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DEVELOPMENT OF A QUEUEING MODEL FOR COMMUNICATION CONGESTION CONTROL IN THE PRODUCTION INDUSTRY

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Abstract: *A M/M/1 queueing model was developed to control communication congestion in the production industry. The arrival rate of the customers and the link capacity of the system were used as the input parameters to determine congestion state of the system and the mean service rate at which congestion can be avoided. Server utilisation, delay time, probability of blocking and through put of the system were used as the performance measure of the model to determine the optimal point at which congestion can be avoided in a manufacturing system. The model is based on first-come-first-serve service discipline. A computer program using visual basic was developed for quick evaluation and to determine the optimal point and the congestion state of the networks after the series of iteration.*
Key words: *queue model, communication networks, congestion control, manufacturing system, server utilisation.*

Razvoj modela masovnog opsluživanja komunikacija u proizvodnoj industriji. *Razvijen je model M/M/1 za kontrolu opsluživanja komunikacija u proizvodnoj industriji. Stopa dolaska kupaca i kapacitet veze sistema korišćeni su kao ulazni parametri za određivanje stanja zagušenja sistema i srednje brzine servisa na kome se može izbeći zagušenje. Korišćenje servera, vreme kašnjenja, verovatnoća blokiranja i postavljanje sistema korišćeni su kao merilo performansi modela kako bi se odredila optimalna tačka na kojoj se zagušenje može izbeći u proizvodnom sistemu. Model se zasniva na servisnoj disciplini prvog dolaska i prvom servisu. Računarski program koji koristi vizuelni osnov je razvijen za brzo evaluiranje i određivanje optimalne tačke i stanja zagušenja mreža nakon serije iteracije.*
Ključne reči: *model masovnog opsluživanja, komunikacione mreže, kontrola zagušenja, proizvodni sistem, korišćenje servera.*

1. INTRODUCTION

Production industry is faced with diverse problems which, in most cases led to reduction in productivity, and ineffectiveness of the industry. One of the problems is the communication congestion. This work is aimed at controlling the communication congestion in the production industry. Communication industry was used as an example of production industry for this study. The outcomes of the study are also applicable to other production industries where waiting line single queue and single sever problems can be encountered. A queue model was developed and a computer program was written for the developed model. The model was validated with data obtained from the manufacturing industry.

Meanwhile, the 1970’s revolution in the world of communication gave room to more subscribers in the communication [1], which led to diverse problems in which congestion is one of them. Queue model as a mathematical model is a process of approximation used in the analysis of heavy traffic [2]. It was used for modelling high speed dynamic material flow in palletizing process [3]. Queue models have played a major note in solving problems in the manufacturing industry and for prompt decision making. M/M/1 queuing model was used to recognize appropriate congestion cost by linking marketing and production decision variable[4]. The benefits of production/service capacity sharing for a set of independent firms using queuing system with service rate to minimise delay cost and capacity investment cost in the production system cannot be overemphasized [5]. Queueing model was also applied for performance evaluation analysis in multi-production, multi-echelon manufacturing supply chain network with batch ordering, to determine optimal inventory cost [6].

The importance of queue model is to create value in the polling models where one or more servers provide services to several queues in a cyclic manner [7]. Also, it is relevant in vacation model where machine breakdown, service disruption, cyclic servers’ queues and scheduled job streams are involved. Queuing discipline is of great value for congestion control in the stream network (i.e. wide Area Virtual-circuit data network [8].

Communication congestion occurs when the network or part of a network is overload and has insufficient communication resources for the volume of traffic [9]. In communication network it occurs when the number of packets sent to the network is greater than the number of packets the network can handle [10]. Congestion control is the problem of managing network traffic to avoid overwhelming the network [11]. Congestion handling control in communication network is divided into congestion recovery [11] and congestion avoidance [12]. For the the purpose of this work congestion avoidance was adopted. Congestion control in computer network involves various strategies such as pre-allocation of buffers or servers packet discarding isarithnic congestion control, flow control and choke packets [13-17]. The queue model development followed the mechanism of flow control for congestion control in the production industry. Other studies [18-22] did not consider change in buffer sizes and probability of blocking, among other performance measures in order to determine mean service rate to prevent congestion which are included in this study.

2. METHODOLOGY

The queue model was developed by putting critical parameters, namely; arrival rate, number of buffer, buffer size (the mean service rate of the buffer) and the capacity of the link into consideration. The model is probabilistic and exponentially distributed because the message transmission or customer arrival varies exponentially with time. The arrival rate is Poison distributed and there is constant propagation delay between transmitting and receiving stations. The model is infinite, i.e. number of customers varies with time. It is a single server and single queue model (i.e M/M/1). The queue model is based on FCFS (First-Come-First-Server) service discipline and the mean service rate is assumed to be equal to the size of the buffer. The modeled sample consists of six modes (A, B, C, D, E and F) with 8 links (AB, BC, CD, AE, EF, FD, BF, and EC) as shown in Fig. 1. The network system model was chosen to enable output comparison with the result of [10]. The model is represented by Fig. 2. It consists of Input (waiting customer or message), Buffer (service facility support, that any customer/message that cannot be accommodated return to the queue), Server (that serves the message/customer that can be accommodated by the available facility), and the output (message/customer delivered or serviced).

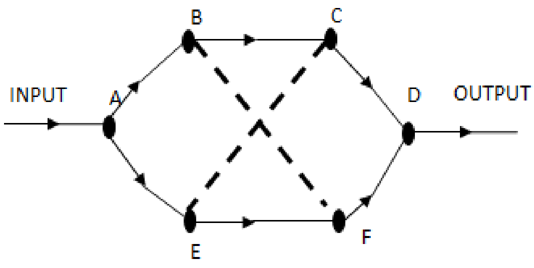


Fig. 1. Network system

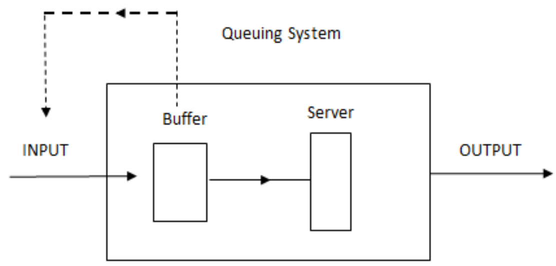


Fig. 2. Model representation

The average time delay in the queue system, probability of blocking, server utilization and the throughput of the system are used as the performance measures for determining the service rate at which the congestion can be encountered. Average time delay of the customer or message in the queue was model as

$$t_i = \frac{1}{\mu C_i - \lambda_i} \quad (1)$$

Where μ = service rate in bit

C_i = capacity of the link in bit per sec

λ_i = Average message rate per secs in the link

The total time delay in the system

$$\frac{1}{\alpha}\sum_{i=1}^{N}\lambda_i t_i \quad (2)$$

Where,

$$\alpha = \lambda = \sum_{i=1}^{N}\lambda_i \quad (3)$$

α, Total arrival in the network

t_i, Average time delay in the link

α , total arrival in the network.

The server utilization or traffic intensity was computed as

$$\rho = \frac{\alpha}{\mu c} \quad (4)$$

The number of customers served per sec (throughput) was estimated as

$$\gamma = \mu\rho \quad (5)$$

The probability of blocking P_B was computed as

$$\frac{(1-\rho)\rho^N}{1-\rho^{N+1}} \quad (6)$$

Where N is the number of buffer in the queue (i,…,N).

Buffer character,

$$I_i = \lambda / \mu_0 \quad (7)$$

Where μ_0 = service rate at the optimal point, T.

The queue model is able to analyze the cost of transmission in the system and the cost of money receiving after the basic requirements have been met. Total cost of transmission [13].

$$W_T = \sum_{i=1}^{N} W_i C_i \quad (8)$$

Where

W_i , cost per unit

C_i , capacity of link in bit per sec

λ_i, traffic load (i.e arrival at the nodes)

The capital cost in the basic system was determined from [13],

$$C_C = \sum_{i=1}^{N} W_i I_i \quad (9)$$

Therefore

$$C_W = \sum_{i=1}^{N}(W_i C_i - W_i I_i) \quad (10)$$

Where, C_W, money remaining after basic requirement.

Also time delay T with respect to the money remaining after the basic requirements are met was computed as,

$$T = \frac{1}{\alpha}\frac{\left(\sum_{i=1}^{i}(W_i I_i)^{\frac{1}{2}}\right)^2}{C_W} \quad (11)$$

3. MODEL IMPLEMENTATION AND VALIDATION

The model was applied on the secondary data obtained from literature [10] and primary data obtained from a Nigerian Communication company. Questionnaire was prepared and administered in the manufacturing industries to get the required data (based on the stated parameters) for the validation of the model. The model was applied to determine the server utilization, throughput, delay time, probability of blocking and the service rate at which communication congestion can occur. A computer program was developed to facilitate rapid application of the model by using Visual Basic (VB) computer programming language. The Visual Basic language was used because of its flexibility, supportive to different types of database and capability of graphic user interface. The program is able to determine the optimal service rate at which the congestion can be avoided in a Network system (production industry) and compute the profit of the industry at this point. The computer programme can generate a database/output table for quick decision making in the industry. The Figs 3 and 4 respectively, show the flow charts for Module one (used for determining the Congestion State of the Queue Model) and Module two (applied for determining the cost of money remaining after basic requirements have been met) in the production system.

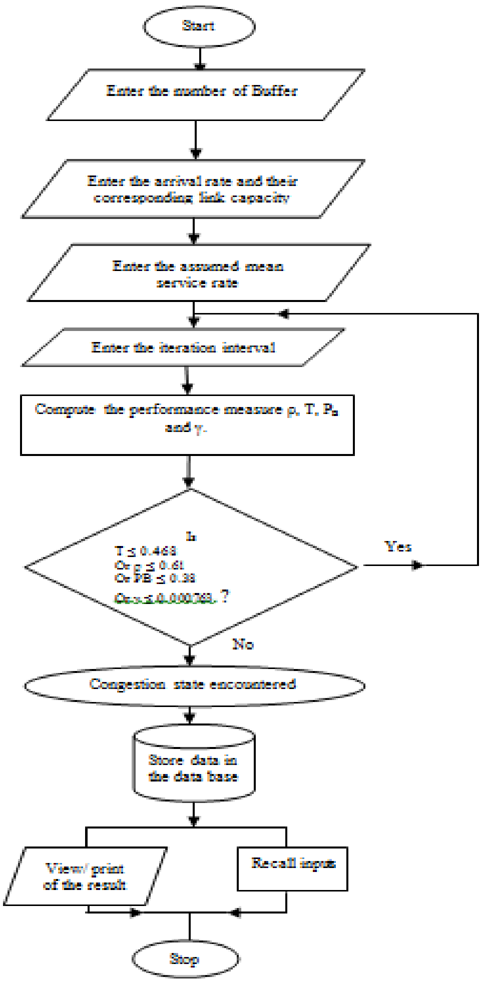


Fig. 3. Flow Chart for Module One.

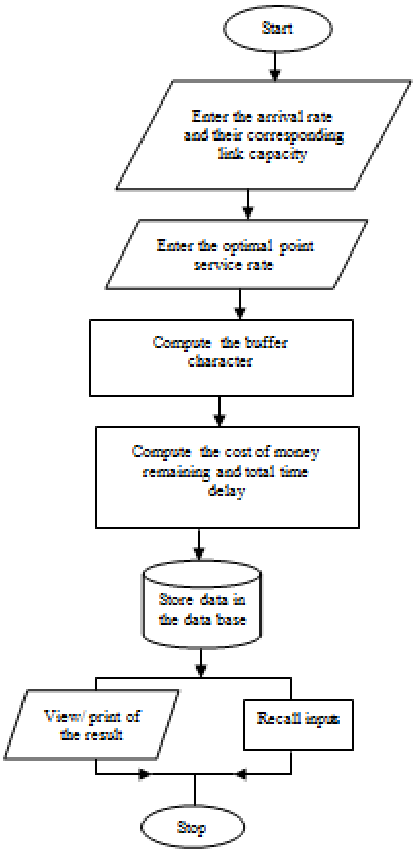


Fig. 4. Flow Chart for Module Two

The algorithms for the model in modules one and two are developed thus;

For module one,

(i) Enter the number of buffer(s) N

(ii) Enter the arrival rate (λ) and their corresponding link capacities C

(iii) Enter the assumed mean service rate μ.

(iv) Enter the iteration interval

(v) Compute the average time delay in each link i.e. $t_i = 1/(\mu C_i - \lambda_i)$
Where, μ = mean service rate, C_i = link capacity, λ_i = arrival rate per link.

(vi) Compute the total time delay of the message in the system
[T = 0], (i=1)
While (i < = N)
T =T +(1/α) * ($\lambda_i t_i$)
N =N+1, end
where, α = λ = total arrival in the network.

(vii) Compute the server utilization i.e. $\rho = \alpha / (\mu C)$
where μ = mean service rate
C = total capacity of the system.

(viii) Compute the throughput of the system i.e. $\gamma = \mu\rho$

(ix) Compute the probability of blocking i.e.P_B = [(1-P) *P^N] /[1-P^(N+1)]
Where N is the number of buffer and ρ is the server utilisation

(x) If $\rho \leq 0.61$? then
Continue the iteration
Else, congestion state is encountered
End if

(xi) If $T \leq 0.468$? then
Continue the iteration
Else, congestion state is encountered

(xii) If $P_B \leq 0.38$? then
Continue the iteration
Else, congestion state is encountered

(xiii) If $\gamma \leq 0.000763$? then
Continue the iteration
Else, congestion state is encountered

(xiv) Store the data in the database

(xv) Recall the input

(xvi) View/print the report

For module two;

(i) Enter the arrival rate (λ) and their corresponding link capacities C

(ii) Enter the optimal point service rate.

(iii) Compute the buffer character per link i.e.
$I = \lambda_i / \mu_O$
λ_i = arrival rate at each node.
μ_0 = minimal point service rate

(iv) Compute the cost of money remaining i.e

$$\sum_{i=1}^{N} (W_i C_i - W_i I_i)$$

Where W_i = cost per unit
C_i = link capacity at each node

(v) Compute the corresponding total time delay at the minimal point

(vi) Store the data in the database

(vii) Recall the input

(viii) View/print the report

Fig. 5 shows the output sample of the program. The task is right click and the modules one and two are displayed. Module one is to determine the service rate at which congestion will occur in a system and the corresponding server utilization, throughput time delay and probability of blocking. Module two is for the cost analysis of the project work to determine the cost of the money remaining at the minimal point and the computed time delay after the basic requirement has been met.

Fig. 5. Program Output sample

Fig. 6 shows output sample for the selection of buffer specification. The number of buffer N must be selected in order to have access to the output sample in Fig. 7. The program cannot accept zero number of buffers for it is impossible for a queue system not to have a queue or buffer.

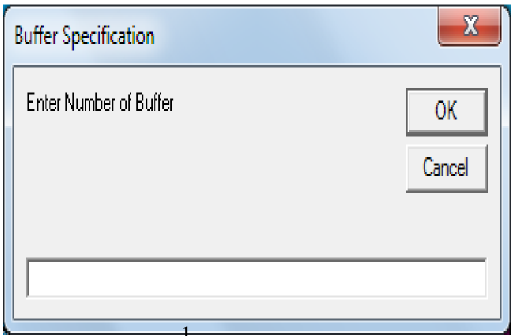


Fig. 6. Output Sample for Buffer Choice

Fig. 7 shows the output sample to determine the minimal point and the mean service rate at which congestion state can be avoided in the queuing system. The arrival rate and the corresponding capacity of each link are used to compute the performance measures (i.e. probability of blocking P_B, server utilization ρ, total time of delay T and throughput, γ) of the system. Assumed mean service rate is selected with an iteration interval ranging from 1 – 10,000 or more depending on the capacity of the system.

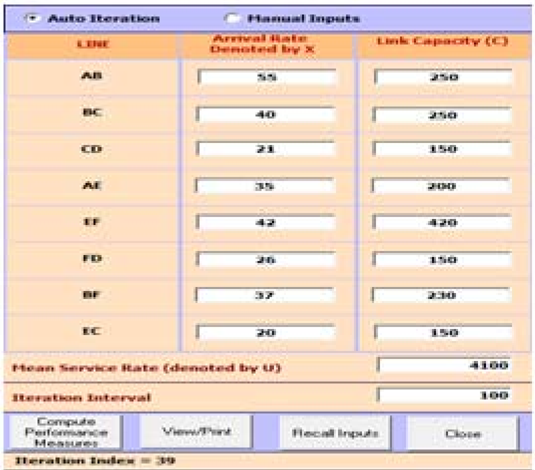
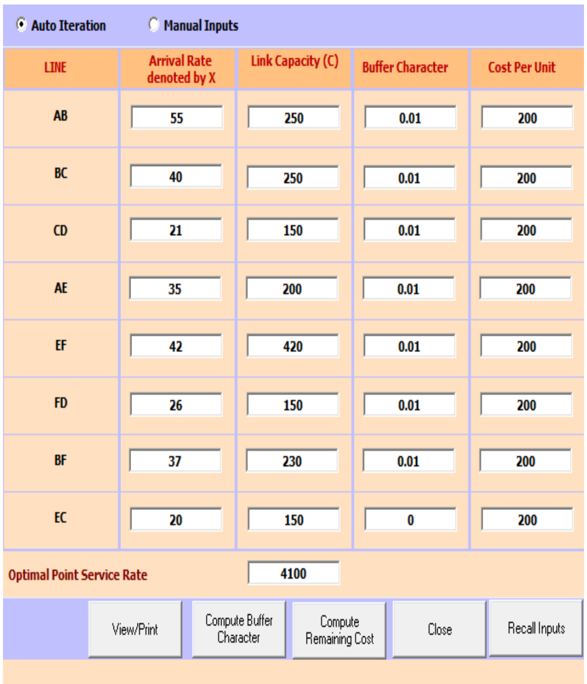


Fig. 7. Output Sample for Congestion State

The iteration interval text is to determine the accurate mean service rate at which congestion state can be encountered. The performance measures are computed with several iterations until the congestion state is encountered. The “view/print command” is to have access to the database result of the program by the decision marker. “Recall inputs command” is to recall the previous data if required by the decision marker. “Close command” is to close the output sample in Fig. 7. Fig. 8 shows the output sample for cost analysis of the queue model. The arrival rate (λ) and their corresponding capacity of the links in the queue network are used with the mean service rate at the minimal point as the input parameter to compute the arriving buffer. The mean service rate at the minimal point is then used to compute the time delay in the system and the balance cost of facility utilisation.



Auto Iteration — Manual Inputs

LINE	Arrival Rate denoted by X	Link Capacity (C)	Buffer Character	Cost Per Unit
AB	55	250	0.01	200
BC	40	250	0.01	200
CD	21	150	0.01	200
AE	35	200	0.01	200
EF	42	420	0.01	200
FD	26	150	0.01	200
BF	37	230	0.01	200
EC	20	150	0	200
Optimal Point Service Rate		4100		

View/Print — Compute Buffer Character — Compute Remaining Cost — Close — Recall Inputs

Fig. 8. Output Sample for Cost Analysis

4. RESULTS AND DISCUSSION

The developed queue model shows that congestion can be controlled within the manufacturing industry with a server utilization of 0.61, time delay of 0.469 ms (i.e. 0.469 secs). Probability of blocking of 0.38 and throughput of 7.63×10^{-4} packet per sec. Fig. 9 shows the graph of time delay in the system against the server utilization. It was observed that the total time delay in the system increases as the server utilization increases before the congestion region. At the optimal point the time delay in the system is 469.1 ms or 0.00469 sec and the server utilization is 0.61. An increase in the time delay with increase in the servers utilization ($0.61 \leq \rho \leq 0.8$) shows the range of congestion state of the system. The sharp drop in the time delay is as a result of the packets or customers being discarded or sent away from the buffer into the customer's population arriving at the buffer.

Considering the result of the developed queue model for communication congestion control it was discovered that congestion occur at the region where server utilization ρ tends to 1. (i.e. $\rho = 1$). Therefore, it is evident that congestion can be controlled in the manufacturing industry by using the model of server utilisation of 0.61, time delay of 469 millisecs, probability of blocking of 0.38 and through put of 7.63 x 10^{-4} packets per secs. Fig. 10 shows the relationship between the probability of blocking and server utilization of the developed queue model for communication congestion control in the production industry. Moreover, it was observed that as the server utilisation ρ tends to 1 the probability of blocking increases. At the server utilisation ρ = 0.61 the probability of blocking in 0.38 when the number of buffer N is equal to 1 with two buffers i.e. N = 2 the probability of block P_B is reduced to 0.19. The probability of blocking reduces as the number of buffer in the queuing system increase. Due to the cost of procuring another buffer (in server) it is preferable to use a single server with the specified server utilization for communication congestion control.

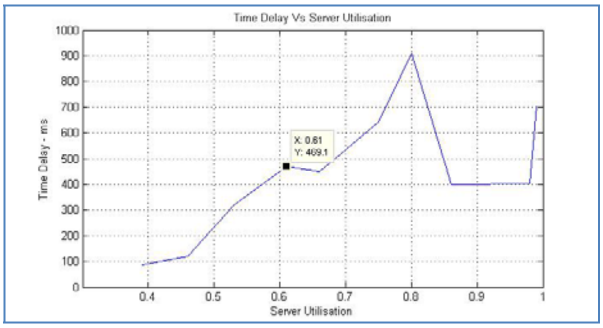


Fig. 9. Time delay and server utilisation

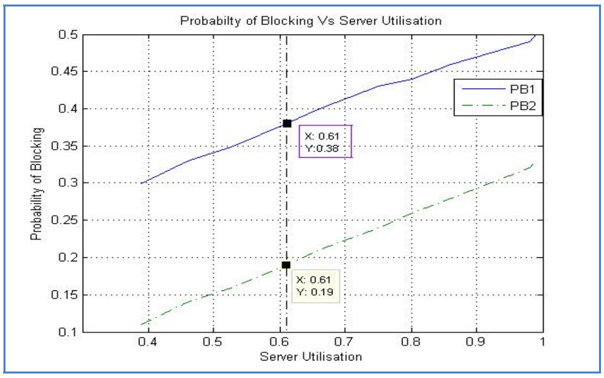


Fig. 10. Probability of blocking and server utilisation

Fig. 11 shows the relationship between the throughput and server utilization. Throughput increases with increase in the server utilisation until the optimal point is attained. At optimal point, the server utilization is 0.61 and the throughput is 7.63 x 10^{-4} packets per secs. The sharp drop in the throughput was due to the increase in time delay at the buffer while the further increase was due to the re-entering of the customers or packet into the customer population.

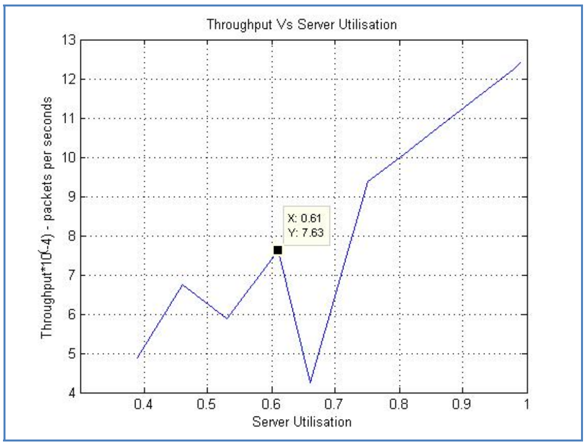


Fig. 11. Throughput and server utilisation

Fig. 12 illustrates the relationship between the throughput and time delay in the queuing system. At the optimal point the throughput γ = 7.63 x 10^{-4} packets per secs and the time delay T = 0.469 sec (469 ms). The throughput increases as the time of delay increases before the congestion region. In the congestion region in the system, sharp decrease in throughput was due to congestion. A further increase was due to the re-entering of the customer into the customer population arriving at the buffer.

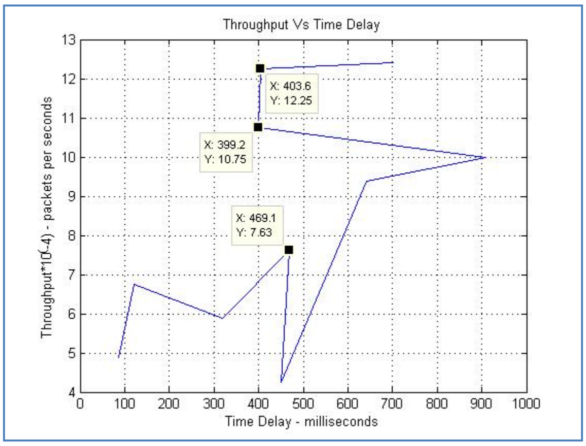


Fig. 12. Throughput and time delay

The queue model applied can determine the minimal point before the congestion state can be encountered after series of auto iteration. Table 2 shows the output results at the congestion state from the data obtained from the literature [10] while table 2 presents the output at the minimal point.

S/N	Modes	Arrival rate λ Packets /sec	Capacity of the Link Kb/sec	μc	Average Time Delay (secs)	$\lambda_i t_i$
1	AB	14	20	16.68	0.370	5.22
2	BC	12	20	16.68	0.210	2.56
3	CD	6	10	8.34	0. 430	2.56
4	AE	11	20	16.68	0.180	1.94
5	EF	13	50	41.70	0.030	0.45
6	FD	8	10	8.34	2.94	23.51
7	BF	10	20	16.68	0.15	1.50
8	EC	8	20	16.68	0.12	0.92
Total		82	170			

Table 1. Congestion state using Tanenbaum, 1989 data

S/N	Nodes	Arrival rate λ Packets/sec	Capacity of the Link Kb/sec	μc	Average Time Delay (secs)	$\lambda_i t_i$
1	AB	14	20	16.69	0.37	5.20
2	BC	12	20	16.69	0.210	2.56
3	CD	6	10	8.35	0. 43	2.56
4	AE	11	20	16.69	0.18	1.95
5	EF	13	50	41.74	0.03	0.45
6	FD	8	10	8.35	2.88	23.04
7	BF	10	20	16.69	0.15	1.49
8	EC	8	20	16.69	0.12	0.92
Total		82	170			

Table 2. Minimum point using Tanenbaum [10] data

Table 3 is the output results for the cost analysis of the network system. By comparing the results of the performance measures at the congestion state and at the minimal point, as shown in table 4. It is evident that congestion can be controlled at the minimal point for the network system without affecting the profit margin of the production industry.

S/N	Nodes	Arrival rate λ	Capacity of the Link	Buffer Character	Cost per Unit
1	AB	14	20	0.01	200
2	BC	12	20	0.01	200
3	CD	6	10	0.01	200
4	AE	11	20	0.01	200
5	EF	13	50	0.01	200
6	FD	8	10	0.01	200
7	BF	10	20	0.01	200
8	EC	8	20	0.01	200
Total		82			

Table 3. Cost analysis using Tanenbaum [10] data

Parameters	Minimal point	Congestion state
Arrival rate λ (Packets/sec)	82	82
Link capacity (kb/sec)	170	170
Service rate μ	1198	1199
Server utilization ρ	0.58	0.58
Probability of blocking P_B	0.37	0.37
Throughput γ (pkt/sec)	0.000484	0.000483
Delay Time T (sec)	0.465	0.471sec
Cost of money remaining C_W	₦33,984	₦33,984

Table 4. Comparison using Tanenbaum [10] data

Similarly, table 5 shows the output results of the iteration process at the congestion state from the data obtained from a Nigerian telecommunication industry (NTI) while table 6 shows the outputs at the minimal point.

S/N	Nodes	Arrival rate λ Packets /sec	Capacity of the Link Kb/sec	μc	Average Time Delay (secs)	$\lambda_i t_i$
1	AB	55	250	62.33	0.140	7.50
2	BC	40	250	62.33	0.140	1.79
3	CD	21	150	37.40	0.060	1.28
4	AE	35	200	49.86	0.070	2.35
5	EF	42	420	14.71	0.020	0.67
6	FD	26	150	37.40	0.90	2.28
7	BF	37	230	57.34	0.050	1.82
8	EC	20	150	37.40	0.060	1.15
Total		276	1800			

Table 5. Congestion state using NTI data

Table 7 presents output of the cost analysis of the network system. By comparing the results at the minimal point and the congestion state as shown in

Table 8, it is evident that congestion can be controlled at the minimal point with the same balance cost of basic facility requirements. By comparing the results from tables 4 and 8, it is very clear that more money is needed to service high rate of blocking due to congestion in the NTI than that of Tenenbaum [10].

S/N	Nodes	Arrival rate λ Packets/sec	Capacity of the Link Kb/sec	μc	Average Time Delay (secs)	$\lambda_i\ t_i$
1	AB	55	250	62.34	0.140	1.49
2	BC	40	250	62.34	0.140	1.79
3	CD	21	150	37.41	0.060	1.28
4	AE	35	200	49.88	0.070	2.35
5	EF	42	420	14.74	0.020	0.67
6	FD	26	150	37.41	0.090	2.28
7	BF	37	230	57.36	0.050	1.82
8	EC	20	150	37.41	0.60	1.15
Total		276	1800			

Table 6. Minimum point using NTI data

S/N	Nodes	Arrival rate λ	Capacity of the Link	Buffer Character	Cost per Unit
1	AB	55	250	0.01	200
2	BC	40	250	0.01	200
3	CD	21	150	0.01	200
4	AE	35	200	0.01	200
5	EF	42	420	0.01	200
6	FD	26	150	0.01	200
7	BF	37	230	0.01	200
8	EC	20	150	0.00	200
		276	1800		

Table 7. Cost analysis using NTI data

Parameter	Minimal point	Congestion state
Arrival rate λ (Packets/sec)	276	276
Link capacity (kb/sec)	1800 kb/sec	1800 kb/sec
Service rate μ	4010	4011
server utilization ρ	0.61	0.62
Probability of blocking P_B	0.38	0.38
Throughput γ (pkt/sec)	0.000152	0.000154
Delay Time T (sec)	0.68	0.68
Cost of money remaining C_W	₦359,986	₦359,986

Table 8. Comparison using NTI data

This result will enable the decision marker to determine the profit of the communication industry at the minimal point. The cost per unit for the analysis of the model was assumed to be ₦200 (USD, $0.60) based on the source of the data. Also, the number of buffer used is one (i.e. N = 1) because the model is a M/M/1 queueing model. However, the model is made flexible, and hence can permit the use of more than one buffer in the system with additional cost.

5. CONCLUSIONS

The developed queue model for communication congestion control in the production industry is a model to reckon with for prompt decision making. It is good for the manufacturer to determine the mean service rate and the optimal point to control communication congestion. The model is applicable to every manufacturing industry where M/M/1 waiting line congestion can be encountered. Also, it can be used in the preliminary planning of the production industry and in future capacity planning as well.

The model can be used for congestion cost analysis of the industry in other to enhance profitability as evident from the generated outputs from the case studied. The model will be of great benefit to the manufacturer to take prompt decision such as increasing the capacity or bandwidth of the communication system, controlling the number of customers arriving a system, allocating jobs or messages to the right server with the required service rate, determining the approximate profit of the industry and maximizing the profit and productivity of the industry. The model is capable of assisting the manufacturer to determine the size of the buffer required to control communication congestion.

The developed congestion control model can be utlised in production industries including communication, machine-tool, computer manufacturing, medical, and transportation industries, for their capacity planning, improved service rate and congestion control. In the machine-tool industry it can be used to allocate jobs to various workstations. In transportation industry, it is a useful tool for determining the number of forklift required to offload goods for high efficiency and productivity. It can be utilised to design optimal network systems to prevent congestion in electrical/electronic industry. The tool can be applied in wood and timber production industry to determine number of machines and workers required for the wood processing to avoid congestion. The model is useful to every production system where single queue waiting line problem exists and at the same time facing the challenges of congestion and productivity. A comprehensive analysis of the systems related to multi-queueing systems will be looked into in the future. Realisation of model to solving complex congestion challenge of multi-queuing systems being witnessed in many fast-moving goods production industries including financial institutions, medical centres and and petrol stations will be remarkable in enhancing effective capacity utilisation in the production industries. The objective of such study should address how best to minimise the cost of increasing buffer sizes.

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