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The application of Queuing Theory in Solving Automobile Assembly Line Problem

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***Abstract* - The main assembly line problem is the queueing among stations during task achievement which is an obstacle to an effective and efficient assembly line. The main aim of this paper is to carry out queuing analysis to examine an automobile assembly line performance to reduce queuing through harmonizing the tasks in each workstation. The Kendall's notation for the queuing problem is M/M/1: FCFS/∞/∞. It is a single channel multi – server service with infinite system capacity and infinite number of calling population. The arriving and service distribution data for the system were determined. These data were employed to estimate the performance parameter of the system. The results obtained from the analysis are used to predict the efficiency and effectiveness of the system and make logical recommendations on how to improve the system. Based on the results obtained, it can be concluded that if the level of automation is increased, the waiting time of parts will be reduced thereby reducing the cost of waiting.**

Keywords: Assembly Line; Queuing Analysis; Kendall's Notation; M/M/1: FCFS/∞/∞; Multi-Server

1.0 INTRODUCTION

Waiting is a phenomenon found in everyday life like in post offices, banks and filling stations. The waiting phenomenon is not an experience limited to human beings only; jobs wait to be processed on a machine and cars stop at traffic lights. In situations where facilities are limited and cannot satisfy the demand made upon them, bottlenecks occur which manifest as queue. An assembly line is a manufacturing process in which parts are added to a product in a sequential manner using optimally planned logistics to create a finished product in the fastest possible way. It is a flow-oriented production system where the productive units performing the operations, referred to as workstations, are aligned in a serial manner. Assembly lines are mostly designed for a sequential organization of workers, tools or machines and parts. The work pieces visit stations successively as they are moved along the line usually by some kind of transportation system, e.g. a conveyor belt. Assembly lines can be classified into single-model, batch-model and mixed-model lines. In a batch-model assembly system, a few product models are produced in batches, but one product at a time, on the same line and a change over time is allotted to make the line ready for production of another model. A procedure is needed to determine a particular configuration for the products to be produced on the line which will not only minimize the balance delay or number of workstations but also satisfy the other conflicting criteria like production rate, variety, minimum distance moved, division of labor and quality.

The assembly line of the case in point produces five bus models and is basically made up of 15 workstations, which are divided into 3 zones with different supervisors and group leaders. Zone 1 starts from WS 1 to WS 6, zone 2 from WS 7 to WS 11 and zone 3 from WS 12 to WS 15. There is a quality inspection bay at the end of the assembly line, where all vehicles produced on the line are inspected for faults. The fifteen workstations are operated in an asynchronous mode and there are no storage buffers between the stations due to the facility space constraints as well as the firm's policy on minimizing work – in – progress inventory.

The main purpose of applying queuing theory in assembly plant is to model the assembly process in manufacturing plant by using an appropriate analytical model of queuing theory in order to increase the efficiency of each workstation and the overall production system. Certain measures of this model will be derived and can serve as comparison with the standard data available in the company to determine whether the present capacity level in the production line strikes a balance between cost of waiting and cost of providing service. By utilizing queuing model, we can make decisions about the waiting line which lead to better productivity. Engineers have applied results of queuing theory to show how cycle time is related to utilization of machine and statistics of inter – arrival time and service.

2.0 LITERATURE REVIEW

The manufacturing line was first introduced by Henry Ford in the early 1900's. It was designed to be an efficient, highly productive way of manufacturing a particular product. The basic assembly line consists of a set of workstations arranged in a linear fashion, with each station connected by a material handling device. The basic movement of materials through an assembly line begins with a part being fed into the first station at a predetermined feed rate. A station is considered any point on the assembly line in which a task is performed on the apart. These tasks can be performed by machinery, robots, and /or human operators. One the parts enters a station, a task is the performed on the part and the part is fed to the next operation. The time it takes to complete a task at each operation is known as the process time (Sury, 1971). The cycle time of an assembly is predetermined by a desired production rate. This production rate is set so that the desired amount of end product is produced within a certain time period (Baybars, 1986). In order for the assembly line to maintain a certain production rate, the sum of the processing times at each station must not exceed the stations' cycle time (Fonseca et al, 2005). If the sum of the processing times within a station is less than the cycle time, idle time is said to be present at the station (Erel et al, 1998). One of the main issues concerning the development of an assembly line is how to arrange the tasks to be performed. This arrangement may be somewhat subjective, but has to be dictated by implied rules set forth by the production sequence (Kao, 1976).

Queuing theory was developed to provide models to predict behavior of systems that attempt to provide service for randomly arising and not unnaturally demand. The earliest problems studied were those of telephone traffic congestion (Syski, 1986). Mital (2010) carried out queuing analysis to analyze patient load in outpatient and inpatient services to facilitate more realistic resource planning. Queuing analysis reported in his case study provides a basis for estimating medical staff size and number of beds, which are two very important resources for outpatient and inpatient services in a large hospital, and all other hospital resources in one way or another depend on them. As presented by Cooper (2000), Hoover and Bartlett have also applied the results of queuing theory to show how the cycle time is related to large and small production. In large production, cycle time is important to determine the amount of work in progress, and it can be determined by using queuing models. However, their study had limitation which it can be applied only in large production. Their simulation has showed greater fluctuations in cycle time compared to the value predicated by queuing theory.

BASIC ELEMENTS OF A QUEUE

The analysis of queue is based on building a mathematical model representing the process of arrival of item that joins the queue, the rules by which they are allowed into the service, and the time it takes to service. Queuing theory embodies the full scope of such models cover all perceivable systems which incorporate characteristics of a queue. We identify the unit demanding service, whether it is human or otherwise. A basic queuing system has these general elements:

i) Arrival distribution
ii) Service – time distribution
iii) Design of the service facility
iv) Service discipline (FCFS, LCFS, SIRO and service priority)
v) Queue size (finite or infinite)
vi) Calling source (finite or infinite)
vii) Human behavior (jockeying, balking and reneging)

Arrival: Arrival refers to the number of parts that require service within a specific period of time. The pattern of arrivals may be deterministic (e.g. items on a production flow line) or more usually random. Deterministic arrival is the simplest case in which a given time period is known with certainty while random arrivals is probabilistic in nature i.e. any given time period is completely left to chance. Customers can be people, work-in-process inventory, raw materials, incoming digital messages, or any other entities that can be modeled, who are to wait for some process to take place. It may be infinite or finite.

Queue (Service) Discipline: This is the rule applied for selecting parts to be waited on in the queue. It refers to the priority system by which the next customer or parts to receive service is selected from a set of waiting customers or parts. One common queue discipline is first-in-first-out (FIFO) or first-come, first-served (FCFS), last-come, first-served (LCFS), random selection for service (RS) and shortest processing time. (SPT). The simplest arrangement is FIFO (first-in, first-out). There is also LIFO (Last-in, first-out) as in items drawn from stock or redundancies in a workforce.

Service time: Service time could be constant or completely random. An example of a constant service time is an automated system and other mechanical servicing systems while the distribution of service time of a completely random system is exponential with a mean of $\frac{1}{\mu}$. There may be one or many server, who may differ in speed of service. The speed of service at any service point may be constant or random and may vary with time of day. Servers may be in parallel (as in a supermarkets) or in series (as in self-service cafeteria). The system utilization refers to the proportion of time that a server (or system of servers) is busy handling parts.

In principle, queuing theory can predict how systems will operate. Certain important measures of performance (system parameters) such as average waiting time, expected length of queue, average number of customers or parts in system and probability of experiencing delays can be obtained by analytical results (formulae), real world experimentation or by simulation.

Formulation of the queuing model for the problem

The queuing model under study can be represented by the Kendall's notation M/M/1: FCFS/∞/∞.M/M/1: FCFS/∞/∞ is a single channel multi – server service with infinite system capacity and infinite number of calling population of parts. The system has a Poisson arrival distribution, exponential service distribution, first-come, first-served queue discipline.

Assumptions of the Queue model

In most models certain assumptions are used to simplify the modelling process. The following assumptions were made in the model in attempt to model the detail of a real – life scenario which may be too complicated to understand.

1. The system is assumed to be in a steady state.
2. Arrivals at the system are completely random and neither balking nor reneging occurred and that the calling population is infinite.
3. The capacity of the queue is infinite.

4. The queue discipline is first-come, first-served (FCFS) basis by any of the servers. There is no preference classification for any arrival.
5. The mean arrival rate is constant. The rate is independent of the number of parts already serviced, queue length or any other random property of the line.
6. The service providers (workers) are working to their full capacity.
7. Both the arrival and departure rates are state dependent, that is, they depend on the number of parts in the service facility.

3.0 METHODOLOGY

Procedure for conducting the research: The data used for thus study was obtained by the following steps:

1. Select an assembly line to be studied.
2. The data for each workstation were collected and recorded. The data are number of operators, and number of parts that arrive and leaves during part processing.
3. Analyze the arriving and service-time data to determine its variable distribution (Exponential or Poisson distribution).
4. Conduct performance measures of each workstation by using equations based on Queuing theory. The performance measures need to be measured are: utilization factor (ρ), percentage of workstation idle time (P_o), number of parts in system (L_s), number of parts in queue (L_q), waiting time spent in queue (W_q), waiting time spent in system (W_s), and task time.
5. Determine the efficiency of each workstation.

Layout of an automobile assembly line: Groover and Kolchin (1997) stated that the automobile assembly line, car assembly is split between several workstations, all working simultaneously. When one station is finished with its operation, it passes it on to the next workstation.

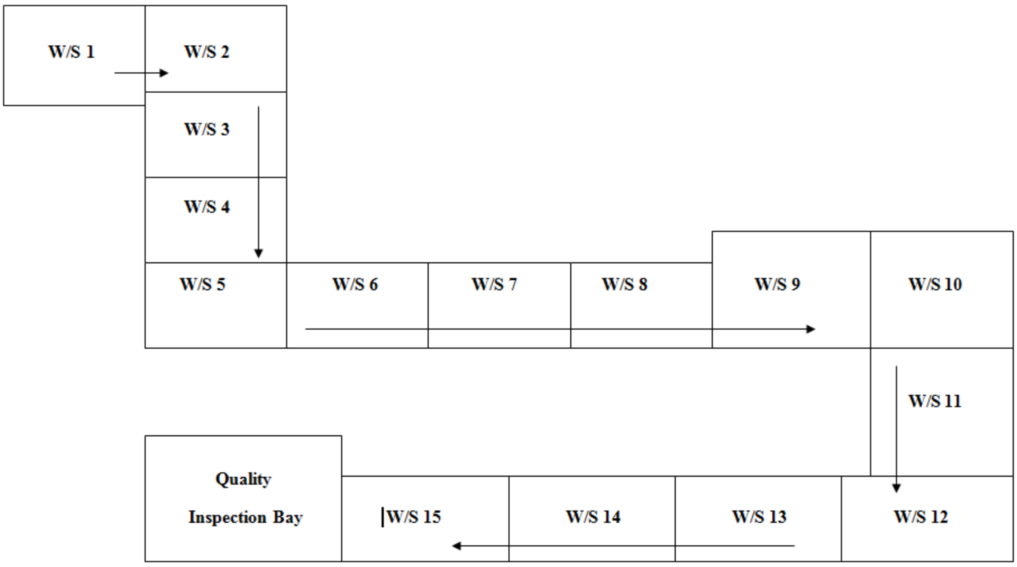

Figure 1: Facility layout of assembly line

Description of the workstation: The table below shows the various workstations in automobile assembly line and the functions performed in each station.

Table 1: Description of the workstation

Workstation	Description of operation
Station 1	Chassis assembly, assembly of suspension legs
Station 2	Peripheral mounting, stabilizer bracket, bogey assembly
Station 3	Fitment of steering box, power steering pipe, brake valves, air tanks and compressor pipe connecting
Station 4	Routing and connection
Station 5	Rear and front spring mounting, tag axle and front axle mounting
Station 6	Assembly of rear axle, fitment of rear axle and prop shaft
Station 7	Assembly of LSV rods and mounting into rear axle, tail light and fuel tank bracket mounting
Station 8	Chassis masking, fitment of speed sensor
Station 9	Chassis painting
Station 10	Drying station
Station 11	Engine subassembly, engine mounting and fitment of exhaust and gearbox
Station 12	Air cleaner assembly, mirrors and mudguard mounting
Station 13	Fitment of fuel tank, tyres and spare wheel
Station 14	Bumper, head light, battery box, trailer loom and mirror
Station 15	Programming, filling of fuel, vehicle inspection (brake roller, mechanical inspection) and start up
Station 16	Vehicle final quality inspection

Work organisation in the plant: Automobile final assembly plants are usually divided into three major departments. These are: body shop, paint shop and trim-chassis-final. The three departments must all be within one building, but the paint shop must be physically separated from the others because of cleanliness, processing and ventilation problems associated with spray-painting technology. In addition, there will be a fourth department called the reprocess shop to fix those cars needing repairs as they exit trim-chassis-final. Storage buffers with substantial capacity will be installed between the body shop and the paint shop and between the paint shop and trim-chassis-final.

In the body shop, thousand spot-welds are made. To begin the assembly, the individual sheet metal parts consisting of the floor pans and side panels are loosely fastened together by human workers. The car body then moves through a series of spot-welding operations, both robotic and manual, to add more parts and permanently assemble the body. After the sheet metal body is completed, it then moves into a temporary storage area that serves as a buffer in case of significant downtime delays in either the body shop or the paint shop that follows. From the temporary storage area, the car bodies move into the paint shop, where a series of processes are performed to paint the car body. The painted car bodies are then transported from the paint shop to another temporary storage area to permit thorough curing and drying of the paint, and to permit proper sequencing of the components that will be added in trim-chassis-final. Cars are produced from customer orders with specific combinations of parts, and the proper parts must arrive at the respective workstations at the same time as the corresponding car bodies. The car bodies then move to the trim-chassis-final department where the remaining parts and subassemblies are assembled into the body. These include the engine and transmission, dashboard, seats, tires, and so on. When all of the trim chassis works have been completed, the cars are ready to be driven off the line. However, in some cases, there are quality problems that must be repaired on the completed automobile. This repair is accomplished in the reprocess department which is located after the end of the line in trim-chassis-final. It consists of a large open area with stalls in which repairs are made on cars that have quality problems or missing components. There is no conveyor line in the reprocess department since even cars needing rework can usually be driven after completion in trim-chassis-final.

4.0 RESULTS AND DISCUSSIONS

The average service time and arrival rate distribution for parts at each workstation were estimated using the stop watch time study technique. Theservice times depend on the variability in materials or parts used to assemble the vehicles as well as the methods. The table below shows a summary of arrival and assembly times for the vehicle under study.

Table 2: Arrival andService time at stations (in minutes)

W/S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Average Service Time	16.9	17.8	17.8	16.4	18.1	19.2	17.2	19.8	17.6	16.9	18.1	17.8	17.1	18.9	18.6	20.0
Arrival Rate/min	11	13	12	10	10	13	11	10	12	10	13	10	11	13	12	14

Mathematical Models Identified

The equations based on queuing theory that is used in this study can be described as follows:

Table 3: Mathematical models

S/N	QUEUE COMPONENT	MATHEMATICAL MODEL
1.	Probability of busy system	$\rho = \frac{\lambda}{M\mu}$ (ρ = traffic intensity)
2.	Percentage of idle workstation	$(1 - \rho) \times 100\%$
3.	Number of parts in system	$L_s = \frac{\lambda}{\mu - \lambda}$
4.	Average waiting time in system	$W_s = \frac{1}{\mu - \lambda}$
5.	Number of parts in queue	$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$
6.	Average waiting time in queue	$W_q = \frac{\lambda}{\mu(\mu - \lambda)}$

Where ρ is the traffic intensity

$\lambda$is the average number of parts arriving in one unit of time

μ is the service rate of parts in one unit of time

L_s is the number of parts in system

L_q is the number of parts in queue

W_q is the waiting time spent in queue

$W_s$is the waiting time spent in system

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Quantitative analysis of the assembly line

There are many factors that affect the dynamic behaviour of work flow in manual assembly systems. The average utilization and the number of tasks per job obviously affect average flow time and work-in-process inventory levels. It is also intuitive, based on elementary queueing theory that the variance of job inter – arrival times and the variance of processing times on individual machines affect flow times. We took into characteristics of waiting lines such as arrival and service patterns, queue discipline and measures of waiting line performance. The case scenario is an infinite source situation, single channel, multi-phase system. The inter-arrival times are considered to be constant and vehicles are assembled on a first-come, first-served basis.

Table 4 shows the arriving and service time distributions collected at each workstation. The utilization factor for each workstation is computed and the idle time in system is determined.

Table 4: Determining the traffic intensity or system utilisation

Workstation	Arrival rate (λ)/min	Mean service rate (μ)/min	Utilization factor ($\frac{\lambda}{\mu}$)
1	11	16.9	0.65
2	13	17.8	0.73
3	12	17.8	0.67
4	10	16.4	0.61
5	10	18.1	0.55
6	13	19.2	0.68
7	11	17.2	0.64
8	10	19.8	0.51
9	12	17.6	0.68
10	10	16.9	0.59
11	13	18.1	0.72
12	10	17.8	0.56
13	11	17.1	0.64
14	13	18.9	0.69
15	12	18.6	0.65
16	14	20.0	0.70

Figure 5 below shows the utilization factor for each workstation. From the graph, it is evident that some workstations are working below capacity. This could be due to the fact that the manpower level or level of automation at such station is low.

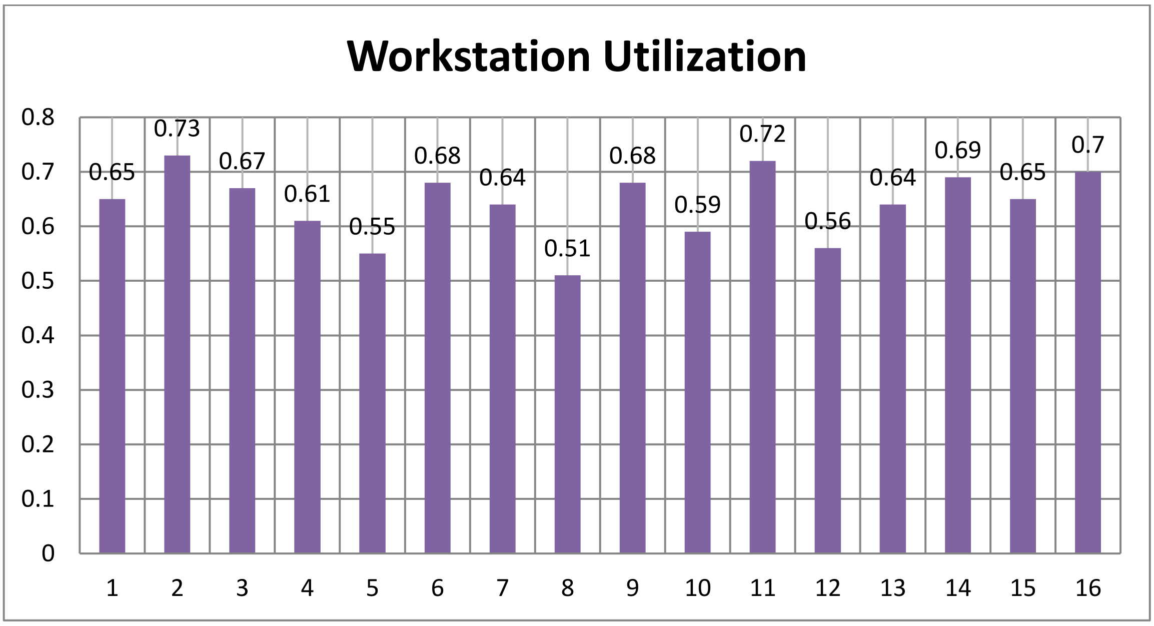

Figure 2: Graph of workstation utilization factor

Manpower Level

The number of workers engaged in productive operations in the assembly line is an important factor to consider when carrying out assessment analysis of an automobile assembly plant. The number of workers is dependent on the level of automation present along the line.

Table 5 shows the current manpower level maintained at each station. The total number of manual workers engaged in the assembly of parts of the automobile are sixty-one workers.

Table 5: Number of manual workers in each station

Workstation	Average number of workers
1	4
2	3
3	4
4	3
5	4
6	3
7	5
8	4
9	4
10	2
11	3
12	4
13	5
14	6
15	3
16	4
TOTAL	61

Output of Assessment Analysis of the problem

The assessment analysis was conducted by calculating the system performance parameter such as idle system, length in system, length in queue, waiting time in system, waiting time in queue and the system's utilization.

At Station 1: λ = 11 parts/min, μ = 16.9 parts/min

(i) Traffic intensity $\rho = \frac{\lambda}{\mu}$

$= \frac{11}{16.9}$

$= 0.65$

(ii) Idle system = 1 - ρ

= 1 – 0.65

= 0.35

(iii) Length in system $L_s = \frac{\lambda}{\mu - \lambda}$

$= \frac{11}{16.9 - 11}$

$= \frac{11}{5.9} = 1.86$

(iv) Length in queue $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$

$= \frac{11^2}{16.9(16.9 - 11)}$

$= \frac{121}{16.9(5.9)} = 1.21$

(v) Waiting time in system $W_s = \frac{1}{\mu - \lambda}$

$= \frac{1}{16.9 - 11}$

$= \frac{1}{5.9} \times 60$ secs = 10.2 secs

(vi) Waiting time in queue $W_q = \frac{\lambda}{\mu(\mu - \lambda)}$

$= \frac{11}{16.9(16.9 - 11)}$

$= \frac{11}{16.9(5.9)} \times 60$ secs = 6.62secs

At Station 2: λ = 13 parts/min, μ = 17.8 parts/min

(i) Traffic intensity $\rho = \frac{\lambda}{\mu}$

$= \frac{13}{17.8}$

$= 0.73$

(ii) Idle system = 1 - ρ

= 1 – 0.73

= 0.27

(iii) Length in system $L_s = \frac{\lambda}{\mu - \lambda}$

$= \frac{13}{17.8 - 13}$

$= \frac{13}{4.8} = 2.71$

(iv) Length in queue $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)}$

$= \frac{13^2}{17.8(17.8 - 13)}$

$= \frac{169}{17.8(4.8)} = 1.98$

(v) Waiting time in system $W_s = \frac{1}{\mu - \lambda}$

$= \frac{1}{17.8 - 13}$

$= \frac{1}{4.8} \times 60$ secs = 12.5secs

(vi) Waiting time in queue $W_q = \frac{\lambda}{\mu(\mu - \lambda)}$

$= \frac{13}{17.8(17.8 - 13)}$

$= \frac{13}{17.8(4.8)} \times 60$ secs = 9.13 secs

The performance parameter for each workstation was computed and summarised in table6.

Table 6: Output of assessment analysis in each station

Station	Arrival rate/min	Mean service rate/min	Traffic Intensity (ρ)	Idle system ($1 - \frac{\lambda}{\mu}$)	Length in system (Ls)	Length in queue (Lq)	Waiting time in system/sec (Ws)	Waiting time in queue/sec (Wq)
1	11	16.9	0.65	0.35	1.86	1.21	10.2	6.62
2	13	17.8	0.73	0.27	2.71	1.98	12.5	9.13
3	12	17.8	0.67	0.33	2.07	1.39	10.3	6.97
4	10	16.4	0.61	0.39	1.56	0.95	9.4	5.72
5	10	18.1	0.55	0.45	1.23	0.68	7.4	4.09
6	13	19.2	0.68	0.32	2.10	1.42	9.7	6.55
7	11	17.2	0.64	0.36	1.77	1.12	9.7	6.19
8	10	19.8	0.51	0.49	1.02	0.52	6.1	3.09
9	12	17.6	0.68	0.32	2.14	1.46	10.7	7.31
10	10	16.9	0.59	0.41	1.45	0.86	8.7	5.15
11	13	18.1	0.72	0.28	2.55	1.83	11.8	8.45
12	10	17.8	0.56	0.44	1.28	0.72	7.7	4.32
13	11	17.1	0.64	0.36	1.80	1.16	9.8	6.33
14	13	18.9	0.69	0.31	2.20	1.51	10.2	6.99
15	12	18.6	0.65	0.35	1.82	1.17	9.1	5.87
16	14	20.0	0.70	0.30	2.33	1.63	10.0	7.00

From the study, it was discovered that the problem of congestion in assembly line is not caused by only inadequate space but majorly by the operational managerial inefficiency. Furthermore, it was also revealed from the study that traffic intensity in the workstation is less than one ($\rho < 1$) which in effect shoes that the current facilities (the level of automation or manpower level) cannot adequately handle the influx of parts arriving the station thereby causing delays.

The result of the analysis revealed that the mean time spent in the station exceeds positive values which indicate that parts have to queue on arrival at the station. Thus, the analysis shows that the probability of having zero part (P_o)in the queue is insignificant because of the present operational inefficiency which shows that queue exist in the system.

5.0 CONCLUSIONS

The study will however be incomplete without some recommendations on the possible means of improving the quality of services to make it effective and efficient. Based on the findings, the queuing problem in an automobile assembly plant can be tackled by the proper implementation of the following recommendations.

- The floor space should be effectively utilized.
- The management should acquire modern and appropriate handling equipment to aid the movement of parts or subassemblies from one workstation to another
- The operations at the plant should be properly designed and automated.
- Increasing the number of human workers and putting in mind the cost implications. The optimum number of workers should be selected for each station such that the

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overall production coast and the assembly time is minimized.

- Motivating and training of staff on the use of modern equipment used in the plant.

It is strongly believed that if all these measures are taken, the queue in assembly line will reduce considerably. It is therefore recommended that the management of the plant should embark on extensive infrastructural development and capacity expansion.

This study is very valuable for the company, because by knowing all information related to the performance of its assembly line, it is more effective and easier for the management of company to plan their production in future.

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