agents. The elements define the process to be simulated with its properties. The agent typically represents one of the model's logical sections. This allows decomposing a model into many levels of detail. The elements are grouped under different pallets and these elements describe the dynamic processes in the model. They are considered as the nodes or places through which agents flow or where from agent source or sink is. Agents are a model's building blocks, and it is possible to use them to model all kinds of real-world objects, including organizations, companies, trucks, processing stations, resources, cities, retailers, physical objects, controllers, and so on. The characteristics of each element and agent are explicitly described in the properties view.

Production line of the case company is a purely assembly line. Different components or accessories assemble together to produce the end product. But due to the complexities of the components, considering all components as agent is difficult since analyzing all of the components is bulky as well as not that much necessary for this paper work. Due to the mentionedreasons, mobile phone is taken as agents in the flow diagrams of the discrete event modeling of the case company. In the development of this discrete-event simulation modeling of the case company TC, Process Modeling Library elements such as source, sink, Delay, Queue, Select Output, Conveyor, resource Pool, Seize, Release, Services, Time Measure Start, Time Measure End ETC are as shown in Fig. 2.

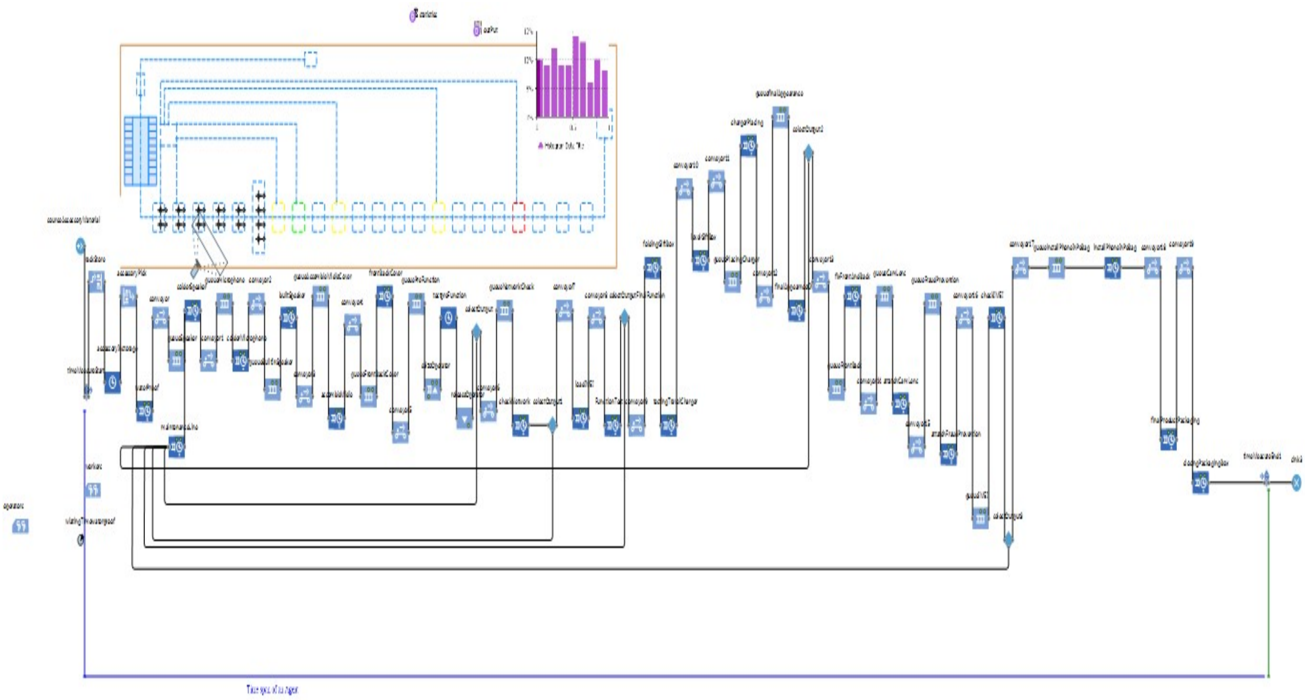

**Fig. 2.** Discrete-event simulation model of TC production process using AnyLogic software

### 3.3. Summarized Factory Performance

Using the above developed analytical model and equations, the following summarized result is obtained for each production process of the case company. In the subsequent table arrival rate and service time characteristics, and some performance measurement values are revealed respectively. Getting these results help to understand and identify which stations are more critical and need special consideration to improve the company's productivity. It can be easily understood that the highest delay time and work in process is observed at attach fraud prevention workstation, i.e. 378 cycle time in queue and 398 seconds total cycle time as well as 23 work in process.

Consequently this station is the bottlenecks of the case company production process. Then special attention is goes to this station and the delay reduction on this station can significantly reduce the whole delay time. In general term improving the performance of this station can improve the performance of the other stations in considerations of improving the whole system.

## 4. Results and Discussion

The modeling capability of both analytical and DES approaches for TC production process are shown in Table 1 and 2. Conferring to these models different results are obtained for the selected performance metrics.

Resources among the performance measurement techniques. Bestowing to this, resources utilization of each production process stage of the case company is analyzed using the two approaches as shown in Table 3. From the results high cycle time is observed at production process stages of line maintenance, attach fraud prevention, pre-function test and front and back cover assemble. Fair results are obtained with less than 5% average error. Also, it is observed that most of the analytically evaluated cycle times are generally higher than the simulation results. The source of error can be traced to several causes including nature of the approximation functions and the effect of re-entrant flows.

From Table 2, it is observed that the analytical results for resource utilization are within 2.65% of simulation result in average, which is within 95% confidence interval. Therefore result is in a high degree of agreement between the two modeling approaches. Though it is within 95% confidence interval, analytical result of resources utilization at production process stage 6 (assemble middle cover) is greatly vary with the simulation result.

From the results high cycle time is observed at production process stages of Line maintenance, Attach Fraud Prevention, Pre-Function Test and Front and Back Cover Assemble. Fair results are obtained with less than 5% average error for both resource utilization and cycle time.

Also, it is observed, most of the analytically evaluated cycle times and resource utilization are generally higher than the simulation results. The source of error can be traced to several causes including the nature of the approximation functions and the effect of reentrant flows.

### 4.1. Tradeoff between Analytical and Discrete-Event Simulation Modeling

Discrete-event simulation models represent the events that could occur as a system operates by a sequence of steps in a computer program. The probabilistic nature of many events, such as processing times, is represented by sampling from a distribution representing the pattern of the occurrence of the event. Thus, to represent the typical behavior of the system (in this case TC production process), it is necessary to run the simulation model for a reasonable time, so that all events was occur reasonable number of times (Vuuren, 2007).

Analytical models described the system (TC production process) using mathematical or symbolic relationships. These relationships are then used to derive a formula in which the performance measures of TC production process stages are evaluated. Further assumptions that modify these relationships then had to be made. The resulting model is then approximate rather than exact, and to validate this approximation, a simulation model is required.

Apart from the results obtained from the two modeling approaches but also the modeling capability, the following table gives summary of the difference between the two types of models.

In addition to this, the value of queue cycle time represented in equation 3 can be valid if the value of the utilization is less than one, otherwise if the value of the utilization is equal to one, the value of the cycle time in queue must be increasing infinitely but in simulation model the value of the queue cycle time is independent of the utilization of the server (production process stage) and increase with a normal fashion which has a specific numerical value of this parameter. In regarding to analysis of server utilization the equation; $\boldsymbol{U = \lambda E[Ts]/C}$ is used to analysis analytically. Where; U=utilization, $\lambda$=arrival stream rate, E[Ts]= service time or operational time and C=number of servers. Based on this analytical equation, the value of server utilization have a probability of being greater than or equal to one where as in simulation analysis the value of server utilization never be greater than one. In actual situations the value of utilization can be greater than one which is called implied utilization. Then in respect to the utilization and workload analysis the analytical modeling approach is better as compared to the simulation modeling approach due to its closeness to the actual situations. On the other hand for the analysis of queue cycle time, cycle time and throughput, simulation modeling is better as compared to analytical modeling. In general for the performance analysis of a manufacturing system, the two modeling approach had indispensable importance.

From the two model results, it can be analyzed the performance of TC assembly line systems. This performance analysis includes bottleneck analysis and throughput analysis. Bottleneck analysis is utilized as the production improvement method. Both Analytical and DES models helped to identify the bottleneck in the system (Ingemansson et al., 2003). As compared to analytical approach, DES approach is better in improving the performance of a manufacturing system due to the following reasons:

- First, easy to see the results of different changes in the model;

- Second, decision has to be taken regarding key figures such as cycle times, utilization, WIP and queue cycle time and

- Third, different production improvement techniques can be tested before they are applied (Ingemansson et al., 2003). In accordance to this, from models result the bottleneck of the system can be identified and the performance impartment mechanism can be proposed by taking some scenario on the DES model.

Engineering practitioners in the “digital generation” often have the opinion that analytical engineering approximations are increasingly irrelevant in the modern digital world. To them modern simulation modeling appear to offer more power and accuracy for less work. However, skipping the analytical methods leads to a loss of fundamental insight, with a guess-and-check approach to model substituting for closed-form solutions. The solution to this challenge in education and manufacturing area is to combine both analytical methods and simulation methods to demonstrate the power and relevance of analytical modeling in a modern modeling context (Diamond, n.d.).

One of the key powers of DES is the ability to model the behavior of a system as time progresses. At the same time that is a disadvantage in that the results can be hard to interpret. There is no built in analysis method to interpret the simulation. The ‘spreadsheet syndrome’ applies to simulations as well. Simulations generate a large volume of numbers and often have a realistic animation, which tends to generate too much confidence in the results. Simulation is not an optimizing technology since it only produces estimates of a model's true characteristics. With sophisticated output data analysis, optimization can be performed (Randell, 2002). DES has been applied to manufacturing for about 40 years. However, for most of that time it has been within the province of a few specialists, remote from, the manufacturing engineers. This is very much the case today as well, although the gap is getting smaller. The difficulty to find engineers who can build models of complex systems easily can act as a barrier to the use of simulation (Randell, 2002). If we come to the Ethiopian case especially to the case company no one have a capability of modeling and analyzing a manufacturing system in different types of DES software. Lack of theoretical knowledge about DES in the industry is probably one of the causes of the low usage. Actually most complex systems with stochastic elements cannot be described precisely by mathematical models nor can they be evaluated analytically. DES is then the only feasible way of analyzing the system at some level of detail. Furthermore, simulation allows studies of a system over a long time period since time is compressed (Randell, 2002). But studying of simple and less complicated system and parameter with DES is time consuming and costly. For relatively simple systems, the selected performance measures can be computed mathematically at great savings in time and expense as compared with the use of a simulation model-but, for realistic models of complex systems, simulation is usually required. Nevertheless, analytically tractable models, although usually requiring many simplifying assumptions, are valuable for rough-cut estimates of system performance. These rough-cut estimates may then be refined by use of a detailed and more realistic simulation model. Simple models are also useful for developing an understanding of the dynamic behavior of queueing systems and the relationships between various performance measures (Banks et al., 2010). Hence to take on the advantage of DES and analytical modeling, combining the two approaches has indispensable importance.

### 4.2. Bottleneck Analysis

Among the different bottleneck analysis method, queue analysis, server utilization and work in process analysis method are used for this paper work. In addition to this, the production process stage criticality is used as other criteria to identify the bottleneck of the TC assembly line. As compared to other production process stages, the waiting time, work in process and utilization are higher on the following production process stages.

- Line maintenance with values of 19, 0.99 and 678 work in process, utilization and waiting time respectively;

- Attach fraud prevention with values of 24, 0.973 and 367 work in process, utilization and waiting time respectively;

- Pre-function test with values of 21, 0.961 and 212 work in process, utilization and waiting time.

Among the identified production process stages of the case company and based on the bottleneck analysis method mentioned above, attach fraud prevention is identified as the bottleneck point.

#### 4.2.1. Bottleneck elimination

For this paper work, bottleneck can be eliminated by reassigning of resource from one station to another station. The resource in this case is human power for the specified production process stage. When human labor is assigned to a new station, he/she may be new to the bottleneck station. But in TC mobile phone assembly line, the operations at each production process stage requires little skill difference. With short on work training, the skill gap of the assigned labor can be full filled. Then no additional cost is incurred to hire workers and reassignment of workers from one station to another station. In doing so; the following proposal can be made:

- One operator is taken from assemble middle cover and reassigned to fraud prevention;

- One operator is taken from final function test and reassigned to pre-function test.

Hence, this bottleneck elimination can be used as the assembly line system performance improvement mechanism. Based on this resource reassignment, the proposed model can be built. From this proposed model, it is obtained that 12% and 13% system waiting time and work in process reduction. With this reduction of work in process and waiting time the productivity improvement can be obtained.

**Table 1.** Arrival rate and service time characteristics of TC production system

| Process | Mean Service Time | Variance | Squared Coefficient of Service time | Mean arrival rates minute | Squared coefficient of arrival | $C^2a(i)$ | Workload | U(i) | $CT_q(i)$ in second | CT(i) in second | WIP(i) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2. | 15.4 | 112.36 | 0.47 | 4.29 | 0.58 | 0.58 | 1.102 | 0.551 | 5 | 20.5 | 2 |
| 3. | 21.7 | 83.72 | 0.18 | 4.373 | 0.55 | 0.772 | 1.582 | 0.791 | 22.3 | 49 | 4 |
| 4. | 15.9 | 22.37 | 0.09 | 4.373 | 0.59 | 0.594 | 1.16 | 0.58 | 5 | 21 | 2 |
| 5. | 20 | 18.84 | 0.05 | 4.373 | 0.53 | 0.53 | 1.46 | 0.73 | 8 | 28 | 3 |
| 6. | 48 | 112.36 | 0.05 | 4.373 | 0.43 | 0.43 | 3.4984 | 0.8746 | 46 | 94 | 7 |
| 7. | 53.05 | 320.41 | 0.11 | 4.373 | 0.57 | 0.566 | 3.866 | 0.97 | 113 | 166 | 13 |
| 8. | 53.63 | 246.5 | 0.09 | 4.373 | 0.55 | 0.552 | 3.909 | 0.98 | 209 | 263 | 20 |
| 9. | 14.90 | 31.02 | 0.14 | 4.154 | 0.52 | 0.52 | 1.89 | 0.945 | 2 | 17 | 2 |
| 10. | 18.6 | 14.21 | 0.04 | 3.851 | 0.53 | 0.53 | 1.1935 | 0.60 | 3 | 22 | 2 |
| 11. | 45.8 | 59.60 | 0.03 | 3.851 | 0.50 | 0.50 | 2.70 | 0.68 | 4 | 50 | 4 |
| 12. | 11.1 | 14.36 | 0.12 | 3.543 | 0.23 | 0.23 | 0.66 | 0.66 | 7 | 18 | 2 |
| 13. | 11.1 | 15.76 | 0.13 | 3.543 | 0.19 | 0.19 | 0.66 | 0.66 | 7 | 18 | 2 |
| 14. | 10.8 | 26.52 | 0.23 | 3.543 | 0.21 | 0.21 | 0.64 | 0.64 | 4 | 16 | 1 |
| 15. | 14.9 | 106.09 | 0.48 | 3.543 | 0. 42 | 0.42 | 0.88 | 0.88 | 37 | 51 | 4 |
| 16. | 25.4 | 84.27 | 0.13 | 3.543 | 0.40 | 0.40 | 0.97 | 0.97 | 6 | 31.00 | 2 |
| 17. | 22.8 | 60.22 | 0.12 | 3.365 | 0.50 | 0.50 | 1.28 | 0.64 | 4 | 27.10 | 2 |
| 18. | 12.8 | 58.37 | 0.36 | 3.365 | 0.37 | 0.37 | 0.72 | 0.72 | 14 | 27 | 2 |
| 19. | 19.2 | 102.01 | 0.28 | 3.365 | 0.28 | 0.28 | 0.98 | 0.98 | 378 | 398 | 23 |
| 20. | 13.4 | 87.24 | 0.49 | 3.365 | 0.4 | 0.4 | 0.75 | 0.75 | 17 | 31 | 2 |
| 21. | 12.6 | 18.32 | 0.12 | 3.11 | 0.44 | 0.44 | 0.65 | 0.65 | 6 | 19 | 2 |
| 22. | 13.8 | 9.67 | 0.09 | 3.11 | 0.18 | 0.18 | 0.72 | 0.72 | 10 | 23 | 2 |
| 23. | 20.1 | 34.57 | 0.05 | 3.11 | 0.22 | 0.22 | 0.96 | 0.96 | 2 | 22 | 2 |
| 24. | 11.8 | 24.52 | 0.22 | 2.43 | 0.21 | 0.21 | 0.63 | 0.63 | 4 | 16 | 5 |
| 26. | 41.3 | 349.69 | 0.21 | 1.44 | 0.44 | 0.44 | 0.99 | 0.99 | 661 | 702 | 18 |

**Table 2.** Utilization and cycle time comparisons from analytical and simulation model

| Process | % of utilization | | | Cycle time in minuets | | |
|---|---|---|---|---|---|---|
| | Analytical | Simulation | Deviations | Analytical | Simulation | Deviation |
| 2 | 0.551 | 0.5650998 | 0.0141 | 36 | 34.25 | 1.7441 |
| 3 | 0.791 | 0.7980235 | 0.00702 | 19 | 21.54 | 2.5415 |
| 4 | 0.58 | 0.5722806 | 0.0077 | 21 | 19.54 | 1.4516 |
| 5 | 0.73 | 0.7418839 | 0.01188 | 28 | 26.75 | 0.75 |
| 6 | 0.8746 | 0.5443437 | 0.3303 | 94 | 92.50 | 1.50983 |
| 7 | 0.97 | 0.9609148 | 0.0091 | 166 | 163.7 | 2.282 |
| 8 | 0.98 | 0.9609071 | 0.0191 | 263 | 263.61 | 0.61462 |
| 9 | 0.945 | 0.9425981 | 0.0024 | 17 | 15.67 | 1.3225 |
| 10 | 0.60 | 0.6134702 | 0.01347 | 22 | 21.04 | 0.951 |
| 11 | 0.68 | 0.6656160 | 0.0144 | 50 | 49.49 | 0.5073 |
| 12 | 0.66 | 0.6648575 | 0.00486 | 18 | 16.54 | 1.4546 |
| 13 | 0.66 | 0.6960605 | 0.03606 | 18 | 19.6 | 1.6 |
| 14 | 0.64 | 0.6630505 | 0.02305 | 16 | 16.6 | 0.6 |
| 15 | 0.88 | 0.8650298 | 0.015 | 51 | 48.99 | 2.9995 |
| 16 | 0.97 | 0.9502034 | 0.0198 | 31.00 | 29.60 | 1.3995 |
| 17 | 0.64 | 0.6565071 | 0.01651 | 27.10 | 29.00 | 1.9 |
| 18 | 0.72 | 0.7204119 | 0.00041 | 27 | 26.86 | 0.1305 |
| 19 | 0.98 | 0.9730794 | 0.0069 | 398 | 395.69 | 0.69 |
| 20 | 0.75 | 0.7412423 | 0.0088 | 31 | 28.06 | 1.061 |
| 21 | 0.65 | 0.6883059 | 0.03831 | 19 | 19.48 | 0.487 |
| 22 | 0.72 | 0.7317488 | 0.01175 | 23 | 21.43 | 1.5675 |
| 23 | 0.96 | 0.9440622 | 0.0159 | 22 | 23.47 | 1.4745 |
| 24 | 0.63 | 0.6367508 | 0.00675 | 16 | 17.45 | 1.4567 |
| 26 | 0.99 | 0.9876024 | 0.0024 | 702 | 714.76 | 12.76 |

**Table 3.** The difference between analytical and DES in modeling capability of a manufacturing system

| Description | Analytical model | Simulation model |
|---|---|---|
| **Model complexity** | limited | unlimited |
| **Run (computational) time** | short | long |
| **Data requirements** | small | large |
| **Model development** | unpredictable | predictable |
| **Flexibility** | low | high |
| **Resource requirements** | low | high |

## 5. Conclusion

In this paper work comparative analysis and Combination of analytical and discrete-event simulation models of manufacturing systems has been used. The analytical model is developed using general queuing model and the discrete-event simulation model development is performed using AnyLogic software. The pertinent performance measurement parameters selected for a comparison are work in process, queue cycle time, cycle time and workstation utilization.

Both analytical and discrete-event simulation models were built for TC production process (assemble process) of mobile phone. Two different results are obtained from the two models for the selected performance measurement parameters. Based on this results, comparative analysis for the two modelling approaches is performed. From the comparative analysis the following results are obtained.

- The results from the two models for work in process, queue cycle time, cycle time and capacity utilization have high degree of agreement. Though discrete-event simulation;

- Model is better in modeling of complex systems; it is not feasible in the analysis of workload, utilization and arrival stream rate. Since its result closes to the reality, analytical approach is better for the analysis of these pertinent parameters;

- Due to the stochastic nature of operational time of the case company's production process, DES approach is better for the analysis of cycle time, queue cycle time and work in process.

In addition to this, analytical model has indispensable role to validate DES model. Hence, for the increment of accuracy in modelling of manufacturing system the combination of analytical and discrete-event simulation model is important. To address this requirement the combined model framework is developed. In general to model an assembly line system accurately the combination of the two modelling approach is the most important thing. As a finding attach fraud prevention is identified as bottleneck point of the system. By making reassignment of operators from the idle stage to the bottleneck stage the system waiting time and work in process is reduced by 12% and 13% respectively.

By selecting an appropraite model from the two modeling approach, the system characterstics can be more expressed. Additionally, it is useful in eliminating of unenecessary time waste in order to analyze the particular parameter for the specified system. Based on the systems complexity and simplicity each modeling approach has its own applicability. As it is expressed in subportion of tradeoff between analytical and discrete-event simulation modeling, for the analysis of server utilization, arrival stream rate and workload of a workstation, analytical model is better as compare to DES analysis. For the analysis of other pertinent parameters such as queue cycle time, cycle time, work in process and throuhput, DES model is better and it can give a realistic output as compared to the approximation approach.

To get simulation results with high accuracy cycle time, queue time, work in process and throughput there must be a checkup mechanism. To validate the accuracy of the performance measures generated from the DES, the results of DES model must be compared with analytical model result. The importance of choosing analytical model comparison is that the developed DES model methods viewed in different approaches and gave similar results assure accuracy of data and model development process. Usually validation is performed by comparing the DES results with actual manufacturing system throughput. But DES model development process after data collection is a time consuming process. Within this elapsed time the manufacturing system may change its behavior dramatically.

Manufacturing companies in nature are dynamic especially in Tana Communication mobile phone assembly line the assembling process stages can be changed even within a month depending on the type of product produced. For example during data collection, let assembling process stages of final function test was positioned at stage 11 and after the model finishes its model development and verification step the mentioned assembling process stages may be positioned at stage 7 or 8 depending on the conditions. In such situation validating DES model results by comparing with actual manufacturing throughput couldn't give a desired result. Since the developed DES model was developed on the past data, the result of DES model and actual manufacturing system throughput automatically different. To full fill this gap another validation mechanism must be installed.

**References**


Ingemansson, A., Ericsson, J., and Bolmsjö, G. (2003). Increasing Performance Efficiency in Manufacturing Systems with Production Improvement Techniques and Discrete-Event Simulation. *17th International Congress of Mechanical Engineering*. Sweden.

Banks, J., Carson, J. S., Nelson, B. L., and Nicol, D. (2010). *Discrete-Event System Simulation*, 5ed. Upper Saddle River, New Jersey: Prentice Hall.

Curry, G. L. and Feldman, R. M. (2011). *Manufacturing Systems Modeling and Analysis*. Heidelberg, Berlin: Springer.

Diamond, S. G. (n.d.). Parametric Engineering Design: Integrating Analytical Methods with CAD and Simulation. Dartmouth.

Ingemansson, A. and Bolmsjö, G. S. (2004). Improved Efficiency with Production Disturbance Reduction in Manufacturing Systems Based on Discrete-Event Simulation. *Journal of Manufacturing Technology Management*, 15 (3) 267-279.

Randell, L. (2002). *On Discrete-Event Simulation and Integration in the Manufacturing System Development Process.* PhD dissertation, Lund University.

Vuuren, M. V. (2007). *Performance Analysis of manufacturing systems: queueing approximations and algorithms.* Eindhoven: Technische Universiteit Eindhoven.


Mr Melkamu Ambelu Biazen received BSc in Industrial Engineering, MSc in Production Engineering and Management. Currently, he is lecturer in Industrial Engineering, Dire Dawa University, Ethiopia. His research interests include system dynamics, process optimization, and production and operations management. Mr. Melkamu is a permanent member of Ethiopian Industrial Engineers Association.

Dr. Sisay Geremew Gebeyehu received BSc in Chemical Engineering, MSc in Mechanical Engineering, and PhD in Industrial Engineering. Currently, he is Assistant Professor in Industrial Engineering, Bahir Dar Institute of Technology, Bahir Dar University, Ethiopia. Dr. Sisay has research interests mainly on cross cutting issues like sustainable development including but not limited to sustainable industrial development, project management, industrial management, quality and productivity, innovation and technology management. Dr. Sisay is a reviewer in the Journal of Engineering, Project, and Production Management (EPPM-Journal).