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COST ANALYSIS OF POWER SUPPLY QUEUING MODEL M/M/∞

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Abstract: This paper deals with the power supply queuing model M/M/∞. In this paper, we analyze total cost of power supply queuing model with infinite servers. We develop a total cost function and suject it to optimization, which consequently gives us non-linear equations. These non-linear equations are further solved by using Newton-Raphson method with the help of R-software. We also present analysis of sensitivity, tables and graphs of the model to exhibit the comprehensive interpretation of the same.

Keywords and Phrases: Power supply queuing model, cost function, sensitivity analysis, NLE, R-software.

2020 Mathematics Subject Classification: 90B22, 60K25.

1. Introduction

The model supplies power to customers and number of arriving customers are assumed to follow Poisson distribution with parameterλ. Further, it is also assumed that supply-schedule also follows Poisson distribution with parameter μ.This model deals with a queueing system with infinite severs having infinite source of customers. Aziziankohan et al. [1] described how to handle congestion and reduction of energy consumption and emissions from supply chain transportation fleet from green supply chain management by applying queuing theory and its methods. Chen et al. [2] gave mobility optimization for mobile charging points in Internet of objects. Chen et al. [3] analyzed supportable public transportation: exploring the production based on electrical trains applying solar light like an additional potential stations. Chen et al. [4] has discussed online optimized transporting of edge determine and smart grill. Choi et al. [5] presented application of state-dependent queueing models to battery swapping and charging stations.

Dong et al. [6] analyzed at charging stations charging scheduling and power supply optimization. Ebrahimi et al. [7] developed the optimal design of multi-model energy considering uncertainty usually appearance of electrical trains, buses and vehicle charging points with continuous supply method. Efanov et al. [8] have analyzed the application of queueing system to increase reliability index of power supply systems. Ferretti et al. [9] discussed queuing principle build design technique being the defining potential needs in produces systems. Guo et al. [10] established the optimum way planning technique for electric cars taking into current supply. Hu et al. [11] analyzed a block chain-extra smart reduce deals apparatus for current supply and needs. Jiang et al. [12] analyzed the impacts of storeroom and queueing model cases on electric power systems through dual uncertainties. Kumar et al. [13] have investigated threshold supply policies,not reliable servers and recovery mechanisms for machine breakdowns. Kumar et al. [14] have developed comprehensive methods for fast charging of electric cars,bikes and machines through solar and batteries based on queueing principle. Kumar et al. [15] analyzed unrealistic solar storage with the help of solar operation algorithms as perfectly limit DC nanogrids. Iliopoulou and Kepaptsoglou [16] discussed the route network distribution problem and less developed models for operating solid solar power. Mishra et al. [17] studied current technique strategies for fast activity low electric power XNOR with XOR circuits. Momentitbar et al. [18] investigated the formulation model based on queuing model considering supply cost and solar energy storage technology.

Raj et al. [19] have developed the analysis of laboratory experiments of laptop solar power distribution stations based on the queuing model. Said et al. [20] have developed a queuing model of mobile charging at stations to cater to rail passengers. Shen et al. [21] analyzed battery backup allocation workload and solar panel workload migration against side and center solar and electrical load shedding on expressways and highways. Thakur [22] analyzed the cost of optimization for Markovian queues and streamlining in circuits. Viswanatham and Srinivasa Raghvan [23] have examined the design of the model using the Petri net approach and analyzed the performance of the available series with the help of the diffuse net approach. Xiao et al. [24] analyzed a simulation model for a basic size system of electric bike charging considering queuing behaviour and fixed queue length. Zhang et al. [25] studied modern solar available energy and electric vehicle charging platoons. Zhang et al. [26] have investigated the deployment of EV charging networks considering operational circuits and solar supply scheduling.

Esmailirad et al. [9] studied an extended m/m/k/k queuing model to analyze the profit of a multi-service electric vehicle charging station. Jiang et al. [18] developed the analysis of storage and queuing effects based on dual uncertainties. Momenitabar et al. [19] explained the formulation of the model based on queuing in public transit networks considering energy storage technology with demand charges. Meng et al. [20] developed research on the efficiency of charging stations by combining queueing theory of scheduling optimization exchange strategies with energy storage. Zaporozhets et al. [29] analyzed the functioning of multi-component queuing systems with multi-stages under the conditions of implementation of disruptive technologies in air transport.

A review of the relevant literature indicates that previous researchers did not attempt the cost analysis of the power supply model. In order to bridge this critical research gap, we have considered cost analysis of power supply model by introducing total cost function and subjecting it to optimization. Consequently, we obtain non-linear equations involving service rate and other parameters.These non-linear equations have been solved by using R-software. Finally, many analytical tables and graphics have been displayed to provide better perceptibility of the model.

2. Notations & Assumptions

2.1. Notations

The following notation are used in this paper.

n = number of customers for the system.

c_1 = Cost of service rate per unit time.

c_2 = Cost of waiting customers per unit time.

k = Number of customers supply in the system.

E(n) = Average no of customers for the system.

λ = Arrivel rate.

μ = Service rate.

P_0= Steady state probability of the systen being empty.

TC = Total Cost

2.2. Assumptions

The analysis of power supply queuing model mainly the M/M/∞ assumes that customers arrival follow Poisson distribution and service rate the exponential distribution.

3. Cost Analysis

Cost function is explain in the form of

$$TC = c_1\mu + c_2E(n)$$

where E(n)=average no based on clients for the system $E(n)$ = average waiting queues $+(\frac{\lambda}{\mu})$ In special case when $\lambda_n = (k-n)\lambda$ together with $0 \le n \ge k$ and $\mu_n = n\mu$ Using the boundary condition $\sum_{N=0}^{N=\infty} P_0 = 1$, we have

$$P_0 = [1 + k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3} + ... + \frac{\lambda^k}{\mu^k}]^{-1}$$

$$P_0 = \frac{k(k-1)(k-2)...(k-n+1)}{n!}\frac{\lambda^n}{\mu^n}$$

Therefore,

$$E(n) = \sum_{N=0}^{N=\infty} nP_n = (k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + ...)P_n$$

Total cost is defined as

$$TC = c_1n\mu + c_2\frac{\left[k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3} + \frac{k^4-6k^3+11k^2-6k}{24}\frac{\lambda^4}{\mu^4} + ...\right]}{\left[1 + k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3} + ...\right]} \tag{3.1}$$

Again, we got total cost in different cases of service rate. Taking first term only from equation (3.1), we have

$$TC_1 = c_1n\mu + k\frac{\lambda}{\mu}c_2 \tag{3.2}$$

For sum of first two terms from equation (3.1) , we get

$$TC_2 = c_1n\mu + c_2\frac{\left[k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2}\right]}{\left[1 + k\frac{\lambda}{\mu}\right]} \tag{3.3}$$

Again sum of first three terms from equation (3.1), we have

$$TC_3 = c_1n\mu + c_2\frac{\left[k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3}\right]}{\left[1 + k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2}\right]} \tag{3.4}$$

Taking sum of first four terms from equation (3.1), we get

$$TC_4 = c_1 N\mu + c_2 \frac{\left[k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3} + \frac{k^4-6k^3+11k^2-6k}{24}\frac{\lambda^4}{\mu^4}\right]}{\left[1 + k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3}\right]} \quad (3.5)$$

For providing optimum service by the system and assuming arrival as constant, for optimum TC, we have

$$\frac{dTC_1}{d\mu} = c_1 n - \frac{\lambda}{\mu^2} c_2$$

Differentiating it again w.r.t.μ , we have

$$\frac{d^2TC_1}{d^2\mu} = \frac{\lambda}{\mu^3} c_2$$

For the condition of optimization $\frac{dTC_1}{d\mu} = 0$ with $\frac{d^2TC_1}{d^2\mu} \geq 0$.

This implies that

$$\mu^2 c_1 n - \lambda c_2 = 0. \quad (3.6)$$

For optimum solution,we have

$$TC_1 = c_1 n\mu + k\frac{\lambda}{\mu} c_2$$

For total cost sum of first two terms

$$TC_2 = c_1 n\mu + c_2 \frac{\left[k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2}\right]}{\left[1 + k\frac{\lambda}{\mu}\right]}$$

$$\frac{dTC_2}{d\mu} = 0, \& \frac{d^2TC_2}{d^2\mu} \geq 0$$

.

$$c_1 n(1 + k\frac{\lambda}{\mu})^2 - c_2[(1 + k\frac{\lambda^1}{\mu^1})(k\frac{\lambda}{\mu^2} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^3}) - (k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2})(k\frac{\lambda}{\mu^2})] = 0$$

This implies that

$$c_1 n(1 + 2k\frac{\lambda}{\mu} + k^2\frac{\lambda^2}{\mu^2}) - c_2 n(k\frac{\lambda}{\mu^2} + (k^2-k)\frac{\lambda^2}{\mu^3} + \frac{k^2(k-1)}{2}\frac{\lambda^3}{\mu^4}) = 0. \quad (3.7)$$

For first three terms

$$TC_3 = c_1 n\mu + c_2 \frac{\left[k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3}\right]}{\left[1 + k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2}\right]}$$

For the condition of maxima/minima, we have

$$\frac{dTC_3}{d\mu} = 0, \& \frac{d^2TC_3}{d^2\mu} \geq 0.$$

Therefore, optimum solution, we get

$$\begin{aligned} &c_1 n \left(1 + k\frac{\lambda}{\mu} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^2}\right)^2 - c_2 \left[\left(1 + k\frac{\lambda^1}{\mu^1} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^2}\right)\right. \\ &\quad \left(k\frac{\lambda}{\mu^2} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^3} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^4}\right) \\ &\quad \left. - \left(k\frac{\lambda}{\mu} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3}\right)\left(k\frac{\lambda}{\mu^2} + \frac{k^2-k}{2}\frac{\lambda^2}{\mu^3}\right)\right] = 0. \end{aligned}$$

Its implies that

$$\begin{aligned} &c_1 n \left(1 + 2k\frac{\lambda}{\mu} + (2k^2-k)\frac{\lambda^2}{\mu^2} + k^2(k-1)\frac{\lambda^3}{\mu^3} + \frac{k^4-2k^3+k^2}{4}\frac{\lambda^4}{\mu^4}\right) \\ &- c_2 \left[k\frac{\lambda^1}{\mu^2} + (k^2-k)\frac{\lambda^2}{\mu^3} + (k^3-3k^2+2k)\frac{\lambda^3}{\mu^4} + \frac{5}{6}k^2(k-1)(k-2)\frac{\lambda^4}{\mu^5}\right. \\ &\left. + \frac{1}{12}k^2(k^3-4k^2+5k-2)\frac{\lambda^5}{\mu^6}\right] = 0. \end{aligned} \tag{3.8}$$

for first four terms

$$TC_4 = c_1 N\mu + c_2 \frac{\left[k\frac{\lambda}{\mu} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3} + \frac{k^4-6k^3+11k^2-6k}{24}\frac{\lambda^4}{\mu^4}\right]}{\left[1 + k\frac{\lambda^1}{\mu^1} + \frac{(k^2-k)}{2}\frac{\lambda^2}{\mu^2} + \frac{k^3-3k^2+2k}{6}\frac{\lambda^3}{\mu^3}\right]}.$$

Now optimum solution For the condition of maxima/minima, we have

$$\frac{dTC_4}{d\mu} = 0, \& \frac{d^2TC_4}{d^2\mu} \geq 0.$$

$$c_1n[\mu^8 + 2k\lambda^1\mu^7 + [k^2 + k(k-1)]\lambda^2\mu^6 + [(k^3 - 11k^2) + \frac{1}{3}(k^3 - 3K^2 + 2k)]\lambda^3\mu^5 + \frac{1}{3}[(k^4 - 3k^3 + 2k^2) + \frac{1}{4}(k^4 - 2k^3 + K^2)]\lambda^4\mu^4 + \frac{(k^5 - 4k^4 + 5k^3 - 2k^2)}{6}\lambda^5\mu^3 + \frac{(k^6 - 6k^5 + 13k^4 - 12k^3 + 4k^2)}{36}\lambda^6\mu^2] - c_2[k\lambda\mu^6 + (k^2 - k)\lambda^2\mu^5 + \frac{(k^3 - 3k^2 + 2k)}{2}\lambda^3\mu^4 + \frac{(k^4 - 6k^3 + 11k^2 - 6k)}{6}\lambda^4\mu^3 + \frac{(k^5 - 6k^4 + 11k^3 - 6k^2)}{8}\lambda^5\mu^2 + \frac{(k^6 - 7k^5 + 17k^4 - 17k^3 + 6k^2)}{24}\lambda^6\mu + \frac{(k^7 - 6k^6 + 31k^5 - 51k^4 + 40k^3 - 12k^2)}{114}\lambda^7] = 0. \tag{3.9}$$

This is non-linear equation (NLE).

4. Formulation of Non-Linear Equations

Particular value of n, λ, c_1, c_2 and varies k; from equation (3.6), we find four non- linear equations in μ. Similarly n ,k ,λ,c_2, are fixed and c_1 varies; n, k , c_1 are fixed and c_2 varies ; n, k, c_1,c_2 are fixed andλ varies. Putting particular value of N,n_1,n_2 andλ, we get some non- linear equations in μ.

From equation (3.6), we get

$$\mu^2 - 5 = 0 \tag{4.1}$$

This result shows that the optimum value of μ is dependent on λ and independent on the n_1 and n_2.

From equation (3.7), we get

$$3\mu^4 + 384\mu^3 + 12.224\mu^2 - 38.40\mu - 16,384 = 0 \tag{4.2}$$

After simplifying the particular value of n_1,n_2, N, λ and μ of the above expression, we get non linear equation (NLE) included µ and other parameters. This NLE is solved by Newton-Raphson method with the help of R- software. We get optimum cost of service rate.

From equation (3.8), we have

$$12\mu^6 + 1632\mu^5 + 107,544\mu^4 + 3,546,880\mu^3 + 56,558,592\mu^2 - 924,800\mu - 94,699,520 = 0 \tag{4.3}$$

From equation (3.9), we have

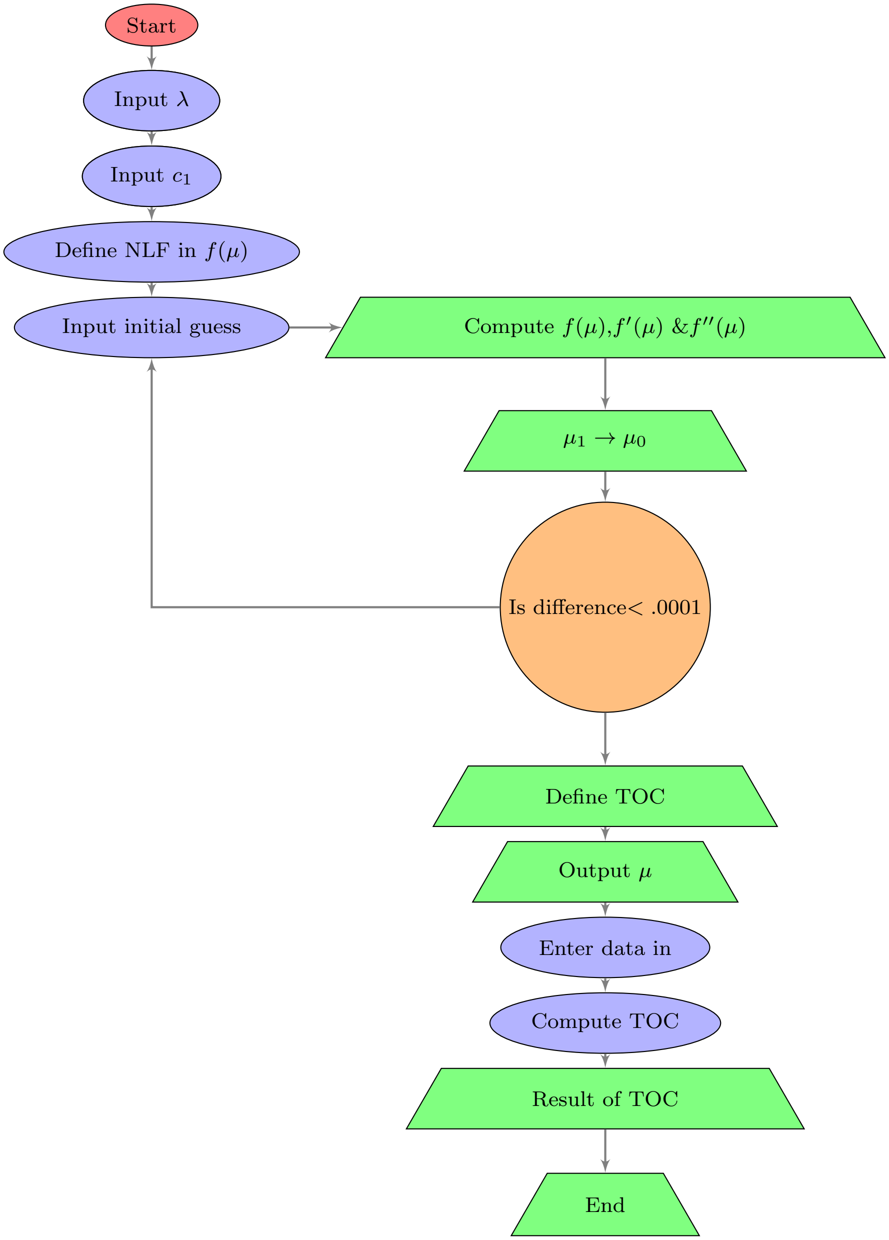
$$12\mu^8 + 1728\mu^7 + 10,008\mu^6 + 452,064\mu^5 + 13,356,288\mu^4 + 252,555,264\mu^3 + 2,727,346,180\mu^2 - 3,835,330,560\mu - 4,091,019,2600 = 0 \tag{4.4}$$

5. Computational Flow Chart

We develop the following computational flow chart to solve the equations (4.1) to (4.4).

Computational Chart

The following flowchart is computed for obtaining the total optimal cost and optimal service rate of the model.



By using above flow chart of computing and R-software,we obtain following table by using simulated data.

Table 1: Computation table for k and TC

Case1	n	k	c_1	c_2	λ	μ	P_0	TC
	6	15	10	5	2	2.236	0.990000	268.41
	6	16	10	5	2	1.295	0.198000	195.93
	6	17	10	5	2	1.252	0.000690	231.66
	6	18	10	5	2	4.946	0.001800	229.20

Table 2: Computation table for c_1 and Tc

Case2	n	k	c_1	c_2	λ	μ	P_0	TC
	6	15	7	5	2	2.673	0.990000	224.47
	6	15	8	5	2	2.489	0.003900	176.99
	6	15	9	5	2	1.239	0.000870	138.38
	6	15	10	5	2	1.0006	0.000035	113.28

Table 3: Computation table for c_2 and Tc

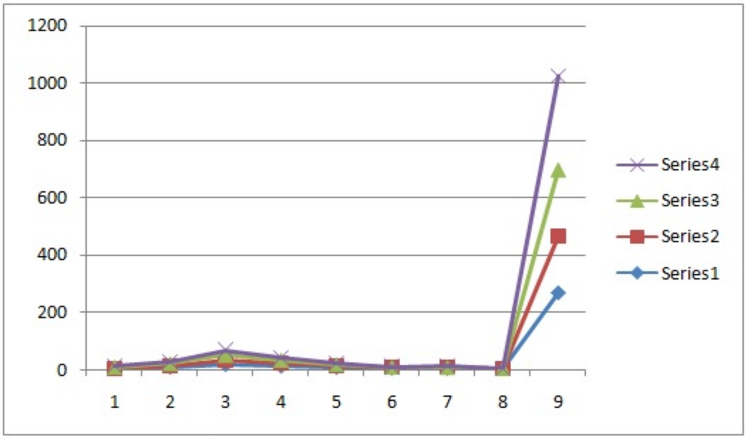
Case3	n	k	c_1	c_2	λ	μ	P_0	TC
	6	15	10	6	2	2.449	0.990000	293.91
	6	15	10	7	2	1.000	0.016300	258.54
	6	15	10	8	2	1.636	0.001330	175.63
	6	15	10	9	2	1.262	0.000650	084.69

Table 4: Computation table for λ and Tc

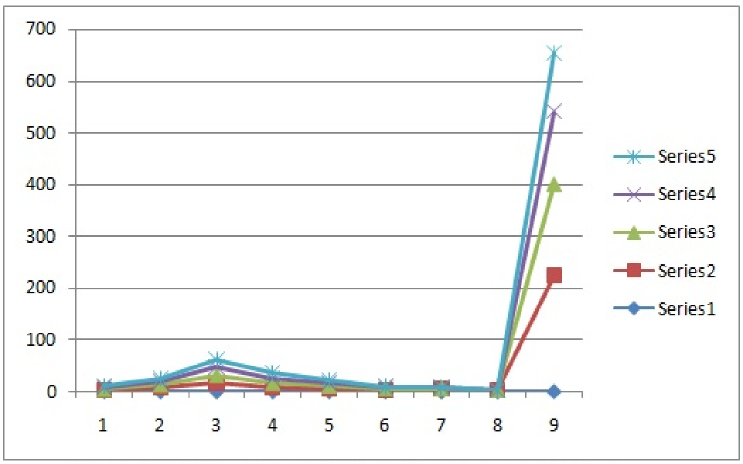
Case4	n	k	c_1	c_2	λ	μ	P_0	TC
	6	15	10	5	3	1.936	0.990000	232.34
	6	15	10	5	4	1.395	0.022700	186.64
	6	15	10	5	5	1.418	0.000373	163.44
	6	15	10	5	6	1.224	0.000018	148.55

6. Sensitivity Analysis

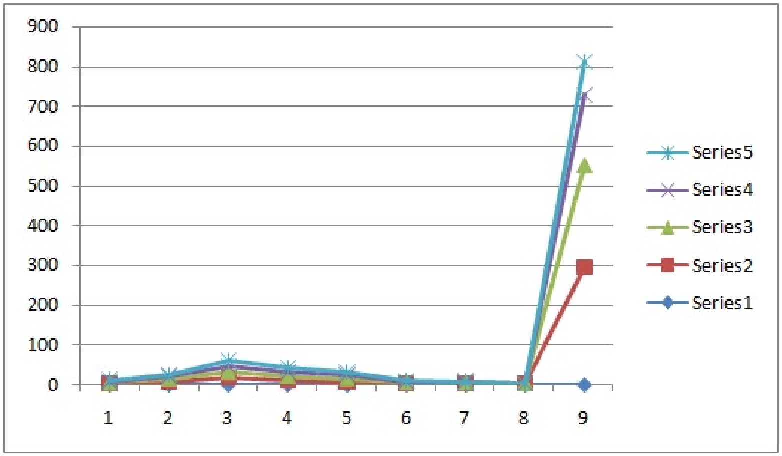
Table 1 presents that if number of customers supplied increases, the total price decreases. From table 2, the service rate per unit time increases, then the total cost of the system decreases. Table 3 makes it clear that total cost of the system decreases, when cost of waiting customers per unit time increases. Total cost decreases if the arrival rate increases, it is evident from table 4.



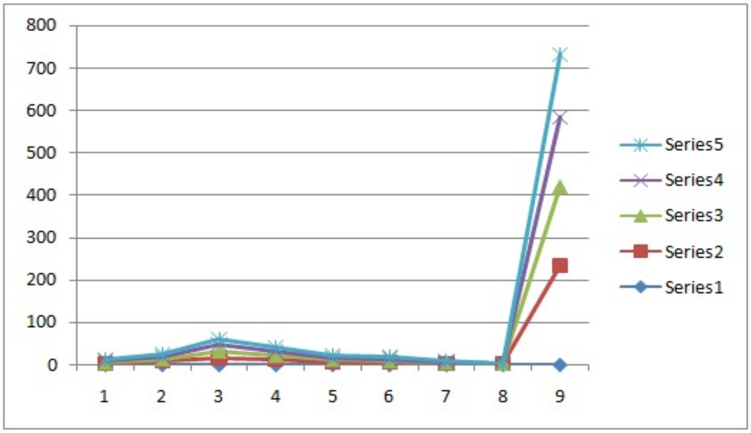
Graph 1: total cost vs no of customers supply in the system



Graph 2: total cost vs cost of service rate per unit time



Graph 3: total cost vs cost of waiting rate per unit time



Graph 4: total cost vs arrival rate

7. Conclusion

In this paper, the cost analysis of the power supply model has been attempted. We have derived main results of the model under consideration such as optimal service, optimal total cost of the model and its sensitivity analysis as performance measures of the model.

The current research is believed to have application in the areas of manufacturing, production and industries etc to enhance power supply strategies according to needs of customers.

We will attempt to control the arrival of customers for this model and derive novel and useful results as a future line of research.

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