DEVELOPMENT OF AN IMPROVED MODEL FOR OUTPATIENT FLOW PROCESSES USING HIERARCHICAL TIMED COLOURED PETRI NETS

BY

OBANSOLA O.Y, GANIYU R.A & OLABIYISI S.O

Presented at

International Conference and Advanced Workshop on Modelling and Simulation of Complex System

May, 2024.

INTRODUCTION

- **Health Sector**
- **Hospital as an important phase**
- **Healthcare service delivery**
- **Process flow in the hospital**
- **Discrete event system**
- **Modelling and Simulation**
- **Petri Nets: OPN, CPN, TCPN, HTCPN**

STATEMENT OF PROBLEM

- **Long waiting time and Queue across all sections in the OPD.**

- **Previous studies:**
- **Ganiyu et al (2015) modelled patient flow processes with emphazy in the medical record and the consultation room**
- **Derni *et al.*(2019) developed a CPN model for modeling and improving emergency department based on simulation process**
- **Kulkarni *et al.* (2020) modelled patient flow in an OPD of a hospital using simulation technique with the use of ARENA simulation software**

- **Research Gap**

- **Hence, this research developed an improved model for patient flow processes which is characterized by medical record section, nursing station, consulting room and pharmacy unit, laboratory section and account section of hospital using Hierarchical Timed Coloured Petri Nets**

AIM

- **The aim of this study is to develop an improved model for outpatient flow processes using Hierarchical Timed Coloured Petri Nets (HTCPN).**

OBJECTIVES

- **develop an improved HTCPN model for outpatient flow processes involving medical record, nursing section, consultation room, pharmacy unit, laboratory section and the account section.**

- **simulate the developed HTCPN model using CPN tools; and**

- **validate the developed model on the basis of simulated and the real patient time of stay (TOS).**

Formal Definition of HTCPN

Definition: A HTCPN is a tuple HTCPN = (PG, Σ, P, T, A, N, C, G, E, I, R, r0)

where:

(i) PG is a finite set of pages such that: (a) each page pg∈PG is a non-hierarchical CPN and, (b) none of the pages has any net element in common;

(ii) Σ is a finite set of non-empty timed or untimed types, also called color sets.

(iii) P is a finite set of places. P=Po∪PP∪Ps, where Po is a set of ordinary places; P is a set of port nodes (places); Ps is a set of socket nodes (places).

(iv) T is a finite set of transitions. T=T1∪T2∪T3∪T4, where T1 is a set of ordinary activity transitions; T2 is a set of timed transitions; T3 is a set of hierarchical transitions; T4 is a set of timed hierarchical transitions.

(v) A is a finite set of arcs such that: P∩T=P∩A=T∩A=Ø.

(vi) N is a node function. It is defined from A into P×T∪T×P.

(vii) C is a color function. It is defined from P into Σ.

(viii) G is a guard function. It is defined from T into expressions such that:

∀t ∈T: [Type (G (t)) =B ∧ Type (Var (G (t)) ⊆∑), B={true, false}

(ix) E is an arc expression function. It is defined from A into timed or untimed expressions such that:

∀a ∈ A: [Type (E (a))=C(P) MS ∧ Type (Var (E(a)) ⊆∑]

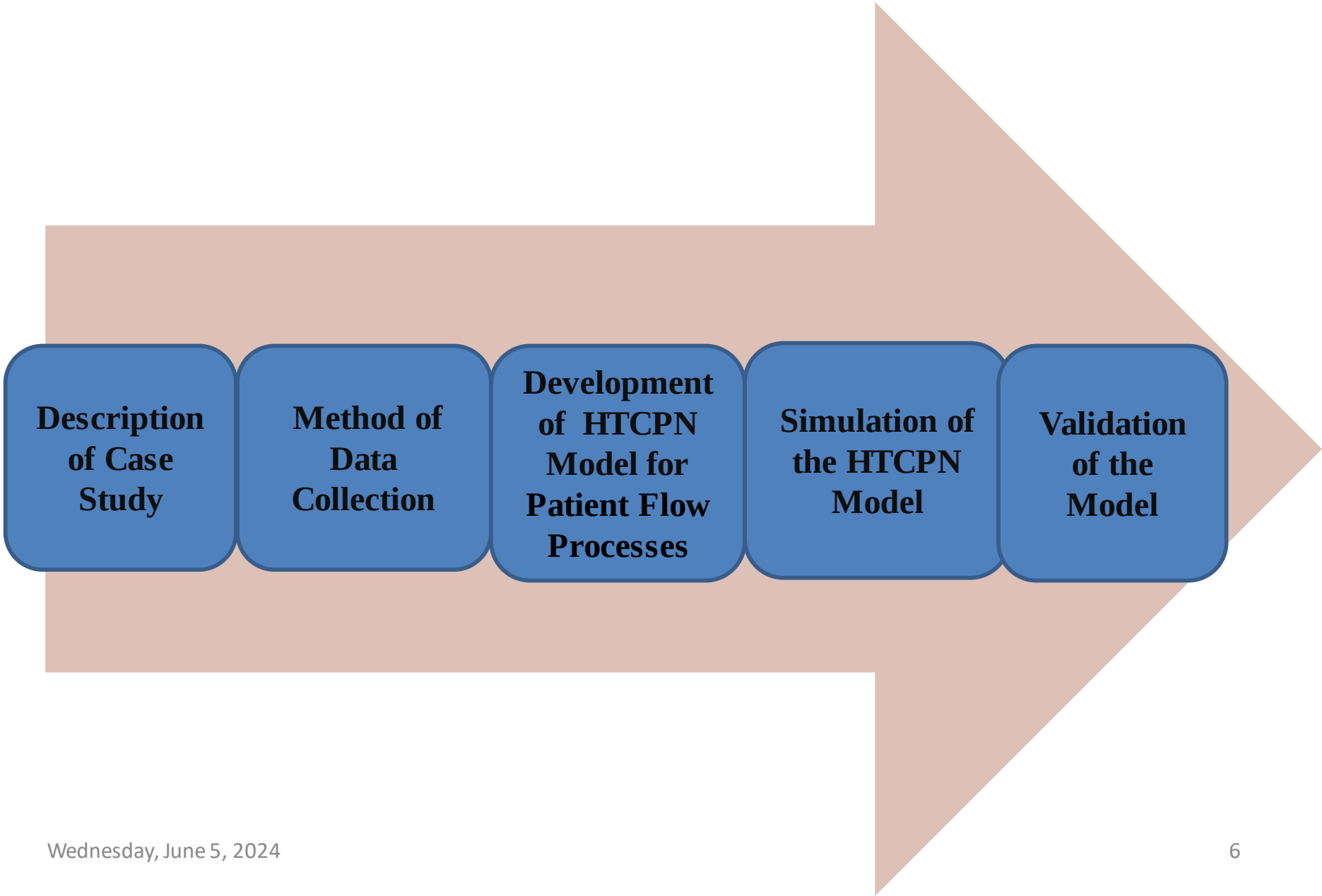
(x) I is an initialization function. It is defined from P into timed or untimed closed expressions such that:

∀p ∈ P: [Type (I(p)) = C(P)MS

(xi) R is a set of time values, also called time stamps. It is a subset of R closed under + and containing 0;

(xii) r0 is an element of R, called the start time

METHODOLOGY



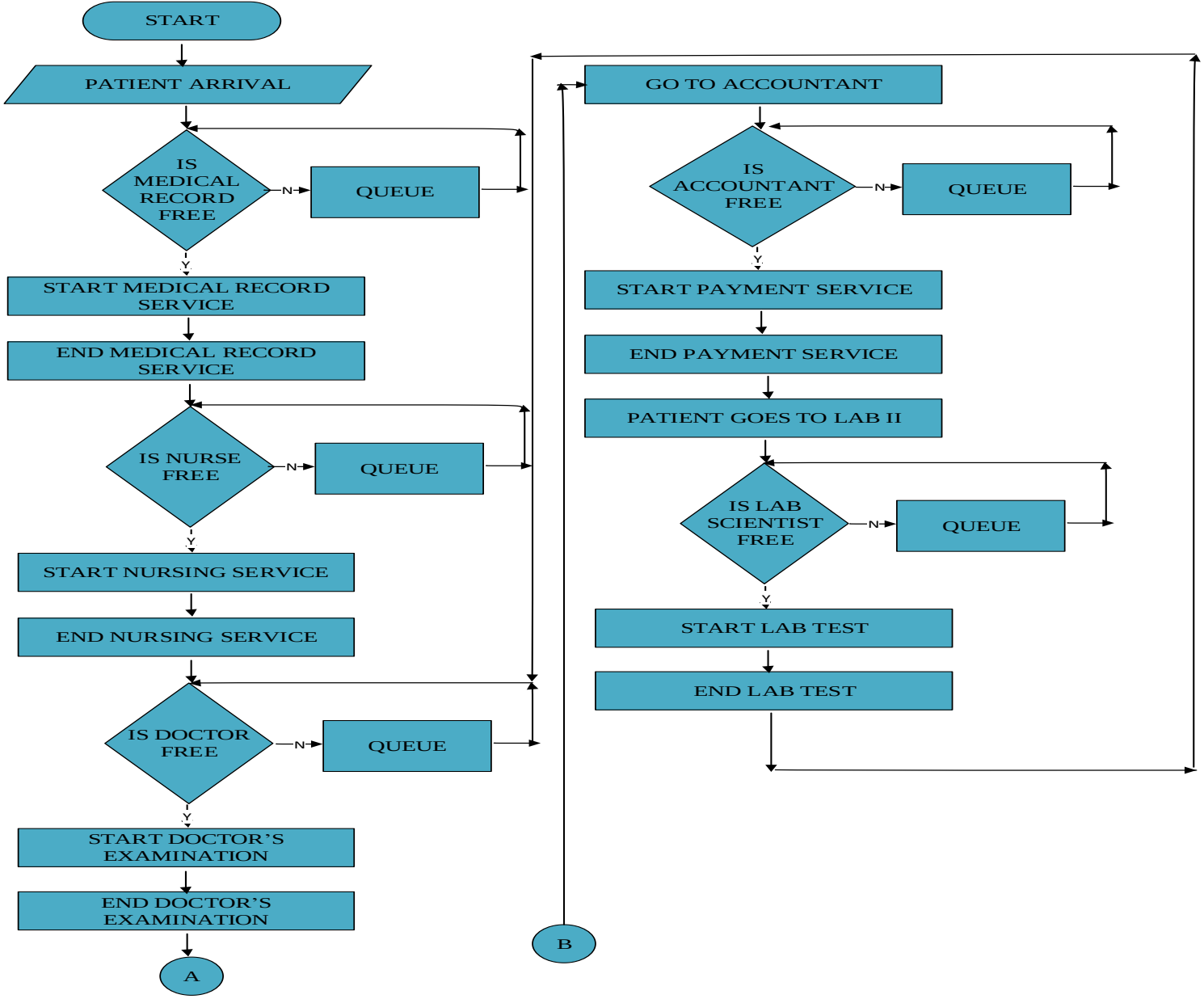


Figure 1(a): Flowchart of Patient flow processes at State Hospital, Oyo

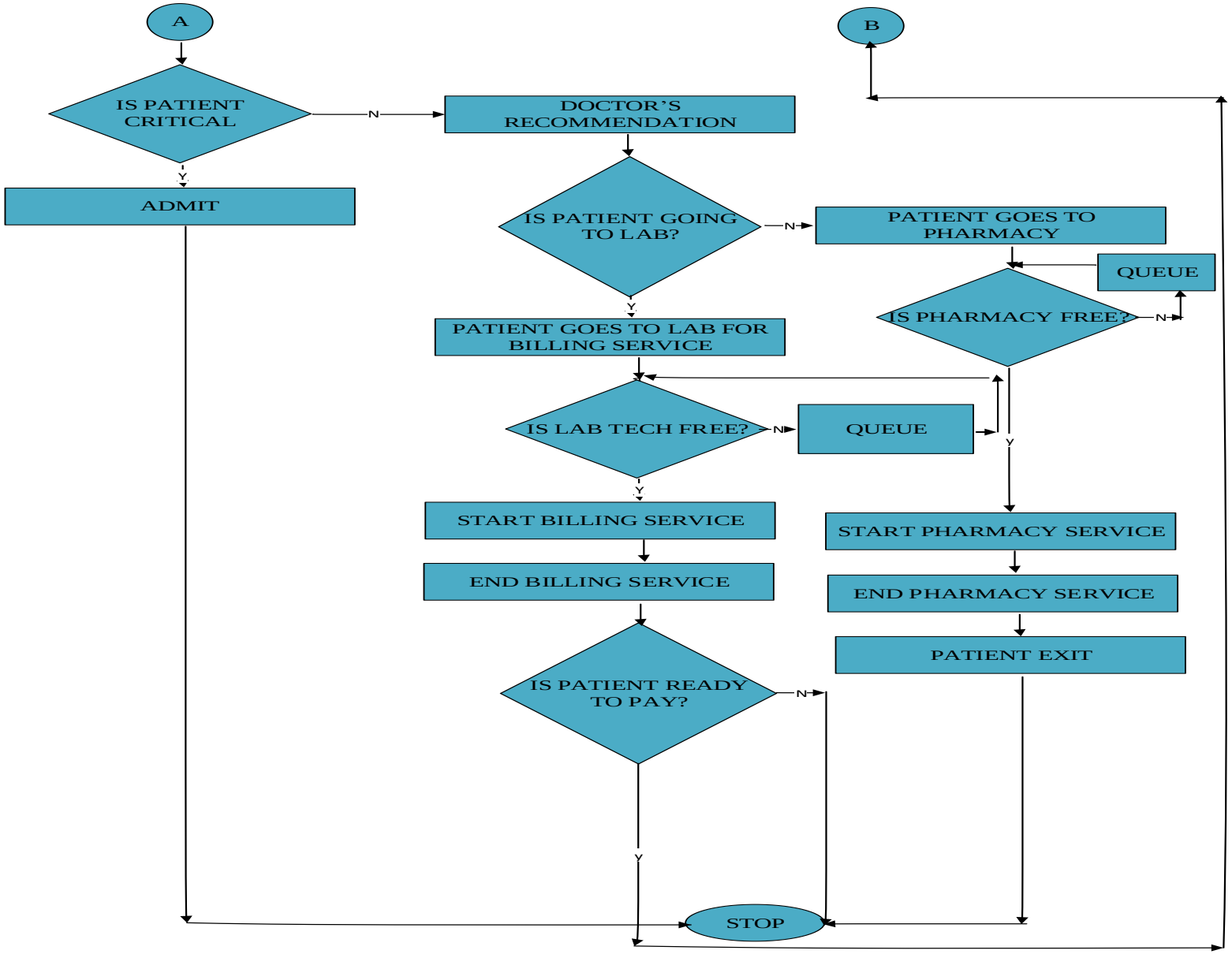


Figure 1(b): Flowchart of Patient flow processes at State Hospital, Oyo (continued)

METHODOLOGY CONT.

Table 1: Description of major places used in the developed HTCPN model

Places	Description
Patient	Models arrival of new patient
Next Patient id	Models the identity of the new patient
Patient Queue	Models Patient on queue
Free	Models the number of free medical officer(s)
Busy	Models the number of busy medical officer(s)
Outpatient leaves	Models Patient that has already been attended to

METHODOLOGY CONT.

Table 2: Description of some major transitions used in the developed HTCPN model

Transition	Description
Patient Arrival	This is a substitution transition. Execution of this transition Modelled the arrival process of patients into the hospital.
Medical Record	This is a substitution transition. Execution of this transition model led the process operation of medical record section by registering the patients.
Nursing Station	This is a substitution transition. Execution of this transition modelled the process of checking vital signs like temperature check, blood pressure by the nurses.
Consultation Room	This is a substitution transition. Execution of this transition modelled the process of examining patients, in order to make reasonable decisions on the patient either to go for further laboratory examination or prescribe medications or be admitted.
Pharmacy Section	This is a substitution transition. Execution of this transition modelled the process of dispensing prescribed drugs to patients by the pharmacist. E.t.c

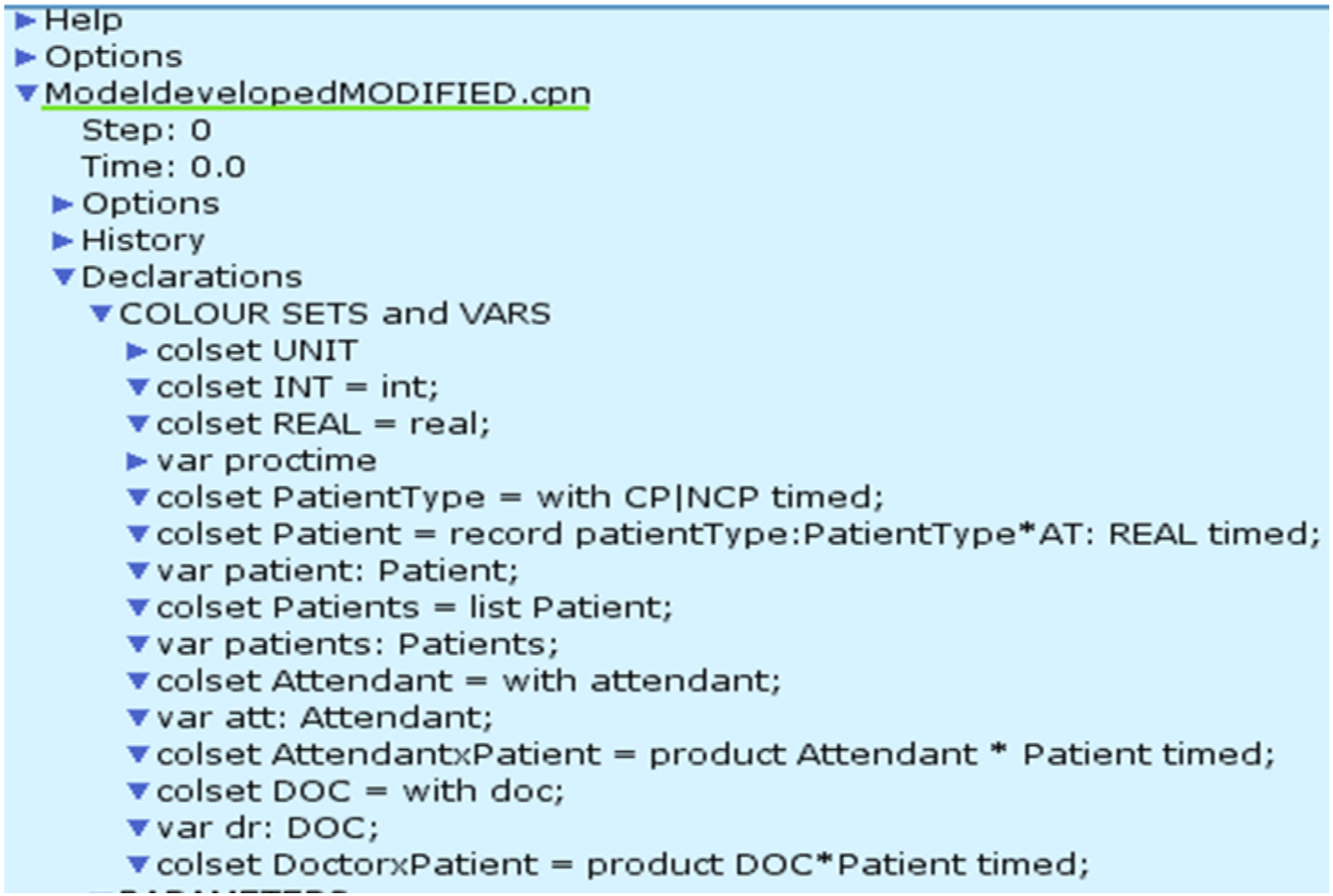


Figure 2: Definitions and Interpretations of the Colours (Colour set) used in the HTCPN Model

RESULTS AND DISCUSSION

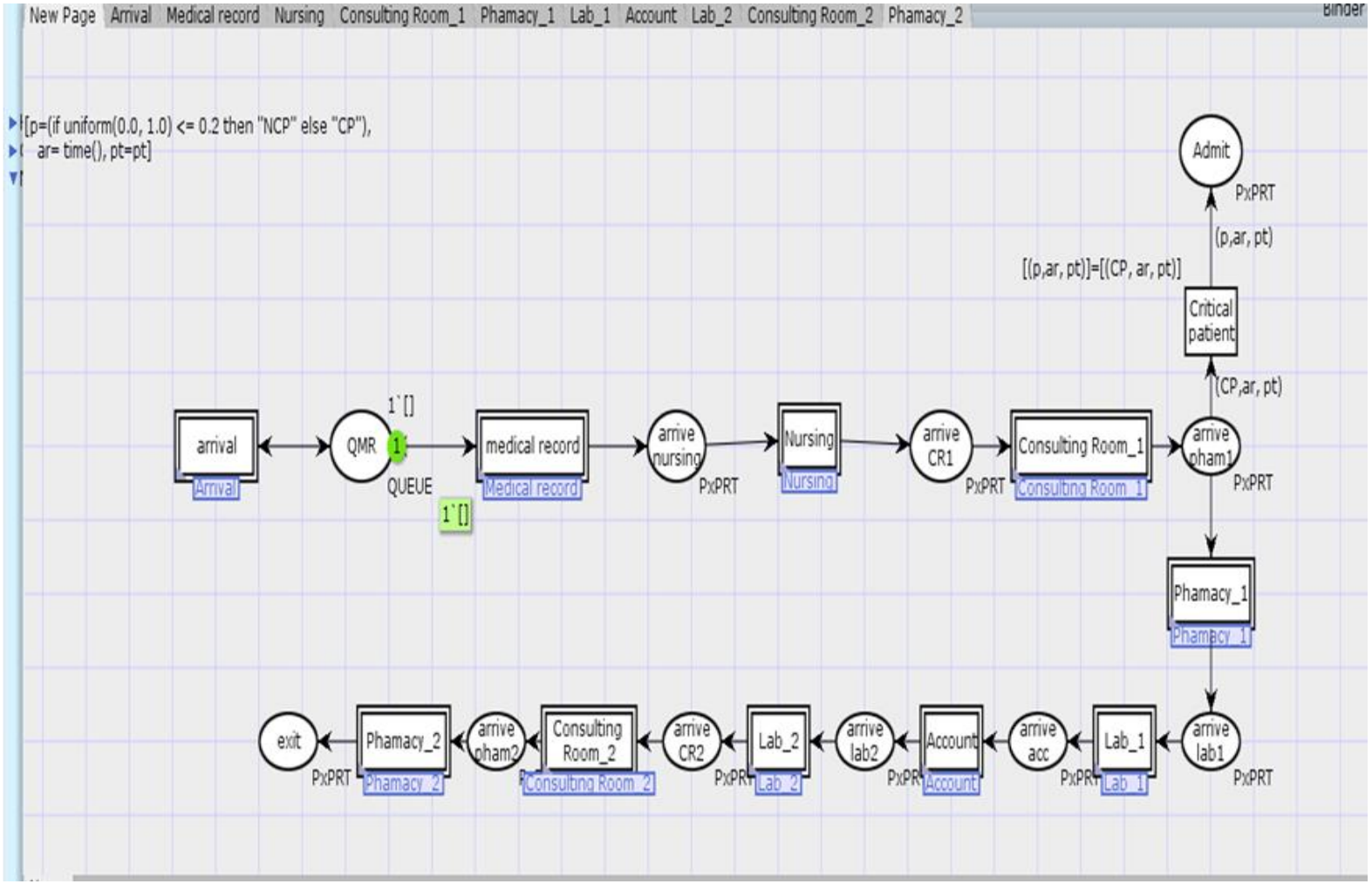


Figure 3: Top page of The Developed HTCPN model for outpatient flow processes

Simulation result of the developed HTCPN model

The developed HTCPN model was simulated on Intel (R) x 64bits 2.20GHz dual core processor board using CPN Tools (Version 4.0).

- **The developed HTCPN model was simulated to verify what could happen in the possibility of server or resources alternation.**
- **Due to the fact that the simulation model is stochastic, it is necessary to execute several simulation runs with the developed model in order to obtain the mean value.**

➔ **Forty (40) simulations were run on the developed HTCPN model for the outpatient flow processes to obtain the performance metrics**

Seven (7) scenarios from the simulation run were further experimented to obtain:

➔ **the average waiting time**

➔ **The average service (operation) time**

➔ **Average utilization rate of medical personnel**

Definitions of the Performance Metrics

The definitions of these performance metrics are as follows:

- **Patient's Average Waiting Time (PAWT): the average time it takes an outpatient to wait in the queue before being attended to (average waiting time). This is measured in minutes (mins)**

- **Patient's Average Operation Time (PAOT): The average time an outpatient spends in receiving treatment from a medical officer.**

- **Average Utilization Rate (SAUR): average busy time of medical officer compared with total working time. This is measured in percentage(%)**

Table 3:Matrix Representation of the Seven(7) Experimented Scenarios

MEDICAL RESOURCES SCENARIOS	Med Rec	Nur.	Cr I	Phm I	Lab I	Acc t	Lab II	Cr II	Phm II
1	A(4)	B(4)	C(2)	D(2)	E(2)	F(2)	G(4)	H(2)	I(2)
2	A	B	C+1	D	E	F	G	H+1	I
3	A	B-1	C	D	E	F	G	H	I
4	A	B-4	C	D	E	F	G	H	I
5	A	B	C	D	E	F-2	G	H	I
6	A-3	B	C	D	E	F	G	H	I
7	A	B	C	D+1	E	F	G+1	H	I+1

Scenario 1 represents the current working conditions of the outpatient flow processes in the considered hospital

Scenarios 2,3,4,5,6 and 7 represent the future working conditions of the outpatient flow processes

Table 4:Simulation Result of the average waiting time(mins) of each processes based on scenarios

MEDICAL RESOURCES → / SCENARIOS ↓	Med Rec	Nur.	Cr I	Phm I	Lab I	Acct	Lab II	Cr II	Phm II
1	1	42	305	1	59	1	6	18	1
2	1	76	150	0	28	0	3	0	0
3	1	89	258	0	2	0	2	1	0
4	1	0	350	0	2	0	1	1	0
5	1	40	318	0	2	0	1	1	0
6	215	0	156	0	2	0	2	1	0
7	1	42	305	1	59	1	6	18	1

Table 5:Simulation Result of the average operation time(mins) of each processes based on scenarios

MEDICAL RESOURCES → / SCENARIOS ↓	Med Rec	Nur.	Cr I	Phm I	Lab I	Acct	Lab II	Cr II	Phm II
1	2	44	310	4	64	1	10	24	3
2	2	73	154	3	33	1	10	4	3
3	2	92	264	7	7	1	7	6	3
4	2	0	355	3	7	1	6	6	3
5	2	42	323	3	7	0	6	6	3
6	218	2	161	3	8	1	8	6	3
7	2	44	310	4	64	1	10	24	3

Table 6: Simulation Results of the average utilization rate(%) of medical personnels based on scenarios

MEDICAL RESOURCES / SCENARIOS	Med Rec	Nur.	Cr I	Phm I	Lab I	Acct	Lab II	Cr II	Phm II
1	17	37	97	46	77	18	73	94	44
2	22	49	88	57	94	23	90	64	54
3	17	47	96	45	74	18	75	74	45
4	17	0	97	44	71	17	70	70	40
5	18	36	97	40	69	0	67	69	40
6	68	37	97	44	74	18	75	73	45
7	17	37	97	45	77	18	72	94	44

Validation results of the developed HTCPN Model

➔**For the purpose of model validation, performance metrics which include the average time of stay (between Monday and Friday) were acquired and compared with the simulation results . The statistical analysis (T-test) of the validation results was carried out through the Statistical Package for the Social Sciences software (SPSS version 17.0)**

➔ **Tables 7 and 8 shows that statistically, there were no significant differences between the simulated and the measured values at 5% level of significance since their p-value ≥ 0.05. This implies that the two datasets do not differ significantly.**

Table 7(a): Actual and Simulated Values of Time of Stay of Outpatients

DAYS	ACTUAL TOS	SIMULATED TOS
MONDAY	510	506
TUESDAY	386	383
WEDNESSDAY	515	513
THURSDAY	505	510
FRIDAY	482	488

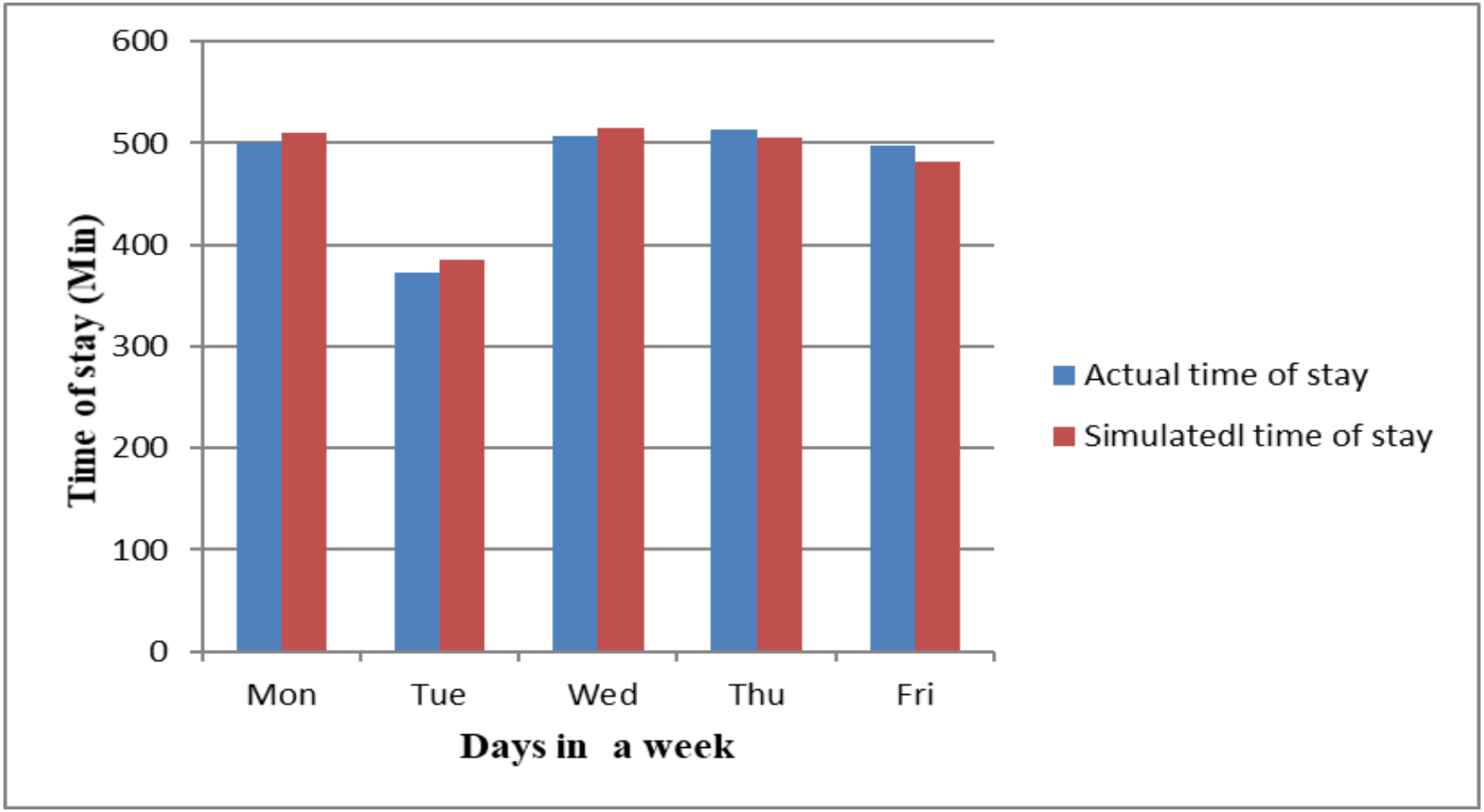


Figure 13:Validation Results of the Developed HTCPN Model

Conclusion & Contributions to Knowledge

➔ **Conclusively, the developed HTCPN model revealed a valid representation of the outpatient flow processes consisting of the states of the considered system and the events or transitions that causes the system to change its state.**

➔**It can as well be concluded that the model could be useful by hospital management in decision making to grasp the essential aspect of developing improvement strategies for outpatient flow processes through modelling and simulation, without deploying the actual resources**

➔**the model is valuable for assuring improved service quality and delivery of outpatient flow processes in hospitals in general, as well as for managing queue and delay issue which is a way of ensuring patient satisfaction**.

Some References

- Akingbade O.Y (2015). Modelling of Patient Flow Processes Using Timed Coloured Petri Nets, *Unpublished M.Tech. Dissertation* (Computer Science), Ladoke Akintola University of Technology, Ogbomoso.
- Adetunji, A.B., Ganiyu , R.A., Adigun, S.O.(2016). Modelling of Decentralized Medication Distribution Processes in Hospital Using Timed Coloured Petri Nets. *International Journal of Advance Research, IJOAR.org* ***4*** (7), 1-13.
- Ganiyu, R. A. (2011). Modelling and Simulation of Multi-Phase Traffic Light Controlled Intersections Using Timed Coloured Petri Nets, *Unpublished Ph.D Thesis* (Computer Science), Ladoke Akintola University of Technology, Ogbomoso,
- Ganiyu, R. A., Olabiyisi, S. O., Omidiora, E. O., and Okediran, O. O. (2011a). The Application of Petri Nets to the Modelling and Analysis of a Producer- Consumer System. *British Journal of Sciences* ***1***(2): 28-37.
- Ganiyu, R. A., Olabiyisi, S. O., Omidiora, E. O., Okediran, O. O., and Badmus, T. A. (2011b): Development of a Timed Coloured Petri Net Model for Time-of-Day Signal Timing Plan Transitions. *Journal of Innovative Systems Design and Engineering*, *International Institute of Science, Technology and Education, NewYork, USA*, ***2***(5): 125-138.
- Ganiyu, R. A., Arulogun O.T., Okediran O.O., Oyeleye C.A. (2014). Mobile Operating Systems and Application Platforms: A Survey. *International Journal of Advanced Network and Application*.***6***(1) 2195.
-
- Ganiyu, R. A.,Olabiyisi, S. O., Badmus, T. A., and Akingbade, O. Y. (2015).Development of a Timed Coloured Petri Nets Model for Health Centre Patient Care Flow Processes. *International Journal of Engineering and Computer Science, India.****4***(1): 9954–9961
-

THANK YOU FOR LISTENING