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# IDENTIFICATION AND MODELING OF DOMINANT CAUSES OF CONGESTION IN A FIXED-LINE NETWORK

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***ABSTRACT :*** *In this paper, the dominant causes of congestion in the fixed network of the Nigerian Telecommunications (NITEL) Ltd. were modelled and analysed. Teletraffic data were obtained from NITEL fixed network in Kaduna for a period of 18 months. The data were analysed based on the quality of service (QOS) as defined by the Nigerian Communications Commission (NCC). The dominant causes of congestion were identified from the data and their rate of occurrence was seen to be random in nature. A Poisson probability distribution model was implemented for the prediction of congestion in the network. The identified four dominant causes of congestion and their relative weights based on their frequency of occurrence were: (i)* $X_1$*: Faulty System (52.25%); (ii)* $X_2$*: Faulty Trunk(s) (34.24%); (iii)* $X_3$*: Power Failure (11.73%) and (iv)* $X_4$*: Cable Cut (01.78%). MATLAB (M-file Data Acquisition Toolbox) programming environment was used to write a software program in C++ language that simulated the four dominant causes of congestion. Pearson Product Moment Correlation Coefficient formula was used to test the relationship between the measured and simulated congestion. A correlation coefficient of 0.8077 was obtained between the measured and simulated results. This shows that the model is reasonably reliable.*

***Key words – Congestion, Fixed network, Poisson, Probability, NITEL.***

## I. Introduction

In telecommunications networks, congestion is the condition of a network where the immediate establishment of a new connection is impossible owing to the unavailability of network element [1]. In data networks, congestion occurs when a link or node is carrying a large number of packets that approaches or exceeds the packet handling capacity of the network.

In fixed networks, congestion during peak periods and at hot spots is a major problem. Increase in channel capacity may appear to be a natural solution to this problem. However, it is not economically viable due to the heavy cost of infrastructure involved [2]. Since the traffic demand is increasing on daily basis, the problem of congestion is going to persist. Consequently it needs to be effectively addressed.

### 1.1 Main Causes of Congestion

The main causes of congestion in NITEL's fixed network have been identified to include:
(i) Irregularity in public power supply; (ii) Copper cable cut; (iii) Destruction of NITEL pole/mask; (iv) Propagation impairments; (v) Traffic build up (peak period); (vi) Terminal equipment failure; (vii) Inadequate dimensioning of the switching network

### 1.2 Objectives of the Study

The objective of this work is three fold: (i) to identify the dominant causes of congestion in a fixed network by using Messrs. NITEL Ltd. telecommunications network in Kaduna as a case study; (iii) to develop a model for the prediction of congestion in the network using Poisson distribution function; (iii) validate the model using Pearson Product Moment Correlation Coefficient method.

## II. Literature Review

Some of the key studies undertaken by researchers on the causes and minimisation of congestion in telecommunications networks are reviewed as follows:

2.1 Mr. Kuboye [3] worked on the 'Optimization Model For Minimizing Congestion In Global System For Mobile communications (GSM) In Nigeria'. He presented six models for minimizing congestion which include: (i) Partnership between government/corporate organization with GSM operators; (ii) Dynamic half rate; (iii) National roaming agreement; (iv) Regionalization and (v) Merging of networks. Finally he concluded that service providers have to monitor and optimize their network continuously.

2.2 Mesrrs. Keon et al [4] reported on 'A New Pricing Model For Competitive Telecommunications Services Using Congestion Discount'. They presented a model that uses price discount to stimulate subscribers to withdraw their calls at peak period to a later time of less congestion, otherwise the customer is serviced at a higher price.

2.3 Merrs. Andreas et al [5] reported on 'Fuzzy Logic based Congestion Control'. They presented an illustrative example of using Computational intelligence (CI) to control congestion using Fuzzy logic. Their model and their review on CI methods applied to ATM networks shows that CI can be effective in the control of congestion.

2.4 Merrs. Chandrayana et al [6] researched into the 'Uncooperative Congestion Control'. They proposed an analytical model for managing uncooperative flows in the internet by re-mapping their utility functions. They implemented the edge-based re-maker in the Network Simulator (NS). They used Exponential Weighted Moving Average (EWMA) and Weighted Average Loss Indication (WALI). Their scheme works with any Active Queue System (AQM) scheme and also with Drop Tail queues. These works helps a great deal in controlling congestion, but, for more effective congestion management, the need for the prediction of congestion in fixed telecommunications network is required.

## III. Measurement Setup

A block diagram of the measurement setup Fig.1

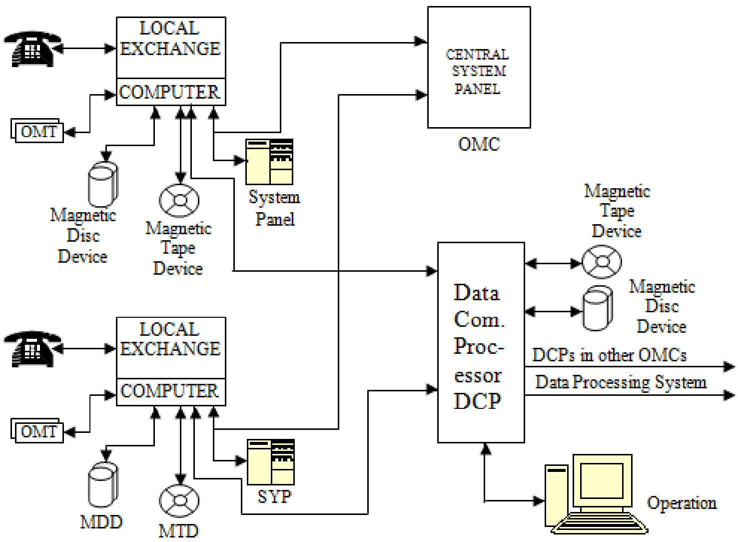


Figure 1. Block diagram of traffic data collection setup. Source: NITEL Ltd.

The Data Communication Processor (DCP) consists of processor of speed 2Mbps and seven storage Magnetic Disc Devices (MDDs) with a capacity of 4.8G each. It is designed to handle a traffic capacity of 25,200 erlangs and have room for expansion. At the operation section, computer with Windows 2000 is used to retrieve data in the DCP. This computer is used to monitor and measure performance indices of the traffic such as:

(i) Call Completion Rate (CCR): This is the ratio of successfully completed calls to the total number of attempted calls (ITU-TE600/2.13). This ratio is expressed either as a percentage or a decimal fraction. The parameter Call Through, which comprises of Answered Call, Unanswered Call and User's Busy, is divided by the attempted call and the results are presented in percentage. The Nigerian Communication Commission (NCC) standard for CSSR is $\geq 90\%$ [7][8].

(ii) Busy Hour Call Attempt: Busy Hour Call Attempt (BHCA) is a teletraffic engineering measurement used to evaluate and plan capacity for telephone network. BHCA is the number of telephone calls attempted at the busiest hour of the day and the higher the BHCA, the higher the stress on the network processor. If a bottleneck in the network exists with a capacity lower than the estimated BHCA, then congestion will occur resulting in many failed calls.

(iii) Call Through: Call Through (also called a Complete Call) is achieved when a call successfully arrives its destination. A complete call is a call that is released by normal call clearing i.e., Released Message "RL_M" and Released Complete Message "RLC_M" has been successfully exchanged in the signaling flow,[9][10] be it during a ringing phase or conversation phase by either the caller or called party. Call Through is an important parameter in the calculation of Call Completion Rate (CCR).

(iv) Answer Seizure Ratio (ASR): The ratio of the number of successful calls over the total number of outgoing calls from a carrier's network. The NCC standard for ASR is ≥ 40.0%.[8][9]

The summary of the data collected and their probability of occurrence were depicted in Table 1[11].

Table 1 Probabilities of dominant causes of congestion. Source: NITEL Ltd.

| WEIGHTED PROBABILITY OF DOMINANT CAUSES OF CONGESTION | | | | |
|---|---|---|---|---|
| *Causes of Congestion* | *Denoted* | *Percentage Range* | | *Percentage weight(s) (based on occurrence)* |
| | | CCR (%) | ASR (%) | |
| Faulty System | $X_1$ | 80 – 90 | 34 – 40 | 52.25 |
| Faulty Trunk | $X_2$ | 50 – 80 | 20 – 34 | 34.24 |
| Power Failure | $X_3$ | 0 – 30 | 0 – 15 | 11.73 |
| Cable Cut | $X_4$ | 30 – 50 | 15 – 20 | 01.78 |

The model is developed using the two major network performance indices namely (i) Call Completion Rate (CCR), and (ii) Answered Seizure Ratio (ASR).

This ratio is typically expressed as either a percentage or a decimal. CCR is the number of calls of specific duration successfully completed measured per 100 calls [10].

$$\text{CCR} = \frac{Call\ Throug\ h}{Total\ Number\ of\ Call\ Attempts} \text{ X } 100\% \quad (1)$$

The traffic data reveals that there were 53 drops of CCR below 90% within the sampling period. The traffic data also reveals 58 records of ASR below 40% within the sampling period. ASR is given as:

$$\text{ASR} = \frac{ANS\ CALLS}{CALL\ ATTEMPTS} \text{ X } 100\% \quad (2)$$

## IV. Development of Model

4.1 Distributions of the Poisson Process

If you consider the arrival process of a call at a switching center as a point process i.e. considering arrivals within two non-overlapping time interval, Poisson process is used in a dynamical and physical way to derive the probability of this arrival. The probability that a given arrival pattern occurs within a time interval is independent of the location of the interval on the time axis.

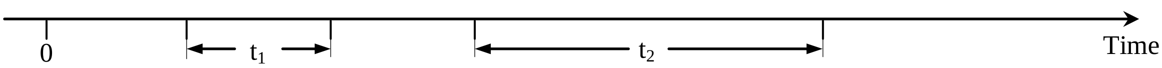


Figure 2 Deriving the Poisson process.

Let p($v$, $t$) denote the probability that $v$ events occur within a time interval of duration t. The mathematical formulation of the above model is as follows [12]:

i. *Independence:* Let $t_1$ and $t_2$ be two non-overlapping intervals Fig. 2. Then because of the independence assumption we have:

$$p(0, t_1).p(0, t_2) = p(0, t_1 + t_2) \quad (3)$$

ii. Equation (3) implies that the event "no arrivals within the interval of length 0" has the probability one:

$$p(0, 0) = 1 \quad (4)$$

iii. The mean value of the time interval between two successive arrivals is 1/β:

$$\int_0^{\infty} p(0,t)dt = \frac{1}{\beta}, \qquad 0<1/\beta<\infty \quad (5)$$

Here p(0, t) is the probability that there are no arrivals within the time interval (0, t), that is the probability that the time before the first event is larger than time t (the complementary distribution function).

iv. Equation (5) implies that the probability of "no arrivals within a time interval of length ∞" is zero as it never takes place:

$$p(0, \infty) = 0 \quad (6)$$

Due to the stochastic nature of congestion occurrence as well as the large sampling size, the Poisson distribution function will be used to model the probability of congestion.

The modeling for this study will be based on the traffic data obtained from NITEL between June 2007 and November 2008.

Congestion is considered when the parameter readings {CCR(%) and ASR(%)} exceed the benchmark set by the Nigerian Communications Commission (NCC). (i.e. 90% and 40% respectively).

Using the total element (sampling size):

$$\eta = 549 \quad (7)$$

Let congestion due to:

Faulty system be $X_1$
Faulty trunk(s) be $X_2$
Power failure be $X_3$
Cable cut be $X_4$ where: $X_1$, $X_2$, $X_3$ and $X_4$ are random variables.

The statistical mean of the Poisson distribution is given as [13]:

$$E\{X\} = \mu_x = \sum_{i=1}^{n} x_i P(X = x_i) = \eta p \quad (8)$$

And the variance of Poisson distribution is given as:

$$E\{[X- \mu_x]^2\} = \sigma_x^2 = \sum_{i=1}^{n} (x_i - \mu_x)^2 P(X = x_i) = \eta p \quad (9)$$

Let the probability that X within the sample space takes a value $x_i$ which is independent of time and also independent of the next value $x_{i+1,}$ then the probability of the four factors causing congestion, i.e. $X_j = x_i$ is given as $P(X_j = x_i)$.

Where j = (1, 2, 3, 4) and i = (1, 2, 3, ............., 549)

The rate of congestion occurrence of any of the factors of congestion is

$P(X_1 = x_i) = 0.1056$
$P(X_2 = x_i) = 0.0692$
$P(X_3 = x_i) = 0.0237$
$P(X_4 = x_i) = 0.0036$

Let these occurrences with their relative weights be given as

$P(X_1 = x_i) = 0.1056 \text{ X } 0.5225 = 0.05517600$
$P(X_2 = x_i) = 0.0692 \text{ X } 0.3424 = 0.02369408$
$P(X_3 = x_i) = 0.0237 \text{ X } 0.1173 = 0.00278001$
$P(X_4 = x_i) = 0.0036 \text{ X } 0.0178 = 0.00006408$

Summing the average outcome of the four factors that cause congestion, with respect to their relative weights, we have:

$$\sum_{j=1}^{4} P\left(X_j = x_i\right) = \sum_{j=1}^{4} p(X_j) = 0.08171417 \quad (10)$$

Using the following equation, the sum mean of the statistical means is:

$$\sum_{j=1}^{4} np(X_j) = (\eta p) = \mu = 549 \text{ X } 0.08171417 = 44.86107933 \quad (11)$$

Therefore, the Poisson model accepts

$X_{1,}$ $X_{2,}$ $X_{3,}$ $X_4$ and η,

Compute:

$$k = \sum_{i=1}^{4} x_i * (weight\ of\ x_i) \quad (12)$$

$$P_{MN} = \frac{e^{-(np)}(np)^k}{k!} \quad (13)$$

Where η = (1, 2, ............, η) gives the number of days within which the probability is required

p = 0.08171417

The median of the distribution is given as [12]:

$$\text{Median} \approx \left(\sum_{j=1}^{4} np(X_j) + \frac{1}{3} - \frac{0.02}{\sum_{j=1}^{4} np\,(X_j)}\right) \quad (14)$$

$$\approx (44.86107933) + \frac{1}{3} - \frac{0.02}{44.86107933})$$
$$\approx 45.194858$$

A program was written in C++ language using MATLAB (M-files Data Acquisition Toolbox) version 7 to implement (12) and (13).

The flowchart of the program is shown in Fig. 3. The flowchart begins by initializing the graphical user interface GUI, and then a selection of the task to be taken. A pop-up menu appears, requesting for the input parameters and the number of days (elements) to be entered. The program calculates the probability of congestion occurring in the network and also displays the probability of Transmission Channel (TCH) Congestion within these days. The program ends when there is no further entering of the congestion parameter.

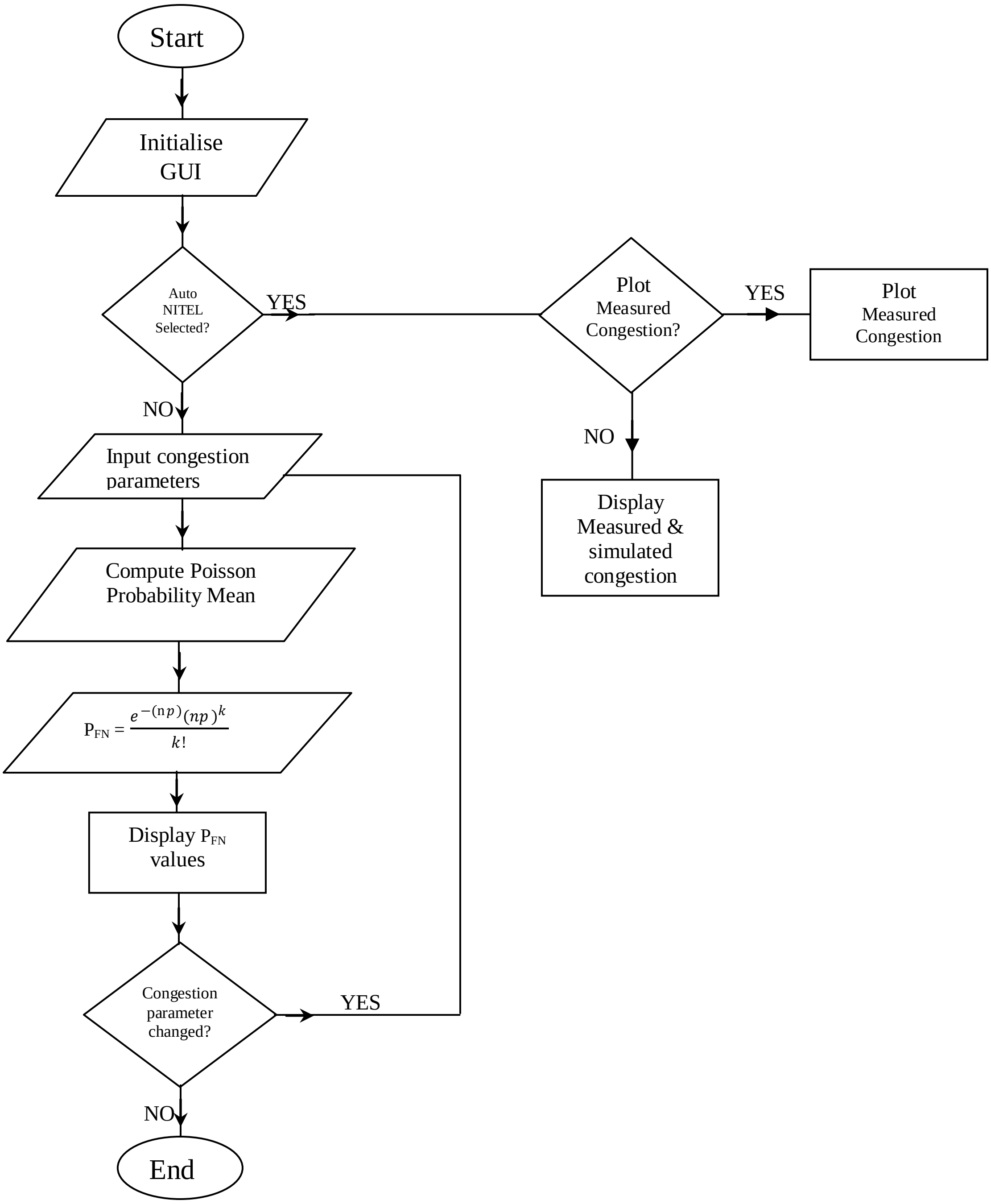


Figure 3. Model Flowchart

## V. RESULTS

5.1 The measured congestion based on the traffic data obtained from Messrs. NITEL Ltd. (see Appendix A) is shown in Fig. 4

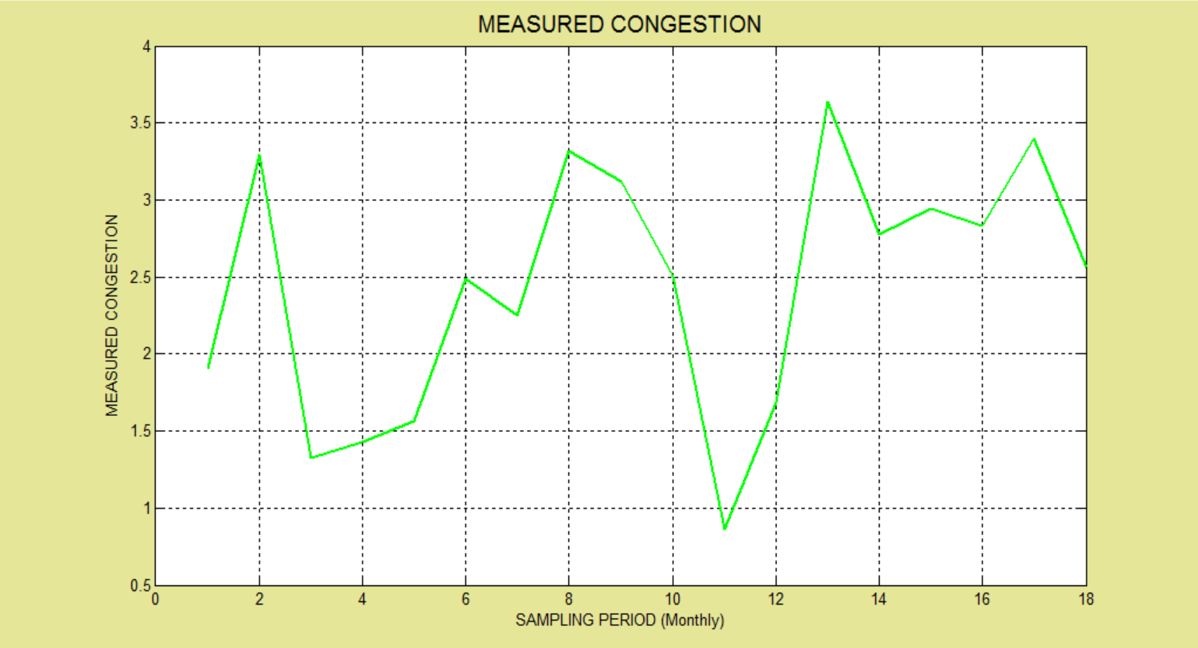


Figure 4. Measured Congestion

5.2 The simulated congestion based on equations (12) and (13) is shown in Fig. 5

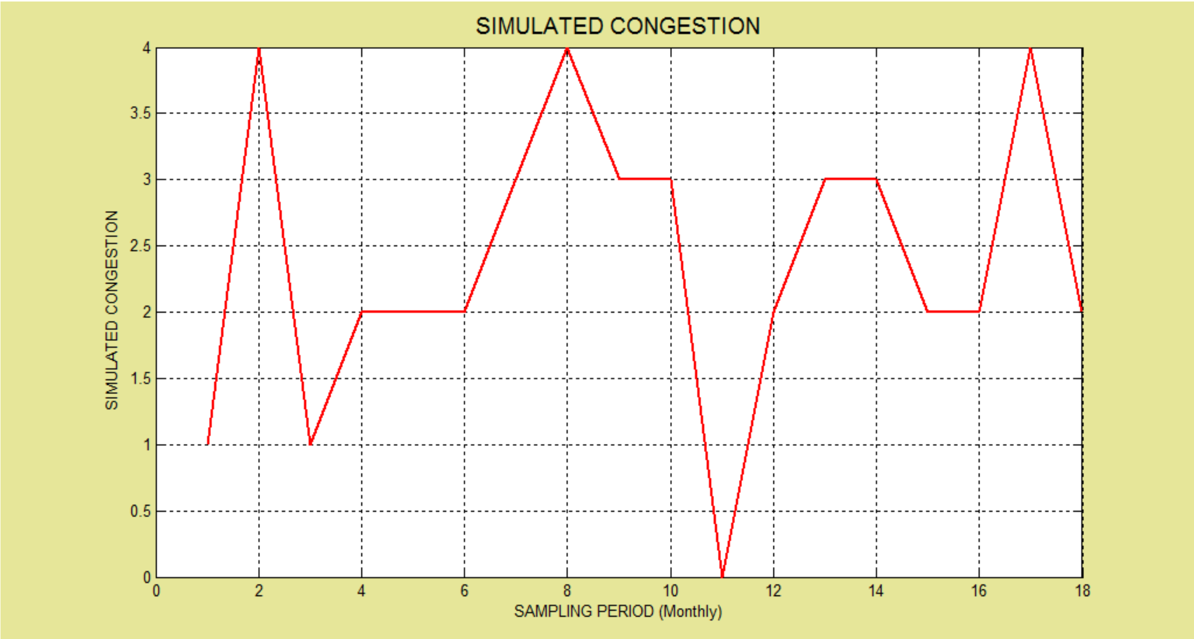


Figure 5 Simulated Congestion

5.3 Comparison of Measured and Simulated Results.

The following equation is used to derive the monthly congestion:

Measured congestion = $X_1 + X_2 + X_3 + X_4$ (15)

Where $X_1 = \sum_{i=1}^{n}(N_i * 0.5225)$

$X_2 = \sum_{i=1}^{n}(N_i * 0.3424)$

$X_3 = \sum_{i=1}^{n}(N_i * 0.1173)$

$X_4 = \sum_{i=1}^{n}(N_i * 0.0178)$

$N_i$ = number(s) of occurrence in the month

In Fig. 6 the green graph depicts the measured congestion while the red graph depicts the simulated congestion.

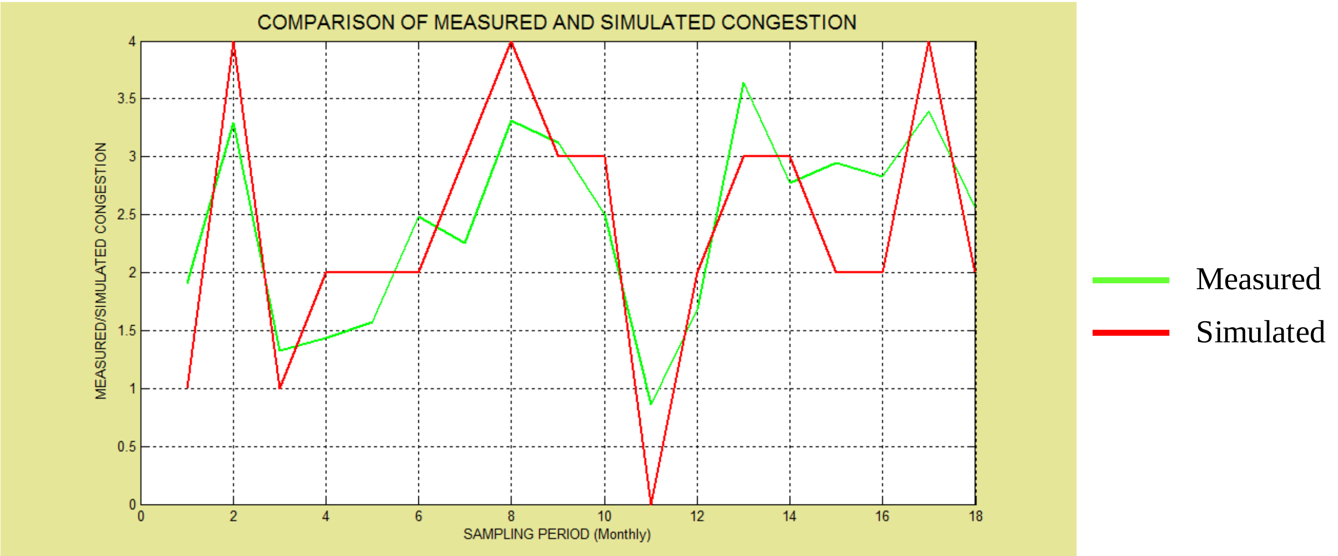


Figure 6. Comparison of Measured Congestion and Simulated Congestion

Reasons for the variation between the measured graph and the simulated graph is that the input values for $X_3$ and $X_4$ are reduced by the Poisson model due to their low weights. Also the Poisson simulated output using MATLAB returns an approximate integer 𝕶 such that the Poisson CDF evaluated at 𝕶 equals or exceeds the probability value.

The Pearson Product Moment Correlation Coefficient formula was used to test the relationship between the measured congestion and simulated congestion. The following equation is used to obtain the correlation coefficient r of the two variations [14]:

$$r = \frac{n\sum XY-(\sum X)(\sum Y)}{\sqrt{\{[n\sum X^2 -(\sum X)^2][n\sum Y^2-(\sum Y)^2]\}}} \quad (16)$$

Table 5.1 Show values for the correlation coefficient r. X and Y are the measured and simulated congestions respectively. The table was used to derive the input parameters for equation (16).

Table 5.1 Values for the correlation coefficient formula r.

| MONTH | X | Y | $X^2$ | $Y^2$ | XY |
|---|---|---|---|---|---|
| Jun’07 | 1.9099 | 1 | 3.647718 | 1 | 1.9099 |
| Jul’07 | 3.2973 | 4 | 10.87219 | 16 | 13.1172 |
| Aug’07 | 1.3246 | 1 | 1.754565 | 1 | 1.3246 |
| Sep’07 | 1.4312 | 2 | 2.048333 | 4 | 2.8642 |
| Oct’07 | 1.5675 | 2 | 2.457056 | 4 | 3.1350 |
| Nov’07 | 2.4869 | 2 | 6.184672 | 4 | 4.9738 |
| Dec’07 | 2.2523 | 3 | 5.072855 | 9 | 6.7569 |
| Jan’08 | 3.3151 | 4 | 10.98989 | 16 | 13.2604 |
| Feb’08 | 3.1172 | 3 | 9.716936 | 9 | 9.3516 |
| Mar’08 | 2.5047 | 3 | 6.273522 | 9 | 7.5147 |
| Apr’08 | 0.8649 | 0 | 0.748052 | 0 | 0 |
| May’08 | 1.6848 | 2 | 2.838551 | 4 | 3.3696 |
| Jun’08 | 3.6397 | 3 | 13.24742 | 9 | 10.9191 |
| Jul’08 | 2.7748 | 3 | 7.699515 | 9 | 8.3244 |

| | | | | | |
|---|---|---|---|---|---|
| Aug'08 | 2.9466 | 2 | 8.682452 | 4 | 5.8932 |
| Sep'08 | 2.8293 | 2 | 8.004938 | 4 | 5.6586 |
| Oct'08 | 3.3963 | 4 | 11.53485 | 16 | 13.5852 |
| Nov'08 | 2.5617 | 2 | 6.562307 | 4 | 5.1234 |
| | **Σ X = 43.9048** | **Σ Y = 43** | **Σ $X^2$ = 118.335822** | **Σ $Y^2$ =123** | **Σ XY = 117.0800** |

Therefore

$$r = \frac{18(117.0800) - (43.9048)(43.0000)}{\sqrt{\{[18(118.335822) - (43.9048)^2][18(123.0000) - (43.0000)^2]\}}}$$

$$= \frac{219.5336}{\sqrt{(202.413333)(365.0000)}}$$

= 0.8077

## VI. Conclusion

From the traffic data obtained, the occurrences of the identified causes of congestion are random in nature and have a relative percentage weights of (i) $X_1$: Faulty System (52.25%); (ii) $X_2$: Faulty Trunk(s) (34.24%); (iii) $X_3$: Power Failure (11.73%) and (iv) $X_4$: Cable Cut (01.78%). Congestion occurrence appears to be high during festive period indicating that the switching processor is not adequately dimensioned to handle such traffic. A correlation coefficient of 0.8077 shows a close relationship between the measured and simulated congestions. This indicates that the prediction model is reasonably accurate.

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APPENDIX A

SUMMARY OF ALL THE CONGESTIONS IN THE DATA OBTAINED FROM MESSRS. NITEL LTD.

| | Call Completion Rate (CCR) | | | | Answer Seizure Ratio (ASR) | | | |
|---|---|---|---|---|---|---|---|---|
| **S/N** | **Date** | **Value (%)** | **Date** | **Value (%)** | **Date** | **Value (%)** | **Date** | **Value (%)** |
| 1 | 13/06/07 | 82.24 | 7/06/08 | 86.43 | 5/06/07 | 36.45 | 19/04/08 | 32.85 |
| 2 | 4/07/07 | 79.41 | 14/06/08 | 86.80 | 15/06/07 | 32.48 | 11/05/08 | 35.78 |
| 3 | 7/07/07 | 74.44 | 19/06/08 | 77.03 | 27/06/07 | 39.36 | 13/06/08 | 32.11 |
| 4 | 11/07/07 | 88.89 | 29/06/08 | 84.10 | 10/07/07 | 37.51 | 15/06/08 | 26.70 |
| 5 | 13/07/07 | 89.74 | 8/07/08 | 86.12 | 12/07/07 | 35.69 | 25/06/08 | 34.17 |
| 6 | 21/07/07 | 86.12 | 20/07/08 | 84.67 | 5/08/07 | 25.76 | 5/07/08 | 35.70 |
| 7 | 10/08/07 | 25.39 | 1/08/08 | 79.41 | 7/08/07 | 36.09 | 10/07/08 | 26.80 |
| 8 | 2/09/07 | 65.03 | 4/08/08 | 0 | 20/08/07 | 32.79 | 15/07/08 | 29.80 |
| 9 | 6/09/07 | 85.96 | 11/08/08 | 78.13 | 16/09/07 | 35.21 | 20/07/08 | 38.90 |
| 10 | 8/009/07 | 89.37 | 16/08/08 | 86.80 | 17/09/07 | 39.43 | 4/08/08 | 0 |
| 11 | 30/09/07 | 66.80 | 31/08/08 | 75.50 | 1/10/07 | 36.32 | 11/08/08 | 35.77 |
| 12 | 3/11/07 | 76.21 | 3/09/08 | 89.74 | 14/10/07 | 37.09 | 21/08/08 | 14.72 |
| 13 | 7/11/07 | 0 | 13/09/08 | 24.87 | 24/10/07 | 37.69 | 23/08/08 | 33.27 |
| 14 | 24/11/07 | 83.73 | 26/09/08 | 0 | 7/11/07 | 0 | 3/09/08 | 31.48 |
| 15 | 25/11/07 | 75.56 | 1/10/08 | 84.87 | 10/11/07 | 38.52 | 6/09/08 | 24.50 |
| 16 | 3/01/07 | 83.73 | 8/10/08 | 84.67 | 29/11/07 | 37.54 | 14/09/08 | 31.59 |
| 17 | 8/01/07 | 47.03 | 9/10/08 | 77.77 | 31/11/07 | 32.47 | 25/09/08 | 36.94 |
| 18 | 10/01/07 | 84.21 | 15/10/08 | 13.73 | 2/12/07 | 35.61 | 26/09/08 | 0 |
| 19 | 17/01/07 | 72.22 | 18/10/08 | 84.21 | 6/12/07 | 36.90 | 12/10/08 | 31.57 |
| 20 | 23/01/07 | 88.01 | 25/10/08 | 79.41 | 22/12/07 | 35.80 | 13/10/08 | 24.99 |
| 21 | 29/01/07 | 76.65 | 4/11/08 | 86.80 | 27/12/07 | 31.70 | 18/10/08 | 31.56 |
| 22 | 1/02/08 | 86.60 | | | 13/01/07 | 35.61 | 6/11/08 | 32.98 |
| 23 | 8/02/08 | 73.14 | | | 19/01/07 | 38.94 | 8/11/08 | 37.86 |
| 24 | 17/02/08 | 83.92 | | | 7/02/08 | 38.55 | 15/11/08 | 12.47 |
| 25 | 3/03/08 | 87.19 | | | 8/02/08 | 32.69 | 20/11/08 | 36.83 |
| 26 | 7/03/08 | 0 | | | 20/02/08 | 38.90 | 27/11/08 | 39.06 |
| 27 | 10/03/08 | 77.20 | | | 29/02/08 | 32.69 | | |
| 28 | 22/03/08 | 75.17 | | | 7/03/08 | 0 | | |
| 29 | 4/05/08 | 84.34 | | | 12/03/08 | 15.48 | | |
| 30 | 7/05/08 | 16.11 | | | 17/03/08 | 36.61 | | |
| 31 | 22/05/08 | 85.06 | | | 24/03/08 | 34.62 | | |
| 32 | 3/06/08 | 84.10 | | | 13/04/08 | 34.82 | | |