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Simulation of Priority Queuing at TOTAL Petrol Filling Station in Makurdi Town Using SimEvents Toolkit

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ABSTRACT

The incessant flash fuel scarcity leading to long queues and prolong waiting time at the TOTAL petrol station along Kashim Ibrahim road in Makurdi town has called for an efficient operational management policy. This study carried out simulation of priority queuing process at the station using SimEvents toolkit in MATLAB software. Field work at the station involved manual count of arriving vehicles and duration of service time of the pumps. It was used for estimating inter-arrival rates (veh/h) and service rate (veh/h) per server. Simulation model was developed using SimEvents toolkit which was simulated for experimental period of 6 hours (360minutes) for the Do-Nothing Scenario on the Normal Queue (NQ) and demand split to a proposed Priority Queue (PQ) at 3%, 5%, 10%, 15%, 20% 25% and 30% of total demand. The split was based on assumed utility maximization of motorist who may be willing to pay extra fare to be served earlier through the PQ in order to reduce waiting time and eliminate risk of waiting on queue by roadside and the stress of waiting on long queues for long period. Results indicated significant reduction in waiting time on queue and queue length on the NQ as compared to the PQ. The optimized service delivery of the system was achieved at 80 – 85% demand on the NQ and 15 – 20% demand on the PQ. Adoption of the built model was therefore recommended for managers of the TOTAL petrol filling stations for optimum system performance and service delivery.

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1. Introduction

Based on the rapid growth of human population worldwide in recent times, there has been corresponding increase in demand for mobility to satisfy human travel desire [1]. The massive use of automobiles for human and freight transportation has direct impact on the economic and socio-cultural activities of cities. In Nigeria, road transport is the common mode of transportation. Basically, it comprises private cars, mini buses, trucks, motorcycles, tricycles, etc. These automobiles require periodic refilling of petrol tanks for smooth commuting. Automobile fuels are usually sold at petrol filling stations situated mostly along road sides to serve commuters. The process of buying and selling petrol requires motorist forming queues at petrol stations to buy the products from pumps or servers then depart after purchase [2]. This management policy or strategy of forming queues aim at maintaining orderliness for managing high demand and improved service pattern for efficient and optimum service delivery [3–5].

The periodic flash scarcity of petrol products over the years in Nigeria has posed challenges in managing high fuel demand at petrol filling stations especially during scarce supply. This consequently leads to traffic congestions, prolong waiting time and tension at fuel stations whenever the system is not properly managed [3,4,6,7]. Also, available space which serve as right-of-way or highway facility downstream along road shoulders are being lost to on-street parking by vehicles waiting to purchase fuel, hence highway capacity is therefore reduced by the parked vehicles.

According to Udo [7], there has been no authentic published data on the amount of daily fuel consumption by motorist in Nigeria over the years. Many agencies only gave estimated values as published in bulletins, flayers, social media, etc. which could not be evidently proven. This therefore complicates planning for optimum service delivery of petrol filling stations in Nigeria. Regardless of the quantity available for sale at the stations, motorists in Makurdi town, Benue State of Nigeria experience prolonged waiting time on queues at petrol stations so often in recent times. This queues last for hours and days as the case may be, thereby abusing commuters' value of travel time and subjecting people to strenuous activities at petrol filling stations for the sake of searching for travel fuel [2].

Generally, it has been observed that motorists waiting on queues become frustrated and decide to breach the queuing process at petrol stations. These persons are usually high ranked personalities in the society such as politicians, security personnel or people with extremely high value of time (VOT) such as the business men and women who are impertinent and see no reason whatsoever to join normal queuing process characterized by long waiting time at the station. This situation is not peculiar to Makurdi alone, but common among cities in Nigeria. Therefore, commercial and administrative activities suffer from this ugly situation as many workers are entrapped in congested queuing system, stocked in queues struggling to obtain fuel for their automobiles. Aside the loss time, motorists become wearied and psychologically depressed due to prolonged waiting time on queues, hence reduces human productivity and other related activities.

Queues formed by the waiting vehicles usually extend downstream occupying road shoulders, thus reduced usable road width or highway capacity resulting to congested situations due to insufficient space. This situation exposes the waiting motorist to the risk of being crushed by moving vehicles that may accidently run-off the roadway. It also has significant negative impacts on the cultural and socio-economic activities of Makurdi dwellers and the nation in general, as motorist's useful times are spent at petrol stations waiting in search of fuel for travelling.

The administration of fuel to motorists at petrol stations has not been properly managed as impatient commuters make serious efforts to enter into stations using wrong entry paths and dubious approaches aimed at minimizing waiting time at the station. These desperate motorists do everything doable to gain access to the pump units out of frustration. Queuing operations at fuel stations in Nigeria are occasionally characterized by features presented in Figures 1 and 2.

Fig. 1. Motorists waiting on long Queue during fuel scarcity in Abuja.

Fig. 2. Disorderliness caused by anxious motorists at Petrol Station during fuel scarcity.

As vehicles continue to wait on long queues as shown in Figure 1, the process of struggling into the service system illegally or jockeying to gain access to the system through wrong paths such as exit paths usually breaches the steady flow of traffic and results to disorderliness and loss of useful service time as shown in Figure 2.

Though commuters' income or VOT are essential variables with significant influence on the behaviour and decision making at the petrol station, estimation of these socio-demographic characteristic in a choice experiment is complicated since most respondent are unwilling to disclose their financial status [8–10]. This therefore necessitated the use of simulation technique which gives a prior knowledge of the system's behaviour based on meaningful assumptions justified by some logical judgments.

1.1. Queue choice in a priority queuing system

A priority queuing system presents different queue options or alternatives to a choice maker from which decisions are made by selection. The system gives preference to available alternatives in a given hierarchical level of importance ranging from highest to lowest based on attributes defined by the organization's management policies [8,11,12]. Travelers' homogeneous and sensitivity to cost and delay in service system creates dis-utility which affects decision making[13]. Except for irrational behaviour of arrivals which is a contrasting behaviour to the economic customer theory where the expected desire for utility maximization by motorists in terms of waiting time might be opposed [14–16]. In a random decision making process where utility denoted as U of an arrival n for alternative j is higher than alternative i, the utility condition is expressed as shown in Equation 1;

$$U_{nj} > U_{ni} \quad \forall \; j \neq i \tag{1}$$

The decision maker's utility measures the sensitivity of attributes offered by alternatives using the expression; $x_{nj} \, \forall \, j$ and s_n, such that its function is expressed as Equation 2;

$$V_{nj} = V\left(x_{nj}, s_n\right) \quad \forall j \tag{2}$$

where, V denotes unknown parameters to be estimated statistically. According to Train [15], since other aspects of the utility cannot be measured then Equation 3 exists;

$$V_{nj} \neq U_{nj} \tag{3}$$

Therefore, the utility function of Equation 2 is then decomposed into Equation 4;

$$U_{nj} = V_{nj} + \varepsilon_{nj} \tag{4}$$

where ε_{nj} captures factors that affect utility but are not included in V_{nj}, The V_{nj} is known by the researcher as random quantities while ε_{nj} is the unknown quantities assumed to be distributed independently with identically extreme values. These factors are unknown and the researcher treats them as random variables such that the probability that an arrival n chooses alternative j is as derived in Equation 5;

$$\begin{aligned} P_{nj} &= P\left(U_{nj} > U_{ni} \quad \forall \; j \neq i\right) \\ &= P\left(V_{nj} + \varepsilon_{nj} > V_{ni} + \varepsilon_{ni} \quad \forall \; j \neq i\right) \\ &= P\left(\varepsilon_{ni} - \varepsilon_{nj} < V_{nj} - V_{ni} \quad \forall \; j \neq i\right) \end{aligned} \tag{5}$$

Based on normalization, the probability of choosing alternative i is given as Equation 6;

$$P_{ni} = 1 - P_{nj} \tag{6}$$

In the probability cumulative distribution of random arrivals, each term, $\varepsilon_{ni} - \varepsilon_{nj}$ is below $V_{nj} + V_{ni}$ for all observed quantities, hence, using the density function $f(\varepsilon_n)$, the cumulative probability is given as Equation 7;

$$\begin{aligned} P_{nj} &= P\left(\varepsilon_{ni} - \varepsilon_{nj} < V_{nj} - V_{ni} \quad \forall \; j \neq i\right) \\ &= \int_{\varepsilon} I\left(\varepsilon_{ni} - \varepsilon_{nj} < V_{nj} - V_{ni} \quad \forall \; j \neq i\right) f(\varepsilon_n) d\varepsilon_n \end{aligned} \tag{7}$$

where I(.) is the indicator function, it is equal to 1 when term in parentheses is true and 0 if otherwise. It is a multidimensional integral over the density of the unobserved portion of utility, $f(\varepsilon_n)$ [14,15].

In theory, a binary logit model is a choice model suitable for examining experiments with only two utility alternatives [15] . The model suits this study since its proposed only two queue types with mutually exclusive alternatives of Normal Queue (NQ) and Priority Queue (PQ) for motorists. Though subjective, the probability of arrivals deciding to join a particular queue is a measure of the queue's utility as affected majorly by long waiting time in the system. Using economic principles, available alternatives are set to presents to the decision maker cheaper but slower and faster but expensive choice options [17] . Based on binary logit model involving alternatives i and j, the probability of arrival n choosing queue category j is given as Equation 8;

$$P_{nj} \quad = \frac{1}{1+ e^{-\mu\left(V_{jn} - V_{in}\right)}} \tag{8}$$

where, μ is the logit model sensitivity parameter assumed to be equal to 1 for simplicity in most cases. Therefore, by normalization, the probability of arrival n choosing queue category i is given as Equation 9;

$$P_{ni} = 1 - P_{nj} \tag{9}$$

1.2. Queuing theory

Several researches on queuing models have been carried out in the past since after it was first expressed by Erlang in 1913 to treat congestion problems associated with telephone call exchange in the beginning of 20th century [5,18–21]. Basically, queuing models are described using probability distribution of inter-arrivals, service time, number of servers and queue discipline, [22,23]. Mathematical analysis of queuing is aimed at describing the process and to predict its behaviour due to changes [22]. The continuous random arrival and departure times are described as Poisson process expressed by the Erlang model [22,24]; service times in queuing systems could be a special case of Markov (or memoryless) process known as stochastic process [19,22,25].

According to previous studies, mathematical models do not adequately handle the aim of queuing analysis since they do not satisfactorily analyze the variability of variables or stochastic nature of the system [26]. Therefore, simulation techniques using software tools such as SimEvents in MATLAB is recommended for more realistic results [2,4]. SimEvents is a MATLAB toolkit which provides a library of built-in graphical blocks used as building blocks for modelling queuing systems [27]. Operations of the individual and integrated queuing blocks is based on analytical formulations and codes used to configure the set [2,27].

This study therefore aims at developing simulation models for examining the suitability of priority queuing process at the TOTAL petrol filling station in Makurdi town, Benue State of Nigeria. Objectives of the study include to; examine the demand pattern and queuing process at the TOTAL filling station, develop a simulation model for the queuing process using SimEvents toolbox and to propose optimum queuing configuration for the filling station.

2. Materials and methods

2.1. Description of study area

The TOTAL filling station situated along Kashim Ibrahim Road in Makurdi town was considered by the study. It is a single site among other TOTAL Company filling stations in Makurdi town, the capital city of Benue state of Nigeria. The city lies along the Benue trough linking the North and Southern parts of Nigeria on Latitude 7^0 43’ 56” and Longitude 8^0 32’ 21” [28]. Human population of Makurdi town is estimated to be over 367,588 people living on a landmass of approximately 800 km^2 [29]. The map of Makurdi town showing TOTAL filling station is as presented in Figure 3.

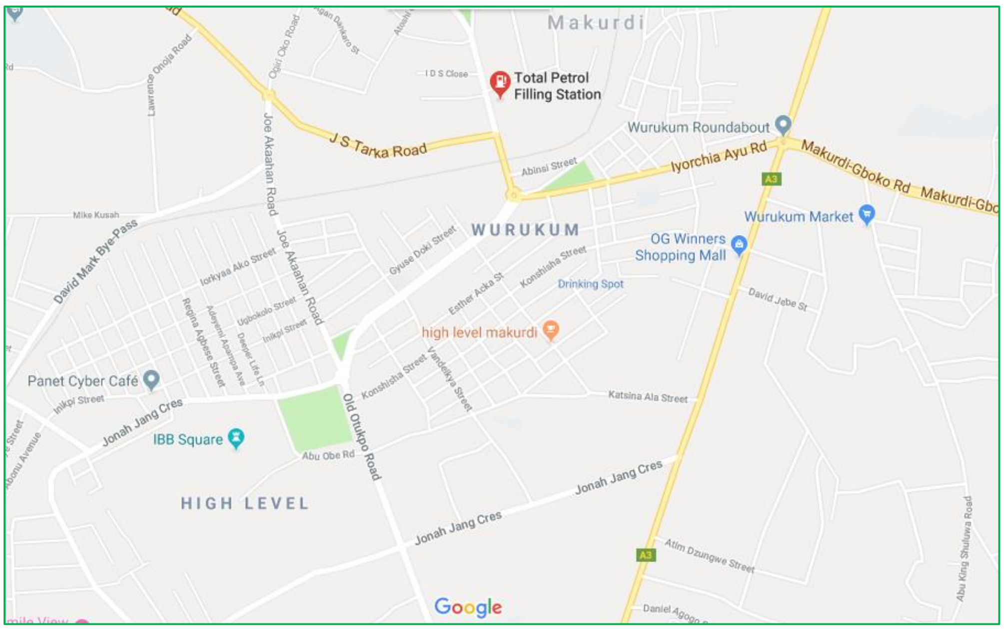

Fig. 3. Aerial view of Makurdi Town [28].

2.2. Data collection and model development

A manual traffic survey was carried out at the station in Makurdi town to examine fuel demand by motorists and service pattern by the system. Materials used for the study included a stop watch for measuring arrival and service rates from which the inter-arrival and inter-service times were estimated. The field work was carried out during partial fuel scarcity when demand was above normal situation as described by managers of the station.

A simulation model was developed using MATLAB SimEvents toolkit which contains appropriate blocks for simulation of queuing process [27]. The First-In-First-Out (FIFO) queuing discipline was adapted for the system, where four (4) servers were used for the Do-Nothing scenario, then three (3) to one (1) server for the NQ and PQ systems respectively. The built simulation model of queuing system at TOTAL filling station is as presented in Figure 4;

The Simulink tool blocks used included; the entity random generator, timers, FIFO queue, Multiple servers, signal scopes and sink blocks. The simulation process considered a Do-Nothing scenario and other scenarios which split arrivals into NQ and PQ based on defined percentages of priorities with NQ having the largest ratio at each scenario.

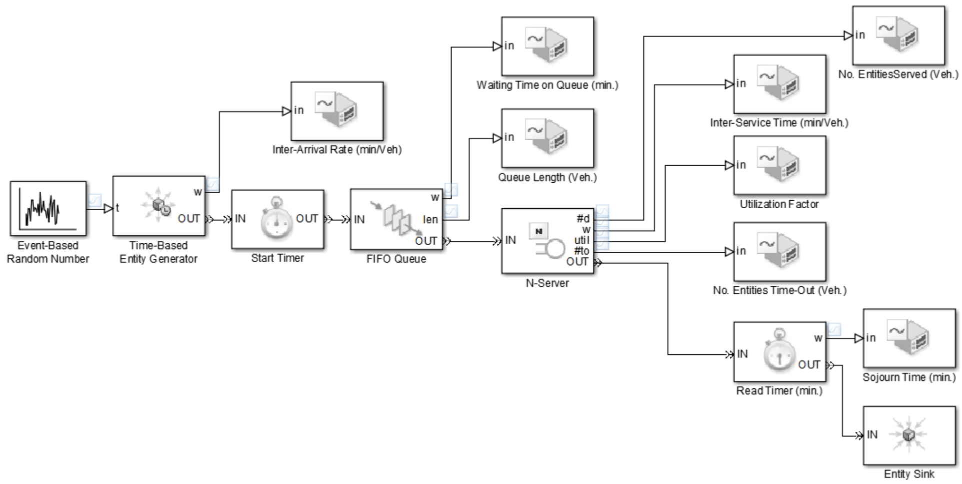

Fig. 4. Simulink Model of Queuing Process at TOTAL Petrol Station in Makurdi Town.

3. Results and discussion

The representative values of input parameters used for simulation of the built model were obtained from the descriptive statistics of field results presented in Table 1;

Table 1
Descriptive Statistics of Queuing Parameters.

Parameters	Arrival Rates (veh/hr)	Inter-Service Time (min/veh)
Sample Size	123	115
Range	73	2.58
Mean	47.293	3.6181
Variance	371.34	0.33227
Standard Deviation	19.27	0.57643
Coefficient of Variation	0.40747	0.15932
Standard Error	1.7375	0.05375
Skewness	-0.03229	0.06114
Kurtosis	-1.0021	-0.90731
Minimum	11	2.3
Median	50	3.7
Maximum	84	5.88

Table 1 presents estimated average arrival rate of 47.30 veh/hr from which the average inter-arrival time was estimated and average inter-service time of 3.62 min/veh for simulating the model. Simulation runs of the model for NQ and PQ for a period of 360 minutes (6 hours) revealed the performance of the single channel queue for Do-Nothing scenario and parallel channels for the priority queuing system. Variations in waiting time in the system based on demand ratio of the NQ and PQ by motorist are as presented in Figure 5;

Figure 5 (a) revealed variation with steady decrease in waiting time on queue from the Do-Nothing scenario to different percentages of demand splits on the NQ. In other words, the system experienced relatively high waiting time on the NQ, which reduces systematically as demand split to the PQ increases. Consequently, the corresponding increase in waiting time on the PQ is as shown in Figure 5 (b). The PQ recorded relatively less waiting time on the queue when serving low demand of 3 %, 5 %, 10 % and 15 % of the total demand a shown in Figure 5 (b).

Results of queue lengths on both NQ and PQ of the simulated system are as presented in Figure 6;

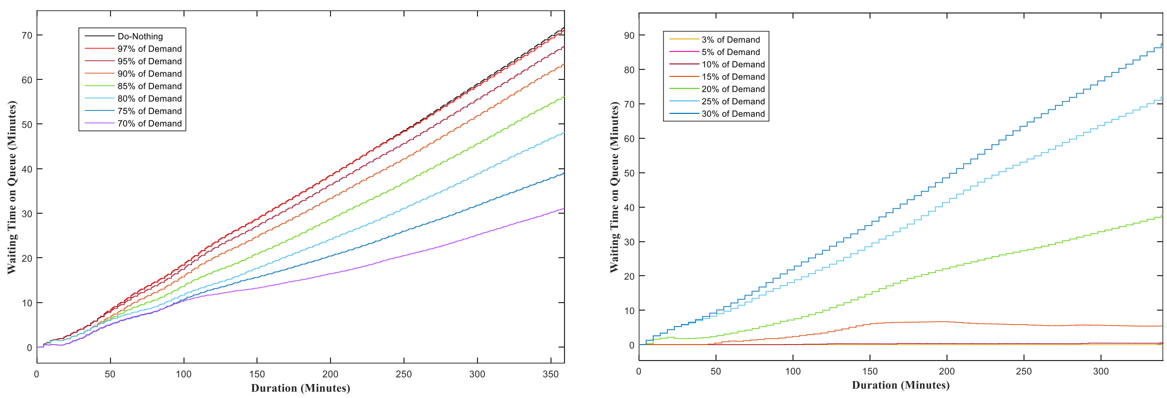

Fig. 5. (a) Waiting time on queue for NQ (b) Waiting time on queue for PQ

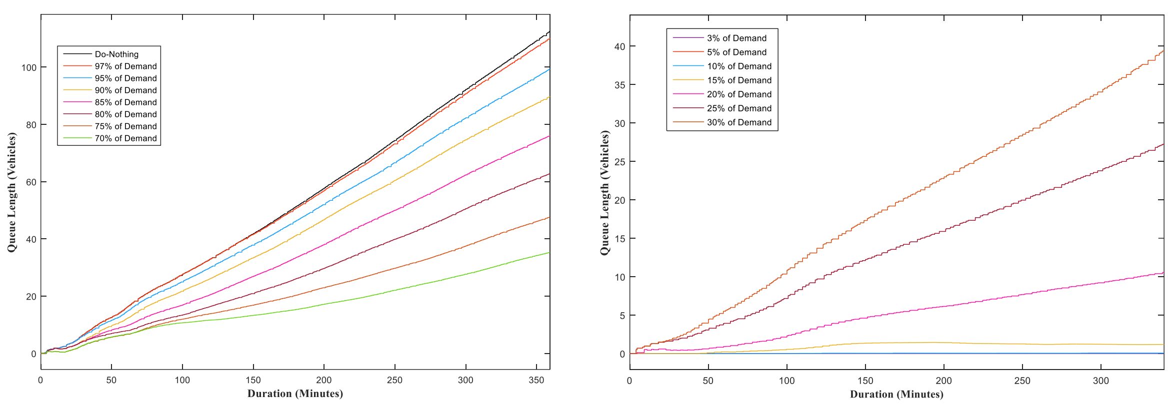

Fig. 6. (a) Queue Length for NQ (b) Queue Length for PQ

Figure 6 (a) revealed that, there was significant queue length at Do-Nothing scenario (100% demand) with corresponding decrease in demand due to demand split for the PQ at defined percentages. This system behaviour is attributed to the relevance of using priority queuing system that could serve motorist with high VOT and would be willing to pay extra fee rather than waiting at the filling station for long time.

Figure 7 presents utilization factor for both NQ (Fig. 7 (a)) and PQ (Fig. 7(b)) systems. It defines the busy period of the system as it worked during continuous influx and departure of motorists within the duration of simulation.

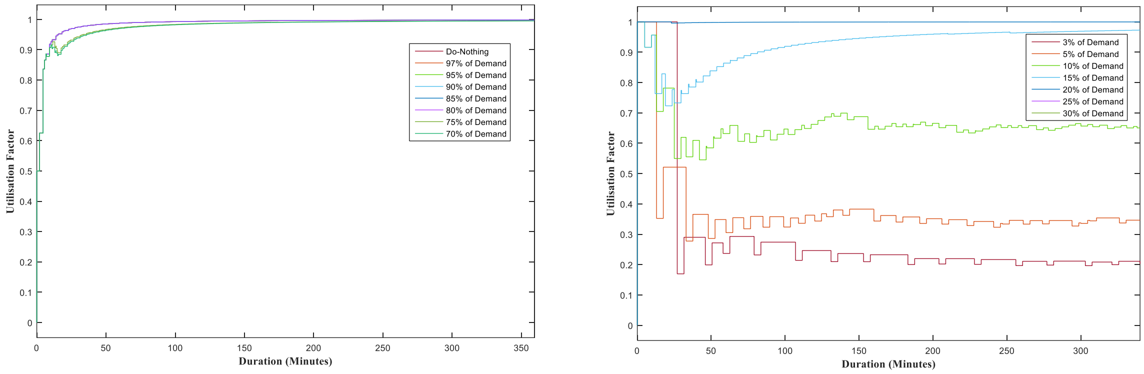

Fig. 7. (a) Utilization Factor for NQ (b) Utilization Factor for PQ

Figure 7 (a) revealed that, the NQ system operated at utilization factor below 100% at the initial stage until the system stabilized at 100th minutes of operations, after which it worked maximally. Figure 7 (b) shows that the system utility was unstable in the PQ system, which was attributed to it scares and unstable demand.

The average numerical values of performance parameters of the queuing system are as presented in Table 2;

Table 2
Average Performance of the Queuing System.

Normal Queuing (NQ)			Priority Queuing (PQ)			% Improvement on NQ	
Demand	**Avg. Waiting Time (mins.)**	**Avg. Queue Length (Veh.)**	**Demand**	**Avg. Waiting Time (mins.)**	**Avg. Queue Length (Veh.)**	**Avg. Waiting Time (mins)**	**Avg. Queue Length (Veh.)**
Do Nothing	34.62	53.63	Do Nothing	-	-	0.00	0.00
97%	34.48	52.56	3%	0.00	0.00	0.40	2.00
95%	32.67	48.05	5%	0.00	0.00	5.63	10.40
90%	30.15	42.60	10%	0.22	0.03	12.91	20.57
85%	26.28	35.63	15%	4.24	0.92	24.09	33.56
80%	22.39	28.63	20%	18.52	5.37	35.33	46.62
75%	18.76	21.97	25%	36.67	14.43	45.81	59.03
70%	15.43	16.81	30%	43.90	20.58	55.43	68.66

Table 2 shows steady decrease and corresponding increase in average waiting time on queue and queue length for the NQ and PQ respectively. Though there was no significant impact when demand share on the PQ ranged between 3 – 10 %. Figure 8 is used for the determination of optimum system performance based on the demand split in this study.

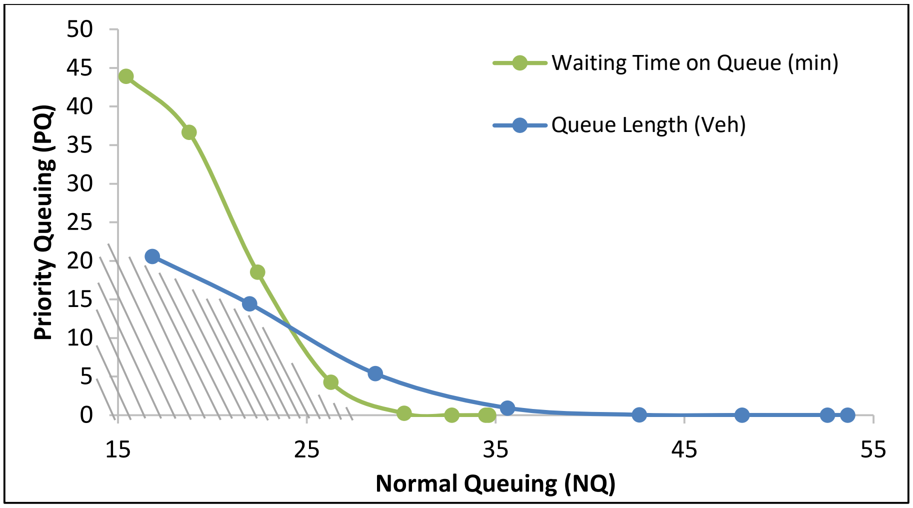

Fig. 8. Optimisation of Queuing System at the TOTAL Petrol Filling Station in Makurdi Town.

Since queuing analysis at the TOTAL filling stations aims at minimizing its function in terms of waiting time and queue length, Figure 8 revealed the feasible region of the optimum solution as presented by the shaded portion. Relating Figure 8 and Table 2 showed that the optimum split ratio of demand for operations of the system falls between 80 – 85 % and 15 – 20 % demand for the NQ and PQ respectively. Therefore, a priority queuing system configuration of three (3) servers for the NQ and one (1) server for the PQ at the TOTAL Petrol filling station is sufficient for optimum service delivery.

4. Conclusion and recommendation

From the analysis of this study, the use of priority queuing system improved the performance of buying and selling operations at the TOTAL petrol filling station with motorists' waiting time and queue lengths in the queuing system being reducing on the NQ as demand shifted to the PQ due to high VOT of some motorist who become impatience and could not wait for long time on the NQ for services. The study therefore recommended a priority queuing system at the TOTAL filling station where about 85 % of total arrivals are unwilling to pay extra fee to be given priority and served earlier for optimum system performance and service delivery.

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