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Investigating the Optimal Service Channels for Effective Operational Machine Performance for Improve Productivity in a Manufacturing Firm

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Abstract:- This study focuses on the impact of waiting time on operational machine performance in a manufacturing company. The data was collected from the case study company by observation of production processes. The multiple service centres queue models were used to analyzed the data. The results revealed that, at the painting section, with 2-service centres and 4-service centres compared, the performance outputs were as follows: traffic intensity was 0.8000 (80%) and 0.4000 (40%), respectively; the probability that the 2-service centre and 4-service centre were idle was 0.1111 and 0.1993, respectively; the average length of queue at the two points of painting section were respectively, 1.4221 and 0.7255; the average jobs in the system was 3.0221 and 2.3255, respectively; the average time job spent in queue was 0.1778 and 0.0907, respectively; the average time job spent in the system was 0.3778 and 0.2907, the waiting costs was 479.65 Naira and 369.14 Naira. Similarly, at the drilling section, with 2-service centres and 4-service centres compared, the performance outputs were as follows: traffic intensity 0.8571(85%) and 0.4286 (43%), respectively; the probability that the system was idle was 0.0769 and 0.1769, respectively; average length of queue was 1.5819 and0.8911; average jobs in system 3.2962 and 2.6054; average time job spent in queue 0.0549 and 0.0149; average time job spent in system 0.0286 and 0.0435; and waiting costs 272.38 Naira and 414.29 Naira. Four service channels are proposed at the painting section and maintain the original 2-service centres at the drilling section to improve on productivity.

***Keywords:-** Arrival Time, Operational Machine, Traffic Intensity, Machine Performance,Utilization Factor.*

I. INTRODUCTION

In any manufacturing firm, the operating effectiveness of the entire production system depends considerably on factors such as layout of facilities, flow of raw materials or components, number of products or finished goods (arrival time and rate), treatment time, capacity of the system, etc. Productivity can depend on the nature of the assembly line since poorly conceived arrangement can consequently cause congestion, increase materials handling cost, rise in production cost, and rise in cost of products. Productivity improvement is nowadays the biggest challenge for companies in order to remain competitive in a global market (Iannone & Nenni, 2015). (Lilly, 2012) asserts that, economically, the goal of any well-run manufacturing process is to have the lowest cost of production loss resulting from an inadequate program of activities. When cost of production is minimize, the primary objective of engaging in business will be achieved and the firm will remain relevant in competitive business. Tremendous attempt has been made by managers of industries to take decisive decisions to improve on time saving in production and quality of finished products. The purpose of the efforts is to maximize profit, customers' satisfaction and retention through reduction in cost of production. To achieve this important quantity, several techniques have been initiated and implemented. Manual skilled labours and automatic machines are ways usually applied to reduce work-in-progress believed to be a major obstacle in an assembly line. Therefore, innovation based on modeling, analyzing, designing, and the implementation of new systems is a necessity (Sivaraman & Bharti, 2017). According to Alex (2019), queuing model is an option to help solve this problem. Queuing model is an essential technique for the performance evaluation of such systems. The basic reason of using queuing theory in assembly processes is to model the assembly process (Marsudi & Shafeek, 2013). Queuing theory is basically a collection of mathematical relationships of various queuing systems(Bakari *et al*., 2014). Formula for each model indicates how the related queuing system should perform, under a variety of conditions. The queuing models are very powerful tool for determining how to manage a queuing system in the most effective manner. Queuing theory allows the mathematical analysis of several related processes, including arrivals at the queue, waiting in the queue, and being treated by the servers. It allows the derivation and calculation of several performance measures which can be used to evaluate the performance of the queuing system underinvestigation.

The arrival of raw materials or components and treatments are observed to assume Poisson and exponential distributions. One key factor repeatedly met is queue. Queuing is the most predominant problem face by industries. Every second that an employee spends waiting for another department or workstation and every second that a component spends waiting to be processed is money wasted (Sivaraman & Bharti, 2017). Every second that a

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customer spends waiting to be served or a component waited to be treated translate into lost business and lost revenue. So many researchers had investigated how to reduce queue or to eradicate it completely. Queue at the hospital, bus stop, supermarkets, office of the vice chancellors at various higher institutions are typical examples. The most disturbing aspect is queue of raw materials or components at workstations of an assembly line. If ignore, queue has the tendency to create negative effects on the economy of a nation.

Adeyinka & Kareem (2018) examined an automobile assembly line performance in an attempt to reduce queuing through harmonizing the tasks in each workstation. They adopted the Kendall's notation for queuing problem. This is a single channel multi-server service with infinite system capacity and infinite number calling population. The arriving and service distribution data for the system were determined and used to estimate the performance parameters of the system. Analysis indicated that increase level of automation can reduce waiting time of parts, thereby reduce the cost of waiting. Sheikh *et al.* (2013) studied the efficiency of two queuing models, (M/M/Z/∞: FCFS and M/M/1/∞: FCFS). Also, investigated was the queuing number, the service stations number and the optimal service rate by means of queuing theory and discovered that the optimal values of the queuing model were feasible. Odunukwe (2013) examined the application of queuing models to customers' management in the banking system using United Bank for Africa, Okpara Avenue Branch Enugu, as a case study. The results obtained from the study showed that the arrival pattern follows a Poisson distribution and that the service pattern follows an exponential distribution. The study recommended that the Bank management should increase the number of servers to three so as to help reduce the time customers spend on queue and also reduce cost incurred from waiting.

Bakari *et al.* (2014) studied the activities at Fidelity Bank ATM in an attempt to reduce waiting line by observing arrival and serviced time. They used queuing theory Poisson distribution to assess the utility function of service delivery. Queuing models of different specifications, M/M/1:(∞/FCFS) and M/M/2:(∞/FCFS) were used for analysis and concluded that the system operates under steady-state condition. Febrianta *et al.* (2017) carried out verification of service- related queuing at Outpatient Pharmacy Installation of Pku Muhamadiyah Hospital Bantul From results of analysis queuing system by the queuing method, it was discovered that Pharmacy Outpatient PKU Muhammadiyah Hospital Bantul have pattern of arrival of Poisson distributed patient, time of patient service of Poisson distribution as follows: Lq = 14,27; L = 16.15; Wq = 0.3036; W = 0.3436; Po = 3.09%. Patel and Patel (2017) studied the waiting time and out patient satisfaction at out-patient department the accessibility of various department of hospital. They observed that the mean age of patient attending the out-patient was 30.31±15.65 years and majority of them are female patient (54.07%). Hospital staff (48.89%) was main source of guidance for searching the OPDs for consulting the doctor. 54.07% patient registered 20 min after standing in queue. The mean waiting time was 12.16±2.35 min. 94.07% and 98.52% patients were satisfied with treatment cost and behavior of staff respectively.

Yakubu & Najiro (2014) conducted research on the use of queuing theory to determine optimal level of service on an ATM. Chi-Square goodness fit was performed. It was found that M/M/s queuing model was feasible for application. Farayibi (2016) studied the application of queue theory in the banking system in GTBank and Ecobank Idumota branch, Lagos, Lagos state. He used Multi-Server Queuing Model to analysed the Multi-Server Queuing Model. The performance measures analysis including the waiting and operation costs for the banks. The waiting and operation costs for the banks were computed to determine the optimal service level and observed that traffic intensity was higher in GTbank than in Ecobank. In furtherance, the potential utilization also indicated that Ecobank was far below efficiency compared to GTBank. He asserted that customers in Ecobank spent more time before being served both on queue and in the system than that of GTBank bank. He concluded that queuing theory is relevant to the effective service deliveryof GTBank and Ecobank.

Vaishali & Soundara-Rajan (2017) measured the waiting time taken in transportation, registration, diagnosis, pharmacy and billing in OPD through survey questionnaire and the waiting time was calculated. Results indicated that transportation was inadequate, registration was poor, and delay was experience in billing. However, the patients were satisfied in diagnosis and pharmacydepartments. Sivaraman and Bharti (2017) reported a review of queuing and reliability model for machine interference and repairing. Analysis was by queuing model with Bernoulli vacation schedule. The failure times, repair times and vacation times were assumed to be exponentially distributed. They concluded that the queue theory is adequate to model machine repairing system.Koko *et al.* (2018) studied queuing theory and its application analysis on bus services using singleserver and multiple servers' models, a case of Federal Polytechnic transport system, Kaura Namoda. The traffic intensity, average number of customers in the system, average number of customers in the queue, average time spent in the system, Average time spent in the queue of a single server and multiple servers were found to be 0.9355,14.5, 13.5645,0.25, 0.2339 and 0.4677, 1.1974, 0.2619, 0.0206,0.0045 respectively. The analyzed results indicated that the multiple servers' model is more efficient than single server model as it minimizes these parameters.

II. MATERIALS AND METHODS

The present chapter entails the materials, method of data collection, experimental design and procedure, the statistical tools for analysis, and improvement strategy.

A. Materials

The data for this research was obtained from both primary and secondary sources. The primary source was by direct observations of manufacturing processes of two distinct work stations at the Lawchris Engineering in Port

Harcourt. Jobs or parts that arrived at the service centres, the time spent before treatment, as well as the time spent in treatment were observed. The arrival and servicetime of jobs, at both the painting and drilling sections were observed for a period of 15minutes intervals and recorded. The recorded information provided the data used to evaluate the quantities needed for analysis in this study.

B. Methods

- *Methods of Analysis and Performance Improvement*

In this study, the multiple service servers queuing modeling, which takes (M/M/y): (∞/FCFC) specification was used for data analysis. The recorded information obtained from field survey by observation of production process was used to determine the performance measures of the systemcharacteristics, including the waiting time, service or treatment time, the utilization factor, number of parts arriving, number of parts in the system, number of parts in the queue, The graphical approach was also applied to illustrate the out puts of the investigations and analysis.

The evaluated performance measure was applied in the cost model, especially at the different servers. The costs relating to waiting time and treatment time were compared. The total cost modelwas evaluated based on Farayibi (2016) as expressed in Equation (1).

$$C_T = W_C S_N + S_C y \quad (1)$$

Where, W_C is the waiting cost per unit time for each job, S_N represent the number of jobs in the entire system. S_C and y represent the service or operating cost per unit time for each server and number of servers, respectively and C_T represents the total cost per unit time. Also, the optimal service or service facilities that minimize the total cost, according Sheikh *et al.* (2013) is computed using Equation (2).

$$\mu = \lambda + \left(\frac{W_C \lambda}{S_C}\right)^{0.5} \quad (2)$$

Where, μ is the average service rate, λ average arrival rate, and W_C and S_C are the cost of waiting in queue and cost of service per unit time, respectively. The mean arrival rate was calculated using Equation (3) according to Panneerselvam (2016).

$$\lambda = \frac{\sum_{i=1}^{8} Oe_i}{\sum_{i=1}^{8} X_i} \quad (3)$$

- *Measures of Effectiveness of the System*

The performance measures and traffic intensity of the system were used to determine the effectiveness of the system. The Equations for multi-channel queuing model are important and were obtained according to (Farayibi, 2016; Koko *et al*., 2018; Alex, 2019; Prabakaran & Kumar,2019).

- *Determination of the Probability of the System Idleness*

The chance that there is no queue (that is the system will be idle) was computed as expressed in Equation (4).

$$Pn = \left[\sum_{n=0}^{y=1} \frac{1}{n}\left(\frac{\lambda}{\mu}\right)^n + \frac{y\mu}{y\mu-\lambda}\left(\frac{\lambda}{\mu}\right)^y \frac{1}{y!}\right]^{-1} \quad (4)$$

Where, Pn represent the chance that there is no job in the system untreated, λ and μ are the mean arrival rate of jobs and mean service or treatment rate, respectively, while y stands for the serversor workstations.

- *Traffic Intensity of the System*

The traffic intensity or utilization factor of the system was obtained by the used of Equation (5 and 6).

$$Pw = \frac{1}{y!}\left(\frac{\lambda}{\mu}\right)^y\left(\frac{y\mu}{y\mu-\lambda}\right) \times Pn \quad (5)$$

$$Pr = \frac{\lambda}{y\mu} \quad (6)$$

Where, Pr is the utilization factor.

- *Average Number of Jobs or Parts waiting in the Queue*

The average number of jobs waiting in the queue or queue length was obtained according to Equation (7).

$$N_Q = \{\frac{1}{y-1})\left(\frac{\lambda}{\mu}\right)^y\left(\frac{y\mu}{y\mu-\lambda}\right) \times Pn \quad (7)$$

Where, N_Q is the average number of jobs waiting in the queue.

- *Average Number of Jobs in the System*

Similarly, the average number of jobs or parts in the entire system was obtained by Equation (8).

$$S_N = N_Q + \frac{\lambda}{\mu} \quad (8)$$

Where, S_N represent average number of jobs in the system.

- *Average Waiting Time of a job in Queue*

The average waiting time of a job in queue was obtained using Equation (9).

$$Wq = \{\frac{1}{(y-1)!}\right)\left(\frac{\lambda}{\mu}\right)^y\left(\frac{y\mu}{y\mu-\lambda}\right) Pn = \frac{N_Q}{\lambda} \quad (9)$$

Where, Wq is the average waiting time of a job in queue.

- *Average waiting Time job Spent in the System*

Equation (10) was applied to evaluate the average waiting time that a job spent in the system.

$$W_S = W_q + \frac{1}{\mu} \quad (10)$$

Where, W_S is the average waiting time that a job spent in the system.

III. RESULTS AND DISCUSSION

The raw data of arrival and service time was obtained from the survey of the painting workstationand the drilling workstation of the case study company. The arrival and service time of jobs, at both the painting and drilling sections were observed and recorded. The information provided thedata used to evaluate the quantities needed for analysis in this study.

- *Determination of Arrival Rate of Jobs at the Painting Section*

From the direct observation of arrival of jobs or parts at the painting section and the associated frequency is presented in Figure 1.

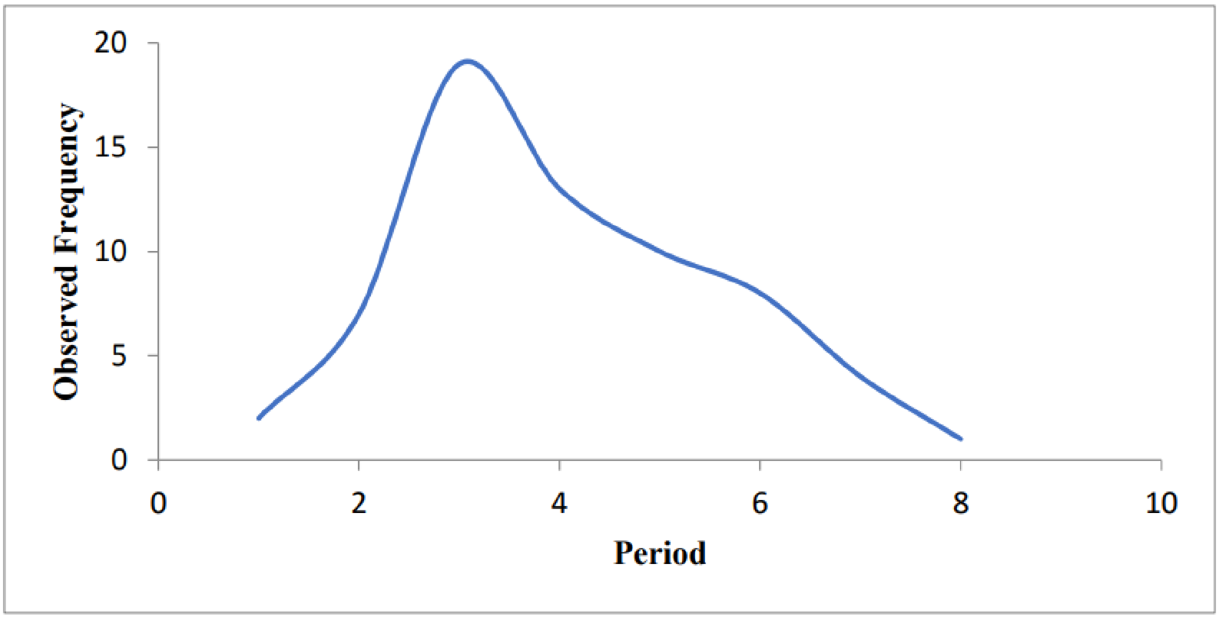

Fig 1 Observed Frequency and Period

From Figure 1, it was found that the frequency of arrival of jobs at the painting section assumed shape of Poisson distribution. In this distribution, the observed frequencies increase up to a point then later decreases. The mean arrival rate of jobs at the painting workstation was computed fromthe available data and was found to be 8 jobs per hour.

- *Analysis of Performance Measures for the Painting Workstation*

The performance measures of multiple channels (y) queuing system with mean arrival rate (λ) of 8 jobs per hour and service rate (μ) of 5 jobs per hour has been evaluated using Microsoft Office Excel, version 2007. The results of the performance measures, based on field data conducted at the painting section of the company for different channels is presented in Table 1.

Table 1 Performance Measures of Queuing System at the Painting Section

Queue parameter	**y2**	**y3**	**y4**	**y5**
P	0.8000	0.5333	0.4000	0.3200
Pn	0.1111	0.1872	0.1993	0.2014
Pw	0.7100	0.2738	0.1814	0.0259
NQ	1.4221	0.8216	0.7255	0.7764
SN	3.0221	2.4216	2.3255	2.3764
Wq	0.1778	0.1027	0.0907	0.0971
Ws	0.3778	0.3027	0.2907	0.2971
Service cost, SC (₦)	792.92	1189.38	1585.84	1982.30
Waiting cost,WC (₦)	479.75	384.38	369.14	377.27
Total cost, CT (₦)	1272.67	1573.76	1954.98	2359.57

From Table 1, results obtained for an M/M/5:∞/FCFC indicates that the average number of jobs in the system was 2.3764; the average length of queue was 0.7764; the average time a job spent in the system was 0.2971; and the average time a job spent in queue was 0.0971. At the same server 5, the chance that the system was idle was found to be 0.2014; the chance that all servers were busy (utility factor) was 0.0259, while the traffic intensity was 0.3200. In a further analysis conducted, the waiting and service costs were found to be 377.27 Naira and 1982.30 Naira, respectively. For an M/M/4:∞/FCFC also observed, results showed that the average number of jobs in the system was 2.3255; the average length of queue was 0.7255; the average time a job spent in the system was 0.2907; and the average time a job spent in queue was 0.0907. Also, at the same server 4, it was observed that the chance that the system was idle was 0.1993; the chance that all servers were busy (utility factor) was 0.1814, while the traffic intensity was 0.4000. Similarly, it was further observed from analysis of an M/M/3:∞/FCFC that the average number of jobs in the system was 2.4216, the average length of queue was 0.8215; the average time a job spends in the system was 0.3027; and the average time a job spends in the queue was 0.1027. At the same server 3, it was also observed that the chance that the system was idle was 0.1872; the chance that all servers were busy (utilization factor) was 0.2738, while the traffic intensity was 0.5333. The waiting and service costs were found to be 384.38 and 1189.38 respectively. More still, analyzed results obtained from M/M/2:∞/FCFC revealed that the average number of jobs in the system was 0.0221, the average length of queue was 0.4221; the average time a job spends in the system was 0.3778; and the average time a job spends in the queue was 0.1778. At the same server 2, it was also found that the probability that the system was idle was 0.1111; the probability that all servers were busy (utilization factor) was 0.7110, while the traffic intensity was 0.8000. Costs analysis also carried out indicates that, the waiting and service costs were 384.38 Naira and 1585.84 Naira, respectively. In term of cost associated with waiting time, the waiting time cost was found to follow a decreases trend, but later increased, (Table 2 and Figure 2). The turning point in Figure 2 may be the optimal number of channels, where minimum cost of waiting occurred. As observed, four channels may be the suitable number of channels expected at the painting section of the case study organization, as against the two channels currently being practice.

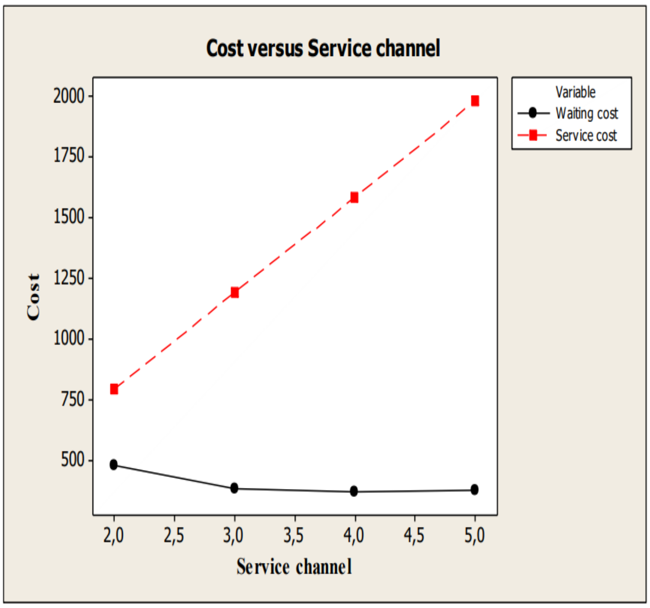

Fig 2 Waiting and Service Costs Versus Service Channel

The M/M/2:∞/FCFC and M/M/4:∞/FCFC were compared based on their queue measures of performance values and presented in Table 2.

Table 2 Comparing Performance Measures of M/M/2:∞/FCFC and M/M/4:∞/FCFC for Painting Workstations

Queue Parameter	M/M/2 :∞/FCFC	M/M/4 :∞/FCFC
P	0.8000	0.4000
Pn	0.1111	0.1993
Pw	0.7100	0.1814
NQ	1.4221	0.7255
SN	3.0221	2.3255
Wq	0.1778	0.0907
Ws	0.3778	0.2907
Service cost, SC (₦)	792.92	1585.84
Waiting cost, WC (₦)	479.75	369.14
Total cost, CT (₦)	1272.67	1954.98

It was observed that increased in the number of channels (painting machines) from two to four decreased the average waiting time of jobs in queue and in system from 0.1778 hour and 0.3778 hour to 0.0907 hour and 0.2907 hour, respectively. This amounted to about 49% decreased in waiting time for both jobs in queue and in the system.

- *Analysis of Queue Performance Measures for the Drilling Section*

The results of the analysis conducted, based on queue model is presented in Table 3.

Table 3 Performance Measures of Queuing System for Drilling Section

Queue parameter	y2	y3	y4	y5
P	0.8571	0.5714	0.4286	0.3429
Pn	0.0769	0.1628	0.1769	0.1795
Pw	0.7910	0.3190	0.1114	0.0337
NQ	1.5819	0.9569	0.8911	1.0111
SN	3.2962	2.6712	2.6054	2.7254
Wq	0.0549	0.0159	0.0149	0.0169
Ws	0.0286	0.0445	0.0435	0.0455
Service cost, SC (ℵ)	792.92	1189.38	1585.84	1982.30
Waiting cost,WC (ℵ)	272.38	423.81	414.29	433.33
Total cost, CT (ℵ)	1065.30	1613.19	1998.13	2415.63

From Table 3, the performance effectiveness at the drilling section of the case study company for an M/M/5:∞/FCFC was found as follows: the average number of jobs in the system was 2.7254; the average length of queue was 1.0111; the average time a job spends in the system was 0.0455; and the average time a job spends in a queue was 0.0169. Also, it was observed that the chance that the system was idle was 0.1795; the chance that all servers were busy (utilization factor) was 0.0337, while the traffic intensity was 0.3429. The waiting cost was found to be ℵ433.33. In a similar analysis, Table (4.4) showed that for an M/M/4:∞/FCFC, the average number of jobs in the system was 2.6054, the average length of queue was 0.8911; the average time a jobspends in the system was 0.0435; and the average time a job spends in the queue was 0.0149. At the same server 4, it was again observed that the chance that the system remained idle was 0.1769; the chance that all servers were busy (utilization factor) was 0.1114, while the traffic intensity was 0.4286. The waiting and service costs were ℵ414.29 and ℵ1585.84 respectively. Further analysed results of M/M/3:∞/FCFC queue model revealed that the following measures of effectiveness were experienced: the average number of jobs in the system was 0.2.6712, the average length of queuewas 0.9569; the average time a job spends in the system was 0.0445; and the average time a job spends in the queue was 0.0159. It was also found that the probability that the system was idle was 0.1628; the probability that all servers were busy (utilization factor) was 0.3190, while the traffic intensity was 0.5714. The waiting and service costs were 423.81 Naira and 1189.38 Naira, respectively. The results of queue performance measures from M/M/2:∞/FCFC indicates that, theaverage number of jobs in the system was 3.2962, the average length of queue was 1.5819; the average time a job spent in the system was 0.0286, and the average time a job spent in the queue was 0.0549. At the same server 2, it was again observed that the chance that the system remainedidle was 0.0769; the chance that all servers were busy (utilization factor) was 0.7910, while the traffic intensity was 0.8571. The waiting and service costs were 272.38 Naira and 792.92 Naira, respectively. The costs and service channels for drilling section is shown in Figure 3. Based on and Table 3 and Figure 3, the M/M/2:∞/FCFC queue model (two channels) with least waiting and service costs has proven to be the optimal.

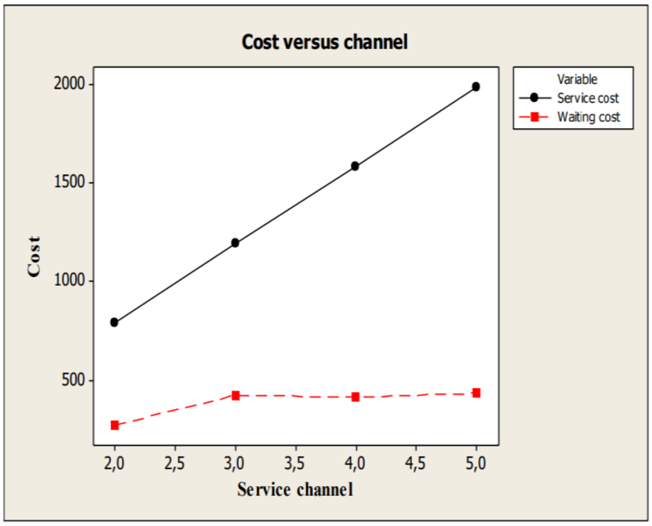

Fig 3 Cost Versus Service Channel for the Drilling Section

IV. CONCLUSION

- The mean arrival rate and treatment rate of jobs at the painting section is 8 per hour and 5 per hour, respectively, while the improved service rate is 9 per hour; At the drilling section, the mean arrival rate and treatment rate of jobs is 60 per hour and 35 per hour, the improve service rate is 64 per hour.
- The least number of jobs in queue is 0.7255 and in the system is 2.3255 at the painting section, while the least number of jobs in queue and in the system are 0.8911 and 2.6054, respectively at the drilling section.
- The utilization of the system is 0.7910 (79%) for 4-servers of the drilling section, whileit is 80% for 2 servers at the painting section
- The minimum cost associated with waiting is 369Naira for 4- servers at the painting section, while the minimum waiting cost for 2-servers is 272Naira at the drilling section.

➢ *Nomenclature*

- y Number of service centre or channels
- SN Average number of parts or jobs waiting in system
  Pr System utilization factor or traffic intensity
- Pn Chance that there are no parts in the system (system is idle)NQ Average number of jobs waiting in the queue

- μ Service rate of parts or jobsλ Arrival rate of parts or jobs
- Wq Average waiting time of parts or jobs in queue
- Ws Average waiting time of parts or jobs in the systemSC Service/ Treatment cost
- WC Waiting cost per unit time for each jobCT Total cost

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