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Application of Multi-Channel Infinite Queuing Network in a Food Production Company

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ABSTRACT

In this research, the production line was modeled according to the various workstation processes for noodle production and optimized with a multi-channel queuing network for application in a food (noodle production company). The service and arrival times for processing in each work station was calculated on an average basis daily. The average utilization of each workstation for noodle process was also determined by mathematical models using the multi-channel queuing system for an infinite queuing network.. It was observed that the arrival rate ranges of 10-25 units/minute was processed at each workstation and the rate of service of each process was from 12-16 units/minutes. The time for each process varied as the highest arrival rate and service were observed at packaging station while the lowest was observed at the cutting station. The workstation most utilized was the cutting (slicking) workstation and the least utilized was the rolling station. In summary, the noodle production company can be able to increase its productivity if results obtained from this research are implanted on the production workstations for each of the processes.

KEYWORDS: First-in-first-out, arrival rate, service rate, queuing, waiting time, system utilization.

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1.0 INTRODUCTION

Queuing theory is the mathematical study of waiting lines and it enables the mathematical analysis of several related processes, including arrivals at the queue, waiting in the queue and being served by the server. The theory enables the derivation and calculation of several performance measures which can be used to evaluate the performance of the queuing system under study (Cruz & Van Woensel, 2014; Ghimire *et al.*, 2017).

Queuing situations generally occur in various types of scenarios, some of these scenarios may include a series of jobs to be processed by a service agent at a computer center, an accumulation of jobs to be processed at a manufacturing facility (Sundarapandian, 2009). Queuing network models are widely used to analyze manufacturing systems, scheduling systems, service systems and computer network systems. There are many applications for closed queuing networks such as a central server network in computer science. An example is a computer with one Central Processing Unit (CPU) and some I/O (Input/Output) devices.. New jobs enter the system by deferent I/O devices, and a single CPU resource is needed to process the jobs. When a job is finished, it returns to the CPU to ask for more resources.

The number of jobs in the system is fixed, and it is also called as the ‘degree of multiprogramming’. Not just in computer science, but in many other applications, optimizing the critical resources is necessary because the demands of saving energy and reducing costs are becoming more and more significant with developing technologies. This is one of the most important reasons why better performance and optimization tools are needed which play a vital role during design and operations.

It would help companies to save cost and resources, and reach the goal in the most economical way. If the best arrangements could be found during the planning stage, it would not only maximize profits but also avoid the extra cost of modification in the future. So, the key factor is to develop a systematic methodology to help one reach this goal, not limited in one or two applications, but could be widely used in many different kinds of network applications (Wang, 2015).

Most of queuing theory deals with system performance in steady-state. That is, most queuing models assume that the system has been operating with the same arrival rate, average service time and other characteristics for a sufficiently long time that the probabilistic behavior of performance measures such as queue length and customer delay is independent of when the system is observed. Clearly, there are many service systems, including health care systems, for which there is time-of-day, day-of-week or seasonality effects (Green, 2011). Noodle foods have become a household delicacy in Nigerian homes due to the economic value and ease of preparation. The demand for noodles is on the rise and its production companies are expanding and installing more production plants across the country to meet up with demand and supply to its customers. In the production of these foods, several processes are required: mixing, rolling, cutting, steaming, frying, cooling and packaging. Each of the various processes are done through mechanized and automated processes where the units are placed in assembly lines for service. In these various automated stations, units of the noodles are placed and processing is done on each as other units queue up to be served. This process continues from one workstation to the next until the final process where it is packaged.

A research into the history of noodles by Zhang (2016) showed that Chinese noodles originated in the Han dynasty, which has more than 4,000 years of history. There are many stories about the origin of noodles. To a certain extent, noodles also reflect the cultural traditions and customs of China, which essentially means “human nature” and “worldly common sense”. The author further asserted that there are thousands of varieties of noodles in China, according to the classification of the shape of noodles, seasoning gravy, cooking craft, and so on. The author agreed that in modern day, noodles have become more accepted by people from all over the world. Zhang (2016) also agreed that the industrial revolution and the development of the food industry realized the transition from a traditional handicraft industry to mass production using machinery. However, Zhang (2016) confirmed that noodles are a kind of cereal food, which is the main body of the traditional Chinese diet. It is the main source of energy for Chinese people and the most economical energy food.

Suha (2015) observed that in retail banking industry, queuing remains one of the most common reasons for lack of satisfaction among bank customers. The author asserted that despite technological advances such as online and mobile banking, customers still complain about their bank queue management systems. A research by Hao and Yifei (2011), focused on improving the queuing system of a bank based on Business Process Reengineering (BPR).

Afolalu *et al.* (2019) did a research on queuing theory models in the Banking Sector. From this research, it was observed that the issue of bank queuing had existed for long time in various nations. Akoja *et al.* (2017) asserted that among the noodle brands in the Nigerian market, research and market data confirmed that Indomie noodles is topmost on the taste pallet of most children. The study attempts to find out why especially since literature provides evidence supporting the fact that television advertisements are highly influential on children. Hani and Muhammed (2014) experimented on examining the multi- product multi-stage in a battery production line. The authors tried that to improve the performances of an assembly production line by determining the efficiency of each workstation.

Gulia *et al.* (2014) asserted in their work, that Noodles are one of the staple foods consumed in many Asian countries and instant noodles have become internationally recognized food, and worldwide consumption is on the rise. Gulia *et al.* (2014) argued that the properties of instant noodles like taste, nutrition, convenience, safety, longer shelf-life, and affordable price have made noodles popular in homes. They emphasized on the quality factors which are important for instant noodles such as color, flavor, texture, cooking quality, rehydration rates during final preparation, and the presence or absence of rancid taste after extended storage. In their research, Gulia *et al.* (2014) acknowledged the efforts of researchers in trying to improve the formulation, extend the shelf life, and promote universal fortification of instant noodles. Accordingly, many researchers are exploring the potential of noodle fortification as an effective public health intervention and improve its nutritional properties.

2. MATERIALS AND METHODS

The data for this project was collected and analyzed from Dufil Prima Foods, Indomie Production Company, Port Harcourt. The single and multi-channel queuing theory with a FIFO (First-in, First-Out) discipline was applied for the queuing theory analysis.

2.1 Analytical Model

The following variables are used to calculate the average queuing time in a system:

i. The arrival rate of items per minute, λ
ii. The workstation service rate, μ
iii. Mean number in the queue, L_q
iv. Meantime spent in the whole process, W_s
v. Mean time spent in the queue, W_q
vi. Probability of zero items in the process, P_0
vii. Probability of n items in the process, P_n

The single-channel queuing process according to Lilly *et al.* (2015) can be expressed as:

$$P_n = 1 - \frac{\lambda}{\mu} \quad (1)$$

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)} \quad (2)$$

$$L_s = L_q + \frac{\lambda}{\mu} \quad (3)$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} \quad (4)$$

$$W_q = \frac{\lambda}{\mu\,(\mu - \lambda)} \quad (5)$$

The equations above are due to the following conditions:

i. The arrival of items follows a Poisson distribution
ii. Provision of service follows an exponential distribution
iii. The average service rate exceeds the average arrival rate; $\mu > \lambda$.
iv. The queuing discipline is First-In, First-Out (FIFO), and there is no jumping the queue.
v. The number of customers is infinite and the queue size is unlimited, according to Lilly *et al.* (2015).

3. RESULTS AND DISCUSSION

3.1 Results from Workstation

Table 1 presents the Noodles production data obtained daily.

Table 1: Production Data for Noodles Daily

S/N	Task	Arrival rate (λ /min)	Service Rate (μ /min)	Utilization Factor ($\frac{\lambda}{\mu}$)
1	Mixing	14	20	0.70
2	Rolling / Sheeting	12	18	0.67
3	Cutting/ Slicing	10	12	0.83
4	Steaming/ molding	14	18	0.77
5	Frying/ Drying	16	20	0.80
6	Cooling	14	18	0.77
7	Packaging	25	36	0.69

3.2 Analysis of the Problem

The data given was analyzed and the values of the following variables were calculated; idle system, length in system, length in queue, waiting time in system, waiting time in queue and the system's utilization.

At Mixing Station: λ = 14 units/min, μ = 20 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{14}{20}$$

$$= 0.3$$

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)} = \frac{14^2}{20\,(20 - 14)}$$

$$= 1.63$$

$$L_s = L_q + \frac{\lambda}{\mu} = 1.63 + \frac{14}{20}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} = \frac{14}{(20 - 14)}$$

$$= 2.33$$

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{14}{20(20-14)}$$

$$= 0.12$$

$$W_s = \frac{1}{(\mu - \lambda)} = \frac{1}{(20-14)}$$

$$= 0.17$$

Rolling and sheeting station: λ = 12 units/min, μ = 18 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{12}{18}$$

$$= 0.33$$

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{12^2}{18(18-12)}$$

$$= 1.33$$

$$L_s = L_q + \frac{\lambda}{\mu} = 1.33 + \frac{12}{18}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} = 2.00$$

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{12}{18(18-12)}$$

$$= 0.11$$

$$W_s = \frac{1}{(\mu - \lambda)} = \frac{1}{(18-12)}$$

$$= 0.17$$

Cutting and slicing station: λ = 10 units/min, μ = 12 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{10}{12}$$

$$= 0.17$$

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{10^2}{12(12-10)}$$

$$= 4.17$$

$$L_s = L_q + \frac{\lambda}{\mu} = 4.17 + \frac{10}{12}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} = 5.00$$

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{10}{12(12-10)}$$

$$= 0.42$$

$$W_s = \frac{1}{(\mu - \lambda)} = \frac{1}{(12-10)}$$

$$= 0.5$$

Steaming and molding station: λ = 14 units/min, μ = 18 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{14}{18}$$

$$= 0.22$$

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{14^2}{18(18-14)}$$

$$= 2.72$$

$$L_s = L_q + \frac{\lambda}{\mu} = 2.72 + \frac{14}{18}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} = 3.50$$

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{14}{18(18-14)}$$

$$= 0.19$$

$$W_s = \frac{1}{(\mu - \lambda)} = \frac{1}{(18-14)}$$

$$= 0.25$$

Frying and drying station: λ = 16 units/min, μ = 20 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} = 1 - \frac{16}{20}$$

$$= 0.2$$

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{16^2}{20(20-16)}$$

$$= \quad 3.2$$

$$L_s = L_q + \frac{\lambda}{\mu} \quad = \quad 3.2 + \frac{16}{20}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} \quad = \quad 4.0$$

$$W_q = \frac{\lambda}{\mu\,(\mu - \lambda)} = \frac{16}{20\,(20 - 16)}$$

$$= \quad 0.2$$

$$W_s = \frac{1}{(\mu - \lambda)} \quad = \quad \frac{1}{(20 - 16)}$$

$$= \quad 0.25$$

Cooling station: λ = 14 units/min, μ = 18 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} \quad = \quad 1 - \frac{14}{18}$$

$$= \quad 0.22$$

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)} \quad = \quad \frac{14^2}{18\,(18 - 14)}$$

$$= \quad 2.72$$

$$L_s = L_q + \frac{\lambda}{\mu} \quad = \quad 2.72 + \frac{14}{18}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} \quad = \quad 3.50$$

$$W_q = \frac{\lambda}{\mu\,(\mu - \lambda)} = \frac{14}{18\,(18 - 14)}$$

$$= \quad 0.19$$

$$W_s = \frac{1}{(\mu - \lambda)} \quad = \quad \frac{1}{(18 - 14)}$$

$$= \quad 0.25$$

Packaging station: λ = 25 units/min, μ = 36 units/min

$$P_0 = 1 - \frac{\lambda}{\mu} \quad = \quad 1 - \frac{25}{36}$$

$$= \quad 0.31$$

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)} \quad = \quad \frac{25^2}{36\,(36 - 25)}$$

$$= \quad 1.58$$

$$L_s = L_q + \frac{\lambda}{\mu} \quad = \quad 1.58 + \frac{25}{36}$$

$$L_s = \frac{\lambda}{(\mu - \lambda)} \quad = \quad 2.27$$

$$W_q = \frac{\lambda}{\mu\,(\mu - \lambda)} = \frac{25}{36\,(36 - 25)}$$

$$= \quad 0.06$$

$$W_s = \frac{1}{(\mu - \lambda)} \quad = \quad \frac{1}{(36 - 25)}$$

$$0.09$$

Table 2: Summary of Theoretical Results for each Workstation

S/N	Work station	λ (units/min)	μ (units/min)	P_n	P_0	L_q	W_s	W_q
1	Mixing Station	14	20	0.70	0.3	1.63	0.17	0.12
2	Rolling Station	12	18	0.67	0.33	1.33	0.17	0.11
3	Cutting and Slicing	10	12	0.83	0.17	4.17	0.50	0.42
4	Steaming	14	18	0.77	0.22	2.72	0.25	0.19
5	Frying and Drying	16	20	0.80	0.20	3.20	0.25	0.20
6	Cooling	14	18	0.77	0.22	2.72	0.25	0.19

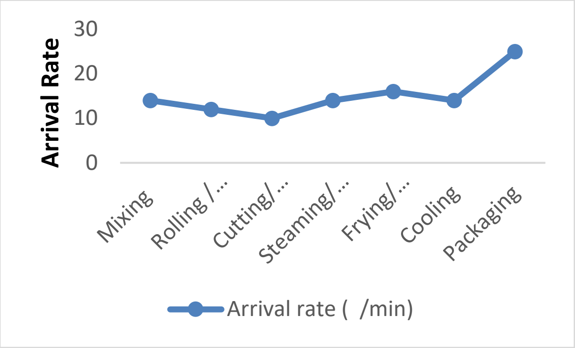

Figure 1: Arrival Rate in Each Work Station

The noodle production (Figure 1) starts with the mixing station where 15 units arrives per minute to be processed and then proceeds to the rolling/sheeting station, cutting station, steaming, frying, cooling and then finally the packaging station (25 units/minute) which has most of the units to be processed at this stage. The workstation with the least amount of units processed was the cutting station (10 units/minute).

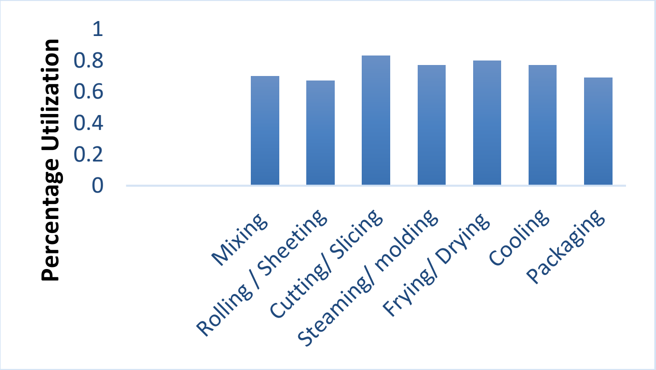

Figure 2: Utilization of Various Work Stations in Noodle Production

However, in the rolling and sheeting station the service rate and arrival rate difference was less and this enabled the rolling process to be a fast one with lesser units of noodles to be processed at every instant and this makes the utilization of the equipment to be at 67% (Figure 2).

3.3 Meantime Spent in Queue and Process

The meantime spent in the process determines how long the queue would be during processing of noodles in each workstation as found in Figure 3.The meantime spent for the mixing and rolling station was observed to be at 0.12 and 0.11.The cutting and slicing unit was observed to possess the highest at 0.5% and 0.4%of the entire process in the queue due to the technicality of the cutting. For the streaming, frying and cooling workstations, the meantime spent were on an average of 0.19%, 0.2% and 0.19% respectively. The packaging had the lowest rating on meantime being spent at 0.09% and 0.06% since the process of packaging was faster and less complicated (Figure 3).

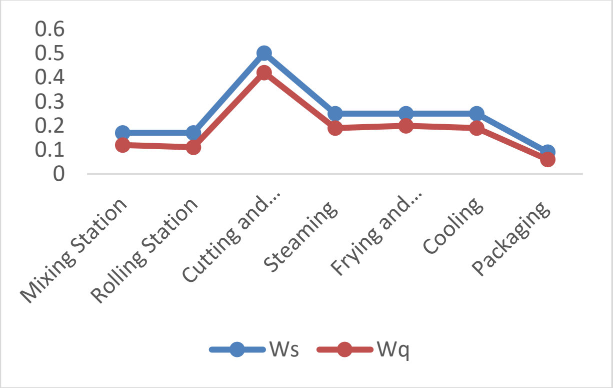

Figure 3: Meantime Spent in the Whole Process and Meantime Spent in the Queue

4. CONCLUSION

From this research, the production process and times of instant noodles were analyzed theoretically with emphasis on the arrival and service rate on each workstation in the plant. It was observed that the arrival rate 0ranges of 10 - 25 units/minute was processed at each workstation and the rate of service of each process was from 12 - 36 units/minute. The time for each process varied as the highest arrival rate and service were observed at packaging station while the lowest was observed at the cutting station.

The utilization of each workstation was determined by using queuing model for multi-channel single server analysis and the results were computed to obtain the meantime spent on each process during operations. The workstation most utilized was the cutting (slicing) workstation and the least utilized was the rolling (sheeting) station. This low utilization of the equipment resulted in the increased time being spent in the whole process thereby reducing the total production time.

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