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MODELLING OF DECENTRALIZED MEDICATION DISTRIBUTION PROCESSES IN HOSPITAL USING TIMED PETRI NETS

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Abstract— Medication distribution system is fundamental to the well-being of patients in hospital because it describes how prescribed drugs are efficiently made available to patients through centralized or decentralized pharmacy services. In this paper, Timed Petri Net (TPN) formalism is explored to develop a TPN model for a decentralized medication distribution processes in hospital using Bowen university teaching hospital (BUTH) as a case study. The model abstracted the medication distribution processes across inpatient-pharmacy department of the hospital and six wards. The model consists of six sub-models which include children's ward sub-model, women's ward sub-model, men's ward sub-model, private ward sub-model, neonatal/maternity ward sub-model and intensive care ward sub-model. Each sub-model abstracted the prescription, checking and billing, transportation and administration of medication to patients subject to two ward aids and two nurses being utilized per ward. The simulation results of the developed TPN model revealed that the two pharmacists were able to completely treat all 260 requests received in the in-patient pharmacy. Also, the simulation results showed that out of 260 requests received in the in-pharmacy, a pharmacist could not treat more than 102 requests. The validation of the developed TPN model showed that there were no significant differences between the simulated and real number of medication requests. Thus, the developed TPN model can be easily used to predict the amount of pharmacist needed for effective decentralized medication distribution processes in hospital.

Keywords — Medication distribution system, Pharmacy, BUTH, Petri Nets, model, Sub-models, Hospital

1. INTRODUCTION

The pharmacy sector is important in any country because it consumes a high proportion of health system expenditure. Therefore, it is a challenge for governments to ensure easy access to a safe and stable supply of pharmaceuticals at the lowest possible cost [1]. The role of the pharmacist has always been to ensure that patients receive the appropriate medication in an acceptable dosage form that facilitates safe administration and improved outcomes. Despite the expanding clinical role of pharmacists, distribution of drug products will continue to be an important responsibility of pharmacists in health care institution [2].

In many hospitals, a drug distribution system is required to supply the medication prescribed for each inpatient. The drug distribution system includes all the processes that occur between the prescription of a drug and the administration of that drug to the patient. There are many varieties of drug distribution system in use throughout the world, but all have the same goal: to ensure that each dose of medication administered to each patient is exactly that which was intended by the prescriber [3]. The dispensing of medication is of great importance for the success of the pharmaceutical and therapeutic treatment. It is a technical and scientific activity directed towards the patient, who should only be carried out by qualified professionals, such as a pharmacist. A rational distribution of medication enables consumers to receive the right product, in the right quantity and specifications, and in a reasonable time, obtaining the best cost efficiency [4].

The drug distribution procedure has various stages, starting with a prescription and ending with the administration of the drug to the patient. All the steps along the procedure depend on the various health care professionals, and are directly connected. Thus, the prescription is the Doctor's responsibility, the dispensing is the pharmacist's responsibility, the distribution or delivery to the floor or sector where the drug is needed is the responsibility of a care-giver or ward aid, and the administrations as well as patient monitoring are the responsibility of the nurse. Drug distribution is among the pharmacist's most important responsibilities. Therefore, to ensure that these responsibilities are met, adequate methods must be developed and implemented.

There are two basic known types of drug distribution systems: collective and individual [5]. The collective system is the most primitive, although there are hospitals worldwide that adopt this system, it is considered to be the simplest and lowest in cost of deployment. The individual distribution system is a more complex system which requires more professional pharmacists and a hospital pharmacy working around the clock. Its main features entails that the product or drug is dispensed per patient, and not for the sector in which one may find himself hospitalized. The individual drug distribution is a unit dose system and it is a unique method for the supply of medication for each patient in the ward based on their twenty-four hour requirements from the in-patient pharmacy [6]. Also, the types of pharmacy services include centralised and decentralised pharmacy services. The centralized pharmacy services is a model that distributes medications from a centralized pharmacy location while decentralized pharmacy services is a model that distributes medications from a decentralized satellite pharmacy located in or near a patient care area [5 ,7].

Petri Nets have been proven to be a powerful modelling tool for various kinds of distributed event systems [8, 9], and its formalism provides a clear means for presenting simulation and discrete event systems. Hence, Petri Nets can be used to model drug distribution systems. Petri Nets is a graphical oriented language for modelling and validation of distributed systems in which communication, synchronization and resource sharing play a major role [10]. It is an example of low-level Petri

Nets which can be extended with time concept [11]. With a Timed Petri Nets, it would be possible to calculate performance measures such as the speed by which a system operates, mean waiting time and throughput.

2. RESEARCH METHODOLOGY

2.1 OVERVIEW OF THE MODELLING APPROACH

In this paper, a Timed Petri Net (TPN) formalism stated in (1) was used to develop a model for the medication distribution system in the hospital under consideration. A Timed Petri Nets are tuples define as four-tuple [12].

PN = (P, T, A, w),

Where:

P is the finite set of places, $P \neq \emptyset$

T is the finite set of transitions, $T \neq \emptyset$

$A \subseteq (P \times T) \cup (T \times P)$ is the set of arcs from places to transitions and from transitions to places

w: $A \rightarrow \{1, 2, 3 \ldots\}$ is the weight function on the arcs.

A marked Petri net is a five-tuple (P, T, *A*,w,M) where

(*P*, *T*, *A*,*w*) is a Petri Net and *M* is a marking, defined as a mapping $M : P \rightarrow \mathbf{N+}$

Thus, a marking is a row vector with |P| elements.

2.2 DESCRIPTION OF THE CASE STUDY

In developing a Timed Petri Nets (TPN) model for decentralized hospital medication distribution processes, Bowen University Teaching Hospital (BUTH), Ogbomoso, Oyo state Nigeria was used as a case study. The teaching hospital has In-patient Pharmacy where various types of prescription are being received from doctors. The In-Pharmacy department serves six wards, which include children's ward, women's ward, men's ward, neonatal/maternity ward, private ward and intensive care unit. The three basic types of medication request characterizing the medication distribution system of BUTH include urgent request, regular (daily) prescription and medical (ward stock) request. There are three basic types of medication request identified in the medication distribution system of the Bowen University Teaching Hospital. These include urgent request, regular (daily) prescription and medical cabinet request.

(i) Urgent request: This happens if a determined medication is required in a ward but is not available in the ward's cabinet. Because the medications to be used cannot be predicted, and patient's treatment needs to be adjusted quickly, medications (which are not in the predicted daily request ordering or in the ward's medical cabinet) will be ordered directly from the hospital's in-patient pharmacy. The medication is immediately administered to the patient. Of the three requests being used in this hospital, urgent (emergency) request is highly prioritized, because it is characterized by urgency.

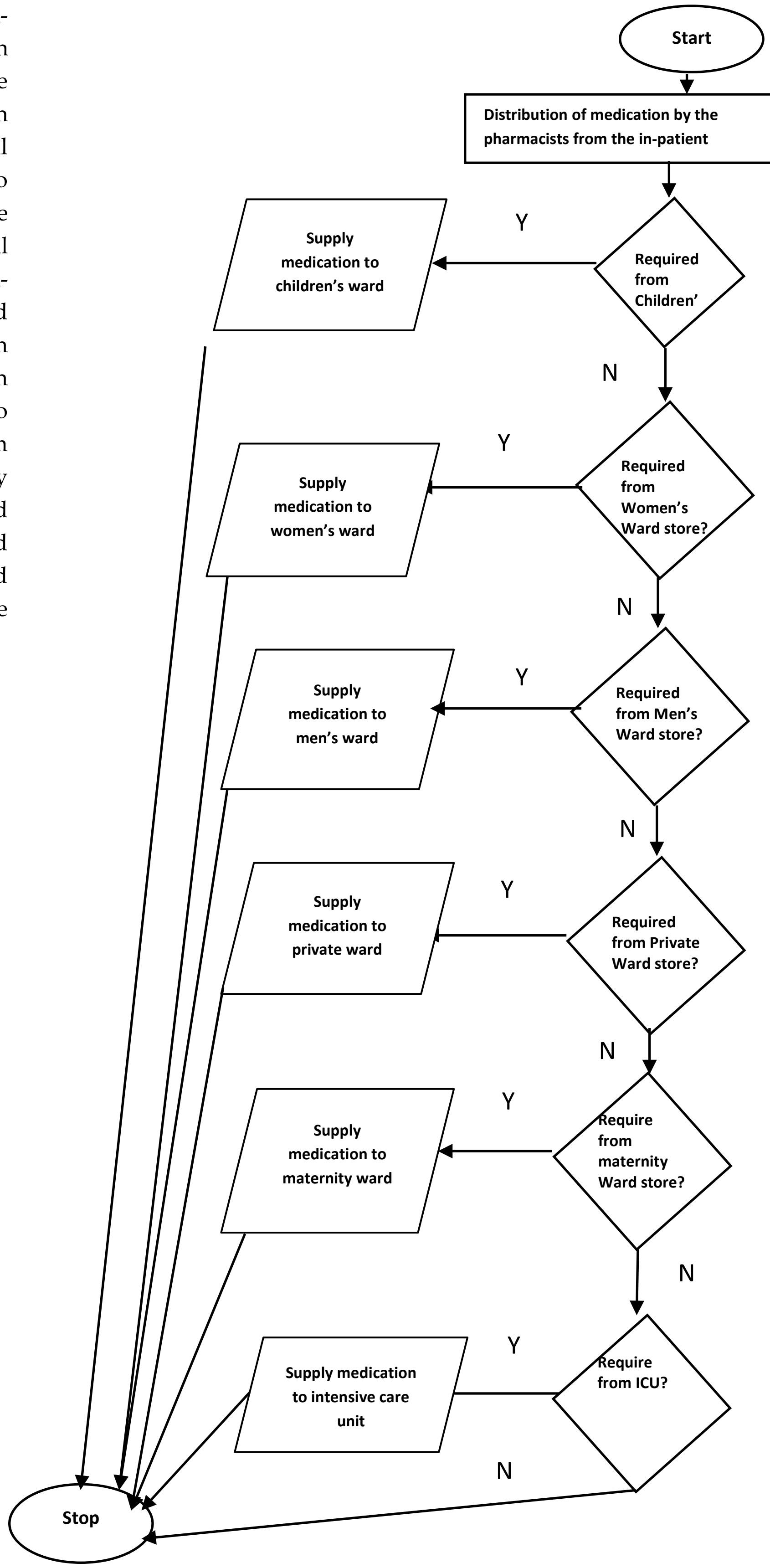
(ii) Daily Prescription: Under this type of request, each ward's nurse orders medications in accordance with pre-determined patient's treatment. Consequently, at the hospital (BUTH), there are six set of orders which are sent to in-patient pharmacy for preparation: these are then loaded into trolley for transportation to wards where nurses administer them to deserving patients in unit-dose. Here, the auxiliary nurse or ward aid is the transporter. Transportation of medications to where they are required depends on the distance between in-patient pharmacy and the ward. The nurses are fully responsible for administering medication to the patients. In order of priority, daily prescription is ranked second, because they have to set out on daily basis and at pre-determined time, dictated by patients' condition and deadlines set by nurses in every ward of the hospital.

(iii) Medicine Cabinet Request: It is concerned with re-stocking a medicine cabinet placed in a ward. The requests which are not in unit-dose are in boxes: when the stock in the cabinet is almost finished, the nurse re-stocks the cabinet through requisition from the pharmacy. Thereafter, the nurse prepares the medication into unit-dose for each patient, for distribution to the respective patients. After preparation, a ward aid transports the order in a box to appropriate ward in the hospital. It becomes the duty of the nurse to store the medications into the cabinet. This request is least prioritized, because the order is made before the medications are exhausted.

3.3 Medication Distribution Processes

Figure 1 show the decentralized medication distribution process where the medications are being distributed from the in-patient pharmacy to sub-pharmacy store in each wards under consideration. Figure 2 shows the sequential stages of medication distribution process in Bowen University Teaching Hospital Ogbomoso. It starts with the doctor who prescribes necessary drugs for the patient; the prescription may be urgent, daily or medical cabinet. Transportation of the drug to the in-patient pharmacy is the responsibility of ward aid based on a copy of the doctor's prescription slip. The pharmacist makes the prescription evaluation by checking and billing and also refers the prescription to the doctor if a problem is identified. The treatment of the prescription by the pharmacist is based on urgent, daily and medical cabinet request respectively. The ward aid then returns the medication to the ward where the nurse takes charge of the administration medication to the patient.

Figure1: Flow Chart of Decentralized Drug Distribution in BUTH



2.3 DATA COLLECTION AND ANALYSIS

Data set used in this research work was collected from the medical staff involved in the medication distribution process, which includes number of pharmacists, ward aids and nurses. The ranges of time taken to complete each of the medical personnel's tasks were collected and are shown in Appendices P-U. Also, the number of medical requests observed within seven days in each type of prescription was obtained.

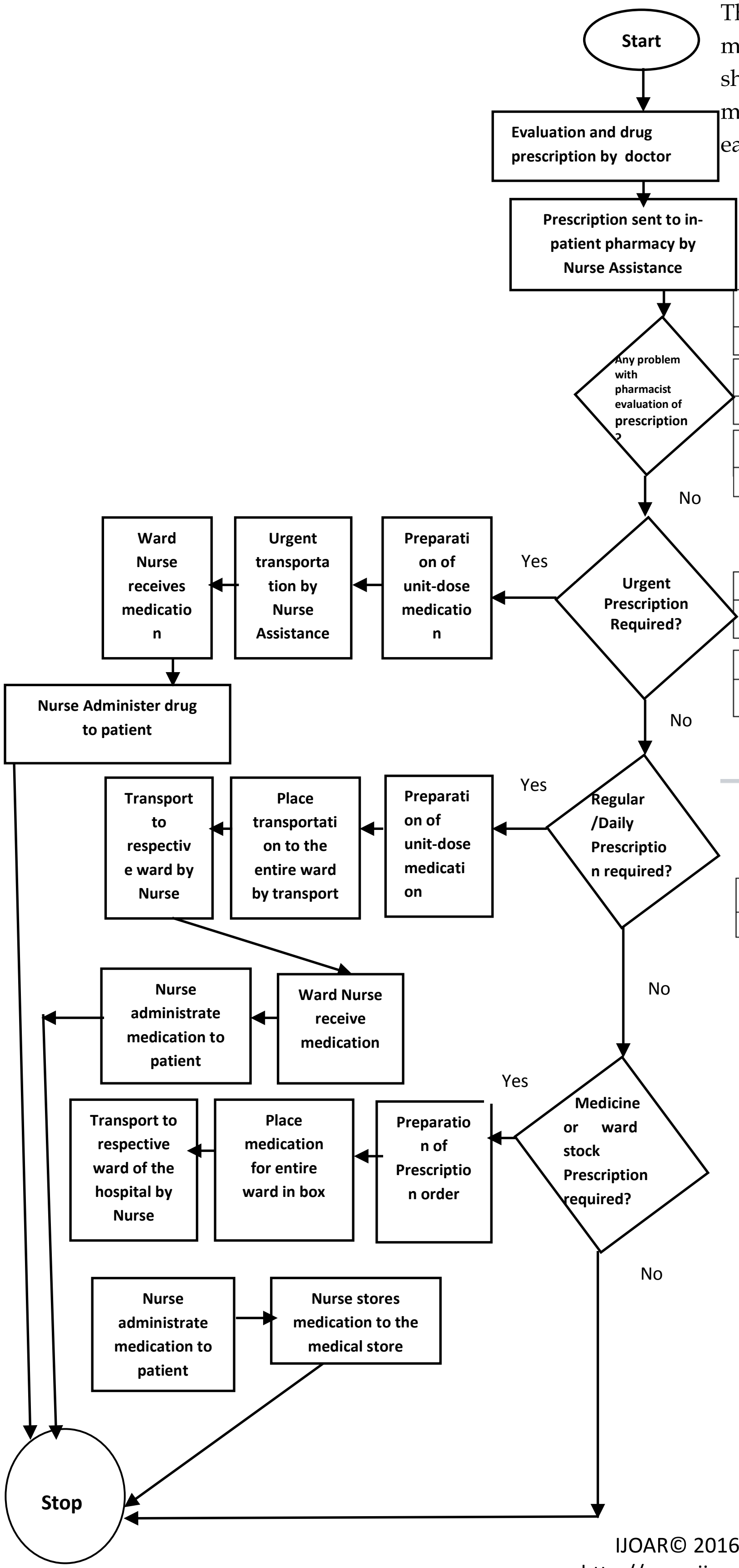


Table 1: Delay times for children's ward

Urgent Req	Checking and Billing	Prep_start	Start_transport	Administration
360	10	4	3	7

Daily Request	Checking and Billing	Prep_start	Start_transport	Administration
1440	7	10	4	45

Med.Cab. Req	Checking and Billing	Prep_start	Start_transport	Med_Cab_Storage
4320	8	7	4	6

Model Resource Values

Pharmacist	Ward aid	Nurse	Ware house
2	2	2	2

Pharmacist	Ward aid	Nurse	Ware house
1	2	2	2

Table 2: Delay times for women's ward

Urgent Request	Checking and Billing	Prep_start	Start_transport	Administration
540	7	4	3	5

Daily Request	Checking and Billing	Prep_start	Start_transport	Administration
1440	7	10	4	60

Med.Cab. Req	Checking and Billing	Prep_start	Start_transport	Med_Cab_Storage
5760	7	7	4	10

Model Resource Value

Pharmacist	Ward aid	Nurse	Ware house
2	2	2	2

Pharmacist	Ward aid	Nurse	Ware house
1	2	2	2

Table 3: Delay times for men's ward

Urgent Request	Checking and Billing	Prep_start	Start_transport	Administr
240	5	3	3	5

Daily Request	Checking and Billing	Prep_start	Start_transport	Administr
1440	7	7	4	60
Med.Cab. Req	Checking and Billing	Prep_start	Start_transport	Med.Cab Storag
2880	10	10	4	15

Model Resource Value

Pharmacist	Ward_aid	Nurse	Ware house
2	2	2	2

Pharmacist	Ward_aid	Nurse	Ware house
1	2	2	2

2.4 MODELLING OF THE MEDICATION DISTRIBUTION PROCESSES USING TPN

The Timed Petri Nets (TPN) model of the medication distribution process developed consist of six sub-models, namely children's ward sub-model, women's ward sub-model, men's ward sub-model, private ward sub-model, neonatal/maternity ward sub-model and Intensive care ward sub-model. Each sub-model comprises transitions, places, arcs and tokens. Transitions represent events occurring in the system that may cause change in condition of the medication distribution under consideration. Places represent the condition in the TPN model while arcs connect places to transitions and vice visa. Token are black dots or integers associated with places, a place containing tokens indicate that the condition holds.

Time delays used in the developed Time Petri Net define the times used to complete each tasks are those obtained from pharmacists and also from the available nurses and ward aids in the ward. Time delays are associated with transitions. The exponential time delays defined in this TPN model make the system unpredictable and random. All the transitions and places present in the net were monitored by setting ON the "watch" that graphically shows the behaviour of place and transition over time.

Table 1: Transitions employed in Children's Ward Sub-Model

Transitions	Actions
T_{URC}	Generates urgent prescription from the doctor.
T_{DAC}	Generates daily prescription of the doctor.
T_{MCC}	Generates medical cabinet request from nurse.
T_0	Checks and bills the urgent prescription in the pharmacy.
T_1	Checks and bills the daily prescription in the pharmacy.
T_2	Checks and bills the medical cabinet request in the pharmacy.
T_3	Prepares the medications in urgent request.
T_4	Prepares the medications in daily prescription.
T_5	Prepares the medications in medical cabinet request.
T_6	Transports the medications in urgent prescription.
T_7	Transports the medications in daily prescription.
T_8	Transport the medications in medical cabinet request.
T_9	Administers drug to the patient for urgent prescription.
T_{10}	Administers drug to the patient in daily prescription.
T_{11}	Stores medications into the medical cabinet.
T_{12}-T_{20}	Immediate transitions without delay in the model.

Table 2: Places employed in Children's Ward Sub-Model

Places	Descriptions
P_{URC}	Models the state of Urgent prescription in the pharmacy.
P_{DRC}	Models the state of Daily prescription in the pharmacy.
P_{MCC}	Models the state of Medical cabinet request in the pharmacy.
P_{Pharm}	Models the state of the pharmacist
P_{Store}	Models the state of storage of drugs in the pharmacy
P_0	Models the state of preparation of drugs in Urgent prescription
P_1	Models the state of preparation of the drugs in Daily prescription.
P_2	Models the state of preparation in Medical Cabinet request.
P_3	Models the state of drugs that are ready for transportation in Urgent Prescription.
P_4	Models the state of drugs that are ready for transportation in Daily Prescription.
P_5	Models the state of drugs that are ready for transportation in Medical Cabinet prescription.
P_6	Models the state of the drug being acquired by the ward aid in Urgent Prescription.

Table 3: Places employed in Children's Ward Sub-Model

Places	Descriptions
P_7	Models the state of the drug being acquired by the ward aid in Daily Prescription.
P_8	Models the state of the drug being acquired by the ward aid in Medic Request.
P_9	Models the state of the drug being delivered into the ward in Urgent Prescription
P_{10}	Models the state of the drug delivered into the ward in Daily Prescription
P_{11}	Models the state of the drug being delivered into the ward in Medic Cabinet Request
P_{12}	Models the state of the drug ready for administration in Urgent Req
P_{13}	Models the state of the drug ready for administration in Daily Req
P_{14}	Models the state of drug ready for administration in Medical Cab R
P_{15}	Models the state of the request being finalised in Urgent prescriptio
P_{16}	Models the state of the request being finalised in Daily prescription
P_{17}	Models the state of the request being finalised in Medical Cab Req
P_{18}	Models the final state of Urgent prescription
P_{19}	Models the final state of Daily prescription
P_{20}	Models the final state of Medical Cab Request
P_{NURC}	Models the state of nurse availability
P_{WAC}	Models the state of ward aid availability

3 The Developed TPN Model

Figure 1 shows the developed TPN simulation model of a decentralized medication distribution process of the hospital under consideration using TimeNet Tool. The figure 1 depicts the main page which models the six wards and the pharmacy department of the case study. Figure 2 depicts a single prescription type model for daily request while Figures 3, 4, 5, 6, 7 and 8 depict the sub-model of multiple prescription type which represents the medication distribution process for children's ward, women's ward, men's ward, private ward, neonatal/maternity ward and intensive care unit respectively.

Figure1: The developed TPN Model of the Medication Distribution Process

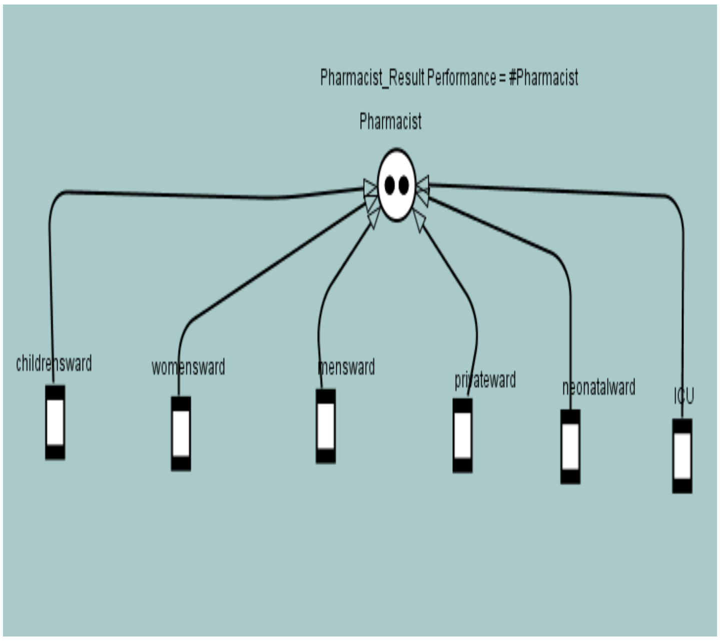


Figure2: Single Request model for the Medication Distribution Process

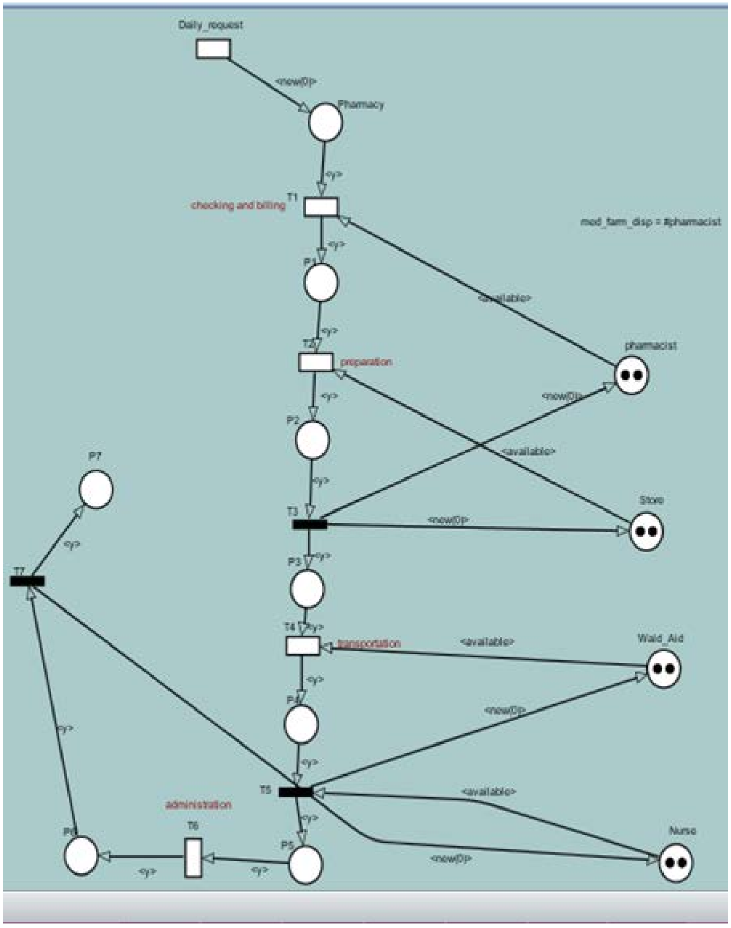


Figure 3: The Developed TPN Sub-model for Children's ward

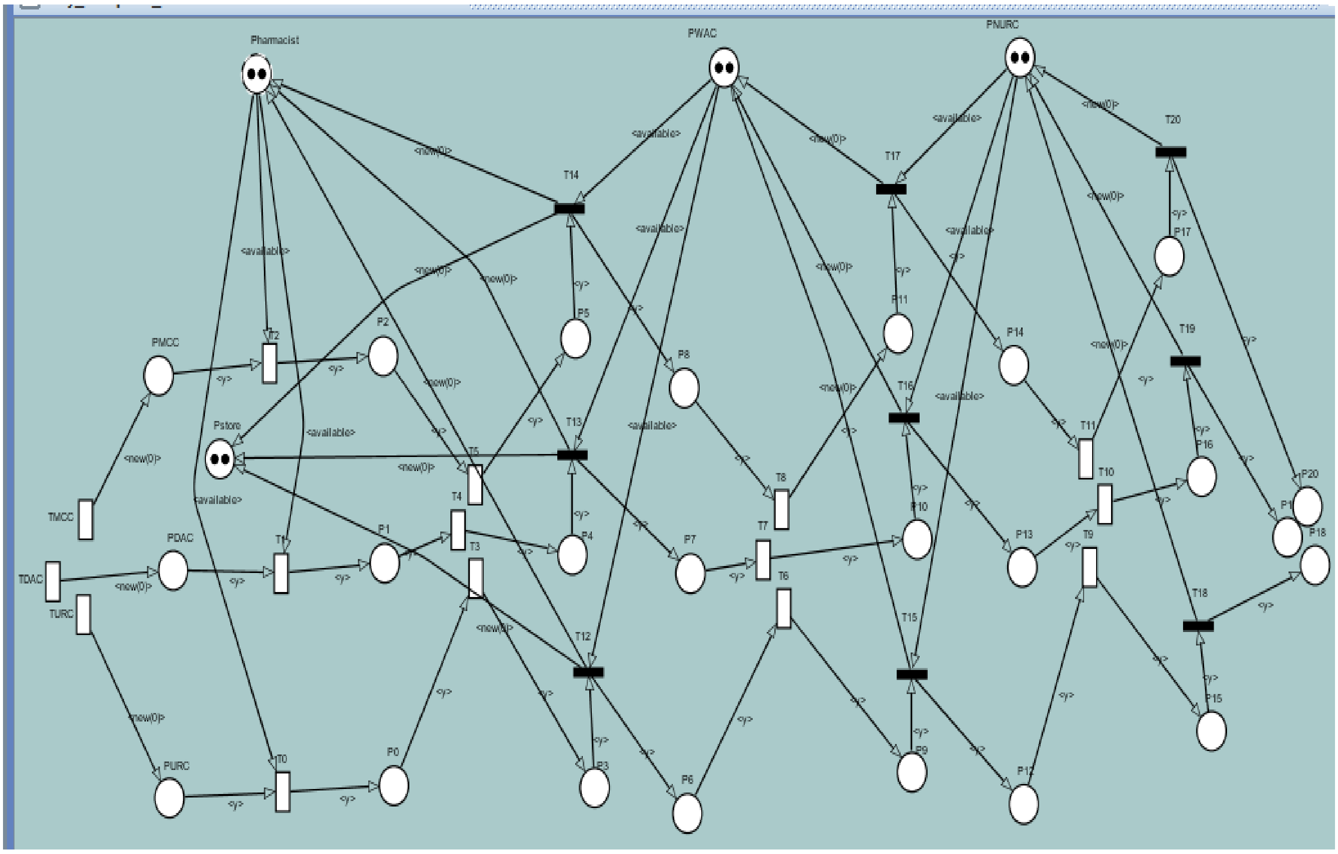


Figure 4: The Developed TPN Sub-model for Women's ward

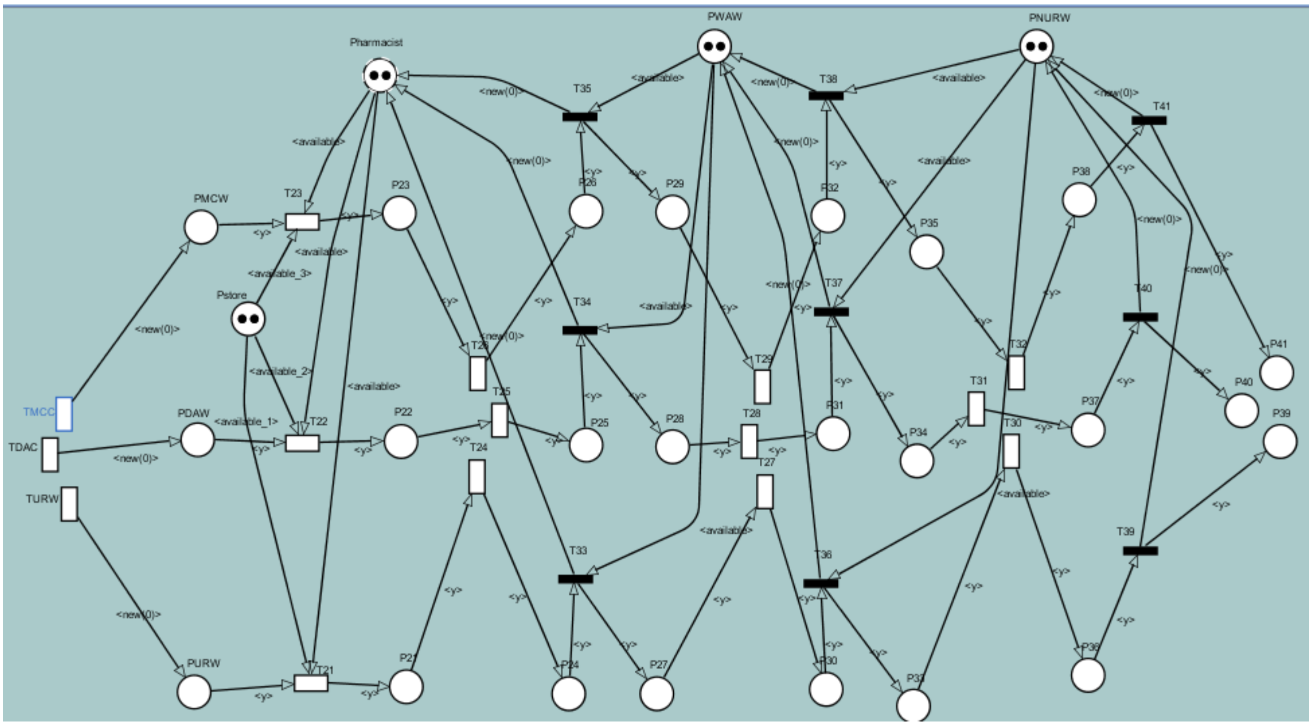
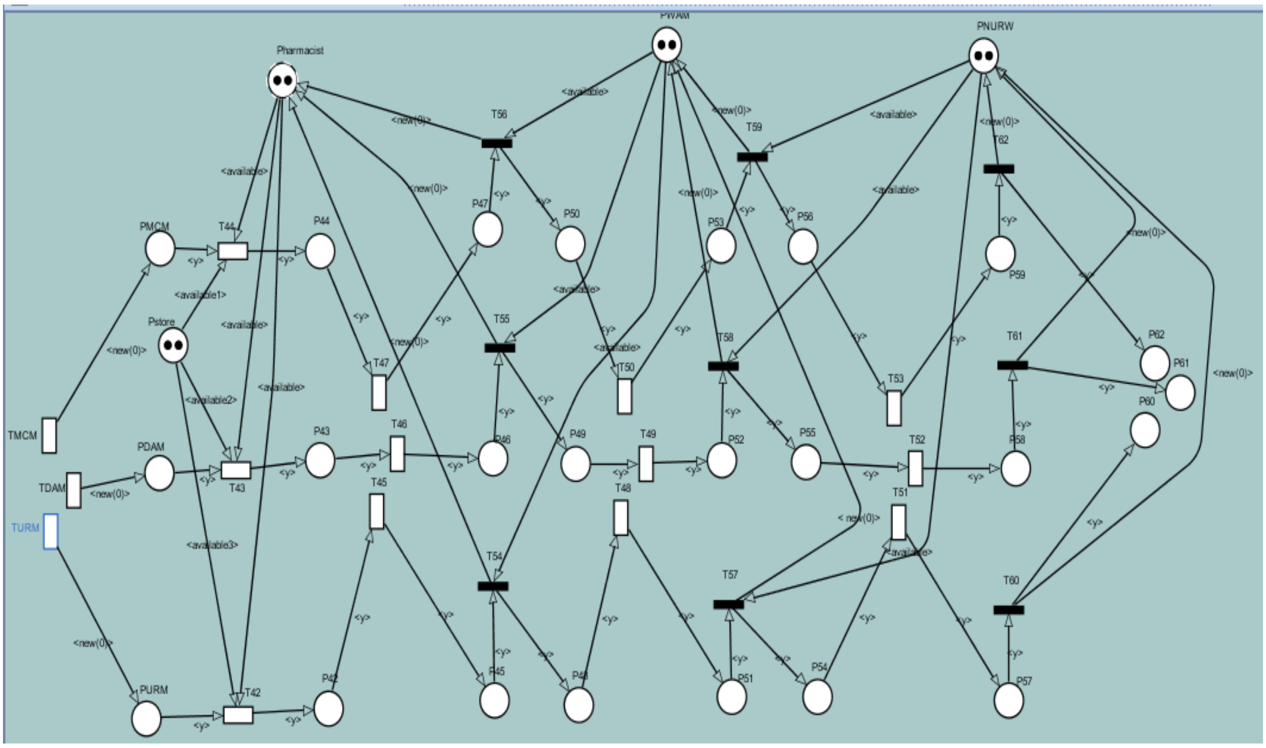


Figure 5: The Developed TPN Sub-model for Men's ward



4 SIMULATION RESULT OF THE DEVELOPED TPNS MODEL

Two simulations were carried out using the developed timed Petri Net model for the decentralized medication distribution. In the first simulation, two pharmacists were used and in the second simulation, the pharmacists are reduced to one (1) in order to verify what could happen in the possibility of pharmacist reduction in the in-patient pharmacy.

In Figure 6, the simulation result shows that 10 requests from daily prescription, 4 requests from medical cabinet request and 31 from urgent prescriptions in children's ward were made into the in-pharmacy in one week. Also, the result performance of the pharmacist shows that the 2 pharmacists were involved in the medication distribution process. Table 4 shows three columns which consist of the number of requests, time of treating each request and number of pharmacist respectively and also shows that the two pharmacists employed were able to treat all the requests received in the in-pharmacy.

In Figure 7, the simulation result shows that, 9 requests from daily prescription, 2 requests from medical cabinet request and 14 requests from urgent prescription in women's ward were made into the in-pharmacy in one week. Also, the result performance of the pharmacist shows that the 2 pharmacists were involved in the medication distribution process. Table 5 shows three columns which consist of the number of requests, time of treating each request and number of pharmacist respectively and also shows that the two pharmacists employed were able to treat all the requests received in the in-pharmacy.

In Figure 8, the simulation result shows that 12 requests from daily prescription, 7 requests from medical cabinet request and 36 requests from urgent prescription in men's ward were made into the in-pharmacy in one week. Also, the result performance of the pharmacist shows that the 2 pharmacists were involved in the medication distribution process. Table 6(a) and (b) show three columns which consist of the number of requests, time of treating each request and number of pharmacist respectively and also shows that the two pharmacists employed were able to treat all the requests received in the in-pharmacy.

Fig 6 Result of children's ward sub-model

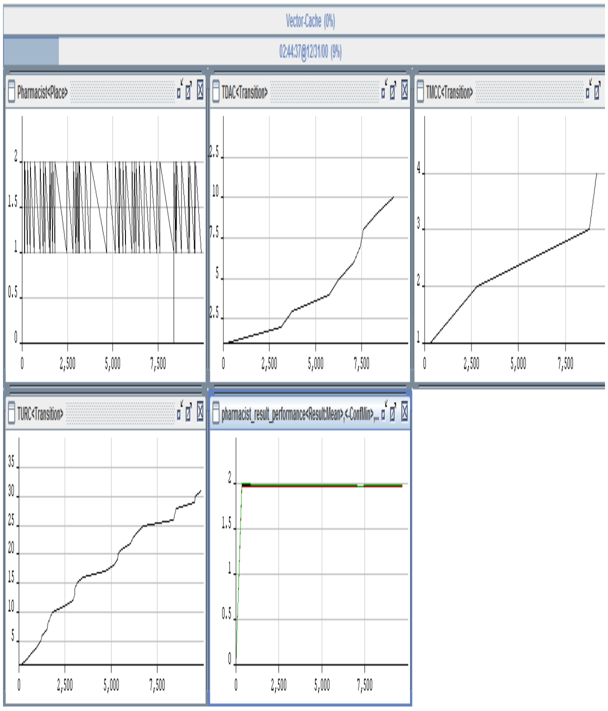


Fig 7 Result of the women's ward sub-model

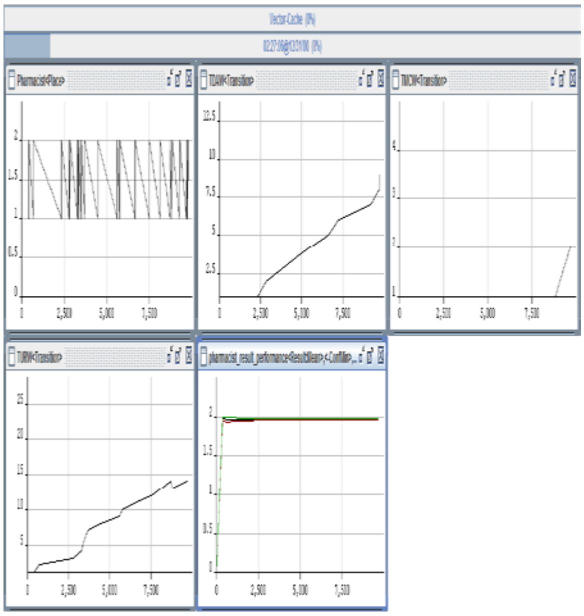


Fig 8 Result of men's ward sub-model

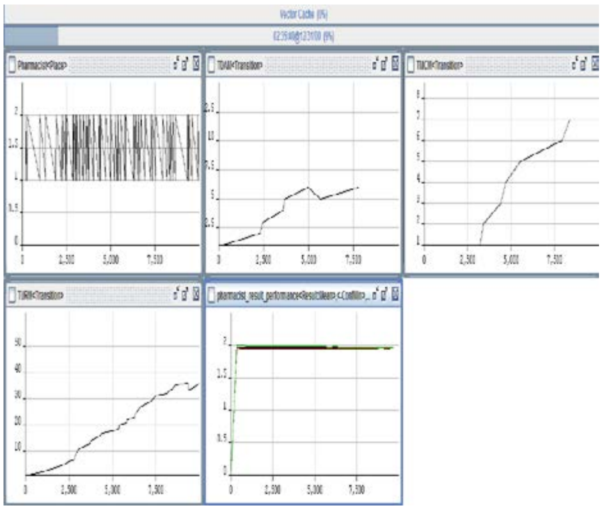


Table 4 Number of requests (from children's ward) treated by two pharmacists

No of requests	Time (seconds) of treating request in the pharmacy	Number of Phar attending to re
1	542.9319	1
2	554.0445	2
3	833.1296	1
4	837.1296	2
5	1298.1842	1
6	1302.1842	2
7	1716.004	1
8	1723.5751	2
9	1725.6721	1
10	1729.6721	2
11	1753.1799	1
12	1760.2719	2
13	1862.6612	1
14	1866.6612	2
15	1998.999	1
16	2001.767	2
17	2288.913	1
18	293.7049	2
19	905.9594	1
20	709.9594	2
21	1434.6812	1
22	2438.5369	2
23	1476.5547	1
24	1480.5547	2
25	1566.4456	1
26	2569.2126	2
27	1658.8063	1
28	1662.8063	2
29	2721.7371	1
30	3737.7336	2
31	3600.0336	1
32	3000.7682	2
33	2076.373	1
34	1079.7862	2
35	1255.8279	1
36	1287.9919	2
37	870.1275	1
38	871.3163	2
39	2592.3421	1
40	1596.2678	2
41	2977.7571	1
42	1981.6986	2
43	2181.5184	1
44	1185.5184	2
45	1965.7981	1

Table 5: Number of requests (from women's ward) treated by two pharmacists

No of requests	Time (seconds) of treating the requests	Number of Pharmacist attending to request
1	54.6582	1
2	58.8582	2
3	183.2384	1
4	187.2384	2
5	330.7215	1
6	334.7215	2
7	1042.8008	1
8	1848.8008	2
9	2068.8558	1
10	2372.8585	2
11	2842.5392	1
12	3000.5392	2
13	1391.8955	1
14	1895.8955	2
15	1495.4549	1
16	939.4549	2
17	2339.5125	1
18	2852.6145	2
19	1258.7187	1
20	3563.1229	2
21	2110.5717	1
22	671.2149	2
23	1241.5727	1
24	2256.2988	2
25	2467.7662	1

Table 6(a): Number of requests (from men's ward) treated by two pharmacists

No of requests	Time (seconds) of treating the requests	Number of Pharmacist attending to request
1	1179.7131	1
2	1182.3283	2
3	1341.7146	1
4	1342.2523	2
5	1829.7934	1
6	1833.7934	2
7	2003.1721	1
8	2307.1721	2
9	2309.4729	1
10	2313.4921	2
11	2372.8491	1
12	2374.8491	2
13	2400.7638	1
14	2410.1787	2
15	297.5656	1
16	3301.5456	2
17	3590.6924	1
18	2594.5924	2
19	2633.066	1
20	637.066	2
21	1734.1924	1
22	1733.1924	2
23	1857.9719	1
24	861.9419	2
25	2054.3971	1
26	2057.2377	2
27	3128.0685	1
28	2132.0685	2
29	2497.3409	1
30	3501.7363	2
31	513.9766	1
32	517.9637	2
33	1986.9178	1
34	1990.9178	2
35	2114.1326	1
36	2116.1326	2
37	1454.9273	1
38	558.9273	2
39	1093.6064	1
40	3097.2034	2
41	2185.3328	1
42	1189.3628	2
43	489.8902	1
44	936.8766	2
45	1600.6706	1

Table 6(b)

No of requests	Time (seconds) of treating the requests	Number of Pha attending to re
46	504.6407	2
47	1625.6463	1
48	3140.1335	2
49	1200.0542	1
50	2204.5632	2
51	1220.4567	1
52	900.2345	2
53	1400.3452	1
54	1500.9909	2
55	999.8768	1

In the second simulation Figure 8 shows that the one available pharmacist was practically involved in the distribution under the same volume of requests received into the in-pharmacy for two pharmacists. Table 7 shows three columns which consist of the number of requests, time of treating each request and number of pharmacist respectively and also show that 102 requests were treated by one available pharmacist.

In both simulations, the second simulation shows that the two pharmacists dedicated are enough to attend to the 260 workload of requests in the pharmacy.

Table 7(a): Number of requests (from all wards) treated by a pharmacist

No of requests	Time (seconds) of treating the requests	Number of Pharmacist attending to request
1	85.7285	1
2	89.5436	1
3	257.0912	1
4	262.7218	1
5	734.4734	1
6	738.4734	1
7	864.1896	1
8	868.2345	1
9	899.8378	1
10	903.4342	1
11	910.232	1
12	920.1110	1
13	943.2120	1
14	970.1110	1
15	1000.0000	1
16	1100.1234	1
17	1231.3864	1
18	1233.8478	1
19	1304.7403	1
20	1308.7403	1
21	1346.1756	1
22	1347.0974	1
23	1583.1875	1
24	1600.8569	1
25	1696.9865	1
26	1700.2345	1
27	1750.3454	1
28	1800.1232	1
29	900.6378	1
30	1920.2324	1
31	1948.0279	1
32	1987.3352	1
33	1991.2322	1
34	2021.4352	1
35	2025.4217	1
36	973.9788	1
37	1277.9768	1
38	2302.5179	1
39	2308.3804	1
40	2385.4222	1
41	2390.1691	1
42	2591.9493	1
43	2595.9493	1
44	2658.519	1
45	2717.611	1
46	2839.4554	1
47	3038.412	1

Table7b: Number of requests (from all wards) treated by a pharmacist

No of requests	Time (seconds) of treating the requests	Number of Pharmacis attending to request
48	1042.412	1
49	1187.7692	1
50	1191.7692	1
51	1491.1936	1
52	811.951	1
53	1530.7823	1
54	1536.1772	1
55	2137.8267	1
56	2190.7417	1
57	1521.6126	1
58	1535.6924	1
59	958.4099	1
61	1962.4099	1
62	1994.8344	1
63	2000.0001	1
64	1066.7189	1
65	1070.4045	1
66	644.195	1
67	797.1775	1
68	815.5756	1
69	1038.4951	1
70	1039.8081	1
71	2590.6306	1
72	1594.9534	1
73	1700.2345	1
74	770.2987	1
75	884.0985	1
76	1900.980	1
77	1992.9534	1
78	998.456	1
79	1550.1592	1
80	554.1592	1
81	935.7162	1
82	2939.3643	1
83	1270.8148	1
84	1274.8148	1
85	1292.9154	1
86	2296.2382	1
87	815.9235	1
88	637.4889	1
89	2875.8484	1
90	879.7632	1
91	1907.7901	1
92	911.7654	1
93	651.2345	1
94	514.2211	1

Table 7c

No of requests	Time (seconds) of treating the requests	Number of Pharmacist attending to request
95	1518.2345	1
96	816.4563	1
97	1820.4548	1
98	2924.5704	1
99	924.5704	1
100	930.2695	1
101	1284.987	1
102	1000	1

5 CONCLUSION AND FUTURE WORKS

In this paper, we have been able to develop Timed Petri Net model for medication distribution processes in hospital using Bowen University Teaching Hospital as a case study. The developed TPN model can be easily modified through its associated modules to suit any future modification in medication distribution system under consideration. Furthermore, it is recommended that future research may be geared towards validating and analysing the performance of the developed TPN model through simulation based analysis technique.

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