MODELLING OF A PRE-HOSPITAL EMERGENCY CARE FLOW PROCESS USING TIMED COLOURED PETRI NETS

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ABSTRACT
Pre-hospital emergency care service is a major gateway to the Accident and Emergency Department that determines the rate of quality emergency service in hospitals. In this paper, Timed Coloured Petri Nets (TCPN) formalism is employed to model a pre-hospital emergency care flow process which is characterized by ambulance localization and emergency call responses using Osun State Emergency Management Ambulance Service (O'ambulance) as a case study. The developed TCPN model consists of Next Arrival Call (NAC) and Process Emergency Call (PEC) modules. The NAC module abstracted the emergency calls that were received by one (1) call receiver agent being utilized while the PEC module abstracts the operation (services) carried out in the units. The developed TCPN model was simulated using Coloured Petri Nets (CPN) tools while its validation was explored by comparing the simulated and actual rescue team average response time and turn-around times of the rescue teams in operation at the considered case study. The simulation results of the developed TCPN model yielded maximum Average Waiting Times (AWT) of 1.65 and 0.35 minutes using one and two emergency call receiver agents, respectively. Also, the simulation results showed that 7.05, 26.17 and 35.13 minutes were recorded as minimum values for Rescue team Average Response Time (RART), Rescue team Turn-around Time in case of non-critical (RTTNC) and Rescue team Turn-around Time Critical (RTTC), respectively. Similarly, the simulation results showed that RART, RTTNC and RTTC yielded maximum values of 15, 34 and 41.62 minutes, respectively. Statistically, there were no significant differences between the simulated and the real number of patients entering the health centre at 5% level. This gave a confirmation that the developed TCPN model accurately described the pre-hospital emergency care flow process under study. The developed TCPN model could serve as a referential model for studying and improving pre-hospital emergency care flow process in a named ambulance centre.

Keywords—Pre-hospital, Timed Coloured Petri Nets, Emergency, Network, Ambulance.

1 INTRODUCTION

n hospitals, emergency treatment is offered by accident and Iemergency (A&E) department, which involves attending to different emergency cases from different patients. As the demand for quality emergency treatment in the accident and emergency department increases, it becomes very important that emergency patients should receive treatment with minimum delay and in a timely manner. Lack of resources capacity, such as, doctors, beds, nurses will affect the care process and reduce quality of emergency treatment as well as increasing overcrowding in the accident and emergency department (Norazura *et al*., 2012). Accident and Emergency (A&E) department overcrowding is due to many complex reasons that can be related to the pre-hospital emergency care network, the Emergency Department (ED) itself, or to the exit of the ED (Yeh and Lin, 2007).

Pre-hospital emergency care service is a major gateway to the accident and emergency department that determine the rate of quality of emergency service. Emergency services exist to fulfill the basic principles of first aids, which are to preserve life, prevent further injury and promote recovery.

Due to the complexity of Pre-hospital emergency care service, Coloured Petri nets as a discrete event simulation modelling language can be used to describe Pre-hospital emergency care flow process. Coloured Petri Nets (CPN) is an example of high-level Petri nets which combines the strength of Petri nets with the strength of functional programming language Standard ML (Jensen, Kristensen and Wells, 2007). It is a graphical and mathematical tool for describing and studying systems that are characterized as being concurrent, synchronous, asynchronous, distributed, parallel, deterministic, non-deterministic and/or stochastic. As a graphical tool, Petri nets can be used as a visual communication aid similar to flowcharts, block diagrams, and networks. In addition, tokens are used in Petri nets to simulate the dynamic and concurrent activities of systems. Petri nets contain places which symbolize states or conditions that need to be met before an action can be carried out and transitions that may be connected by directed arcs which symbolize actions (Murata, 1989; Ganiyu *et al*., 2015). The inclusion of time concepts into a Coloured Petri Net model results in a Timed Coloured Petri Net model (Ganiyu *et al*., 2011a; Ganiyu *et al*., 2013). Most of the existing works focused on modelling pre-hospital emergency care networks with emphasis on ambulance and emergency call services. Albeit, this paper modelled a pre-hospital emergency care flow process which is characterized by ambulance localization, emergency call responses and security agencies using Timed Coloured Petri Nets (TCPN).

2 RESEARCH METHODOLOGY

2.1 Overview of the Modelling Approach

In this paper, the following basic definitions of Coloured Petri Nets (CPN) and Timed Coloured Petri Nets (TCPN) were employed in modelling a pre-hospital emergency care flow process:

A Coloured Petri Nets is a tuple CPN = (□, P, T, A, N, C, G, E, I) where:

(i) □ □is a finite set of non-empty types also called colour sets.

(ii) P is a finite set of places.
(iii) T is a finite set of transitions.
(iv) A is a finite set of arc such that P∩ T=P∩A= Ø
(v) N is a node function. It is defined from A into: PxT□TxP.
(vi) C is a colour function. It is defined from P into □
(vii) G is a guard function. It is defined from T into expressions such that:
□*t* □*T*:[Type(G(t)) =B Λ Type(Var(G(t)))□□□].
(viii) E is an arc expression function. It is defined from A into expressions such that:
□*a*□□*A*: [Type(E(a)) = C(p)MS ∧ Type(Var(E(a)))□□□] where p is the place of N(a).
(ix) I is an initialization function. It is defined from P into closed expressions such that:
□□□□□□□□□□□□□□□□□□□□*p*□*P*: [Type(I(p)) = C(p)MS].

A timed non-hierarchical Coloured Petri Nets is a tuple TCPN = (CPN, R, r_o) such that:
(i) CPN satisfies the above definition.
(ii) R is a set of time values, also called time stamps. It is closed under + and including 0.
(iii) R_o is an element of R called the start time (Ganiyu *et al*., 2011b).

2.2 Description of the Case Study

In this paper, the pre-hospital emergency care service of O' Ambulance was used as a case study. Figure1outlines the flow of arriving calls at the emergency centre and how the calls were acknowledged and serviced. The O' Ambulance service provide care which is assured by the collaborative work of the following services:

i. **O' Ambulance Call Centre:** The centre is charged with the responsibility of selecting and dispatching of the proper response for every call in the shortest possible time. They can provide simple advice over the telephone or order the assignment of rescue team.
ii. **O' Ambulance Rescue Team:** This is a team of mobile medical units equipped to provide emergency care to patients on the scene of an accident and also to transport patients in need of medical attention. They are well distributed around the state, they respond to the call of the Health Call Centre. The rescue team is made up of paramedic staff and ambulance vehicle.
iii. **O' Ambulance Management:** They coordinate every other unit involved in the emergency care unit, responsible for the assessment of the effectiveness and efficiency of the service.

2.3 Data Collection and Analysis

Data acquisition is crucial because the results and findings of a simulation study in the best cases are as good as the input information. The data acquired consist of the number of emergency calls received on a daily basis, the time it was received and the cases attached to each call. A sample of the collected data is depicted in Table 1. The collected data were analysed, from the analysis, seven cases of accident type were reported at the case study under consideration. Besides, the probabilities of occurrence of these cases are depicted in Tables 2(a), and (b). According to the data collected from O'Ambulance service, the total number of emergency calls received was further classified based on their acuity level into case one and case two. Case one emergency calls are those that do not require the service of emergency response team. In this case, the caller only needs health advice over the telephone based on his or her mild health condition. On the other hand, case two emergency calls are those calls that require immediate emergency response. At the time of this study, the ratio of case one to case two emergency calls is 1:4.

Furthermore, the locations of incidents and time interval of emergency calls are depicted in Tables 3(a)-3(i). Besides, Tables 4(a) and (b) show ambulance location code and its response times (interval between the time the mobile medical units respond and the time it arrives at the scene). Since there is no recorded data for the ambulance response times, therefore, the minimum and maximum duration of ambulance response times were assumed based on the staff experience of the operation of the system.

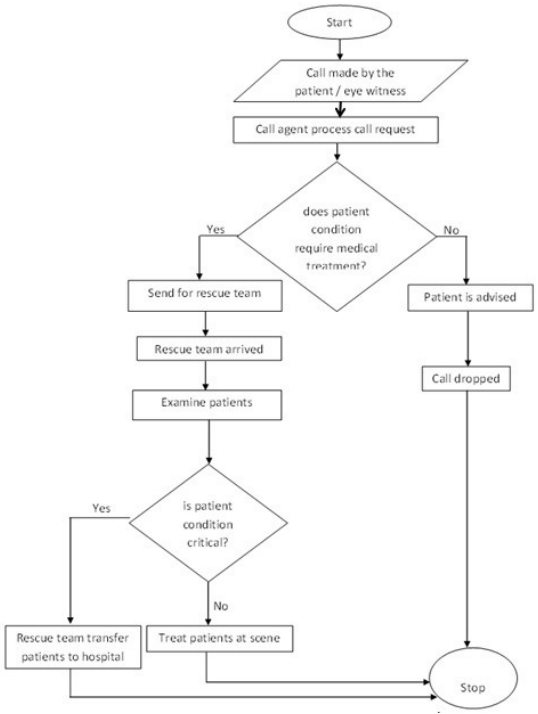

FIG.1: FLOWCHART OF O'AMBULANCE EMERGENCY CARE OPERATION

TABLE 3(A). TIME INTERVAL OF ARRIVING CALLS

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
ILE – IFE	01	01- 11- 2013	5: 17 A.M	
ESA-OKE	02	01- 11- 2013	8: 05 A.M	168
ERIN-IJESHA	03	01- 11- 2013	10:17A.M	132
ADA	04	01- 11- 2013	10:17A.M	0
AKODA-EDE	05	01- 11- 2013	2: 11 P.M	234
GBON[illegible]	06	01- 11- 2013	[illegible]	[illegible]
OBOI				
AYEC				
IKIRE				
IREW				
AKOI				
ERIN-				
EDE				
ILA-C				
APON				
IKIRU				
IWO				
OROI				

S/N	DATE	VICTIM M	VICTIM F	TYPE OF ACCIDENT	REFERRED RESCUE TEAM	HOSPITAL REFERRED
1	01- 11-2013	-	1	PREGNANCY CASE	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
2	01- 11- 2013	2	-	MOTORCYCLE & VEHICLE	O'AMBULANCE PARAMEDICS	TEACHING HOSPITAL
3	01- 11- 2013	2	-	VEHICLES	O'AMBULANCE PARAMEDICS	GENERAL HOSPIAL
4	01- 11- 2013	1	-	VEHICLES	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
5	02- 11- 2013	-	1	VEHICLES	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
6	02- 11- 2013	1	1	VEHICLE	O'AMBULANCE PARAMEDICS	GENERAL HOSPITAL
7	02- 11- 2013	1	-	MOTORCYCLE & VEHICLE	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
8	02- 11- 2013	1	-	MOTORCYCLE & VEHICLE	O'AMBULANCE PARAMEDICS	GENERAL HOSPITAL
9	03- 11- 2013	-	1	MOTORCYCLE & VEHICLE	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
10	03- 11- 2013	1	-	FAINTING CASE	O'AMBULANCE PARAMEDICS	HEALTH CENTRE
11	03- 11- 2013	2	-	VEHICLES	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
12	03- 11- 2013	2	-	VEHICLE	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
13	03- 11- 2013	4	-	MOTORCYCLE & VEHICLE	O'AMBULANCE PARAMEDICS	PRIVATE HOSPITAL
14	04- 11- 2013	1	-	FALL FROM HEIGHT	O'AMBULANCE PARAMEDICS	HEALTH CENTRE
15	04- 11- 2013	2	-	VEHICLES	O'AMBULANCE PARAMEDICS	GENERAL HOSPITAL

TA… …LS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
IWO	19	03- 11- 2013	5: 47 P.M	35
EGBEDORE	13	03- 11- 2013	5: 55 P.M	8
ILE-IFE	01	04- 11- 2013	11: 18 A.M	
ILESHA	22	04- 11- 2013	4: 33 P.M	435
ILE-IFE	01	04- 11- 2013	5: 23 P.M	50
ISOKAN	12	04- 11- 2013	5: 33 P.M	10
IRAGBIJI	04	04- 11- 2013	5: 33 P.M	0
IKIRUN	20	04- 11- 2013	5: 33 P.M	0
ILE-IFE	01	04- 11- 2013	5: 53 P.M	20
EDE	05	05- 11- 2013	2: 07 P.M	
ERIN-ILE	21	05- 11- 2013	2: 10 P.M	3
MORO-JUNCTION	11	05- 11- 2013	2: 15 P.M	5
ERIN-IJESHA	03	05- 11- 2013	5: 07 P.M	172
ILA-ORANGUN	09	05- 11- 2013	5: 07 P.M	0
IKIRUN	20	05- 11- 2013	5: 07 P.M	0
ISOKAN	12	05- 11- 2013	5: 11 P.M	4
ILESHA	22	05- 11- 2013	5: 27 P.M	16
OSOGBO	10	06- 11- 2013	2: 27 P.M	
EDE	05	06- 11- 2013	5: 37 P.M	190
IKIRE	08	06- 11- 2013	5: 47 P.M	10

TABLE 3(C). TIME INTERVAL OF ARRIVING CALLS CONT.

TABLE 2(A). O'AMBULANCE EMERGENCY

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
IKIRE	08	08- 11- 2013	8: 33 A.M	
IBOKUN	02	08- 11- 2013	8: 33 A.M	0
ILESHA	22	08- 11- 2013	10:07 A.M	94
IWO	19	08- 11- 2013	11: 07 A.M	60
OSOGBO	10	08- 11- 2013	2: 07 P.M	180
IWO	19	08- 11- 2013	2: 27 P.M	20
IFE-CENTRAL	01	08- 11- 2013	5: 07 P.M	160
IWO	19	08- 11- 2013	5: 11 P.M	4
IFESOWAPO	01	08- 11- 2013	5: 11 P.M	0
ILESHA	22	08- 11- 2013	5: 17 P.M	6
IKRUN	20	08- 11- 2013	5: 33 P.M	16
IRAGBIJI	04	08- 11- 2013	5: 33 P.M	0
ILE-IFE	01	08 11- 2013	5: 33 P.M	0
IKIRE	08	11- 11- 2013	10: 11 A.M	
IKIRE	08	11- 11- 2013	2: 10 P.M	279
ERIN-OSUN	14	11- 11- 2013	2: 27 P.M	17
ILESHA	22	11- 11- 2013	5: 06 P.M	159
OSOGBO	10	11- 11- 2013	5: 33 P.M	27
ORI-ADE	03	11- 11- 2013	5: 33 P.M	0
IKIRUN	20	11- 11- 2013	5: 33 P.M	0
IKIRUN	20	11- 11- 2013	5: 47 P.M	14
GARAGE-OLODE	07	11- 11- 2013	6: 37 P.M	50

CALLS CASES CONT.

Day (i)	Accident Type (AT_i)	Frequency of Occurrence (f_i)	Probability of Occurrence
14	Motorcycle & Vehicle	4	0.44

TABLE 3(D). TIME INTERVAL OF ARRIVING CALLS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
IKIRE	08	12- 11- 2013	4: 17 P.M	
OSU	17	12- 11- 2013	5: 07 P.M	50
OSOGBO	10	12- 11- 2013	5: 43 P.M	36
GARAGE-OLODE	07	13- 11- 2013	10: 07 A.M	
OSOGBO	10	13- 11- 2013	10: 07 A.M	0
IKIRUN	20	13- 11- 2013	10: 27 A.M	20
EJIGBO	24	13- 11- 2013	2: 10 P.M	223
OSOGBO	10	13- 11- 2013	5: 07 P.M	177
OSOGBO	10	13- 11- 2013	5: 11 P.M	4
OSU	17	14- 11- 2013	2: 27 A.M	
IFE-EAST	16	14- 11- 2013	10: 33 A.M	486
OSOGBO	10	14- 11- 2013	10: 33 A.M	0
ILA-ORANGUN	09	14- 11- 2013	10: 47 A.M	14
ILOBU	14	14- 11- 2013	11: 33 A.M	46
ILA	09	14- 11- 2013	11: 33 A.M	0
MODAKEKE	16	14- 11- 2013	5: 11 P.M	338
IKIRE	08	14- 11- 2013	5: 33 P.M	22
ILESHA	22	14- 11- 2013	5: 37 P.M	4

29	Pregnancy	1	0.071
	Motorcycle & Vehicle	3	0.214
	Vehicle	3	0.214
	Fainting	2	0.143
	Motorcyclist	4	0.286
	Burns	1	0.071
30	Vehicle	1	1.0

TABLE 3(E). TIME INTERVAL OF ARRIVING CALLS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
ILA	09	15- 11- 2013	5: 11 A.M	
BOLUWADURO	23	15- 11- 2013	8: 07 A.M	176
IWO	19	15- 11- 2013	8: 33 A.M	26
ILESHA	22	15- 11- 2013	9: 07 A.M	34
ODE-OMU	06	15- 11- 2013	9: 07 A.M	0
ILESHA	22	15- 11- 2013	9: 17 A.M	10
IBOKUN	02	15- 11- 2013	9: 27 A.M	10
ATAKUNMOSA -WEST	17	15- 11- 2013	10: 07 A.M	40
AAGBA	04	15- 11- 2013	10: 11 A.M	4
IJEBU-IJESHA	03	15- 11- 2013	10: 37 A.M	26
IJEBU-IJESHA	03	15- 11- 2013	10: 47 A.M	10
MORO	11	15- 11- 2013	11: 10 A.M	23
IKIRE	08	15- 11- 2013	11: 27 A.M	17
IWO	19	15- 11- 2013	3: 23 P.M	276
ILE-IFE	01	15- 11- 2013	4: 53 P.M	80
OLODE	13	16- 11- 2013	8: 07 A.M	
EDE	05	16- 11- 2013	8: 33 A.M	26

TABLE 3(F). TIME INTERVAL OF ARRIVING CALLS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
IWO	19	16- 11- 2013	8: 33 A.M	0
ILE-IFE	01	16- 11- 2013	9: 33 A.M	60
GBONGAN	06	16- 11- 2013	9: 33 A.M	0
ILE-OGBO	15	16- 11- 2013	10: 07 A.M	34
IKIRUN	20	16- 11- 2013	10: 11 A.M	4
IKIRE	08	16- 11- 2013	11: 17 A.M	66
OSOGBO	10	16- 11- 2013	3: 23 P.M	246
IFE-SOUTH	07	16- 11- 2013	6: 53 P.M	90
IFE-SOUTH	07	17- 11- 2013	11: 17 P.M	
OSOGBO	10	17- 11- 2013	12: 07 P.M	50
IKIRUN	20	17- 11- 2013	2: 10 P.M	123
IKIRE	08	17- 11- 2013	2: 27 P.M	17
ILESHA	22	17- 11- 2013	3: 27 P.M	60
EDE	05	17- 11- 2013	5: 00 P.M	93
IKIRUN	20	19- 11- 2013	2: 33 P.M	
IFE-SOUTH	07	19- 11- 2013	5: 11 P.M	158
MODAKEKE	16	19- 11- 2013	5: 27 P.M	16

TABLE 3(G). TIME INTERVAL OF ARRIVING CALLS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
OSOGBO	10	19- 11- 2013	5: 33 P.M	6
ILASE	02	19- 11- 2013	5: 33 P.M	0
OWODE-EDE	05	19- 11- 2013	5: 33 P.M	0
ERIN -IJESHA	03	21- 11- 2013	9: 07 A.M	
IDO-OSUN	13	21- 11- 2013	9: 17 A.M	10
IKIRE-JUNCTION	08	21- 11- 2013	3: 23 P.M	366
ISOKAN	12	21- 11- 2013	4: 43 P.M	80
OSOGBO	10	21- 11- 2013	5: 19 P.M	36
IFE-EAST	16	21- 11- 2013	5: 23 P.M	4
IKIRE	08	21- 11- 2013	5: 37 P.M	14
IWO	19	22- 11- 2013	12: 08 A.M	
OSOGBO	10	22- 11- 2013	2: 07 P.M	159
GARAGE OLODE	07	22- 11- 2013	2: 10 P.M	3
EGEDORE	13	22- 11- 2013	2: 27 P.M	17
IREWOLE	08	22- 11- 2013	2: 27 P.M	0
IREWOLE	08	23- 11- 2013	3: 37 P.M	70

TABLE 3(H). TIME INTERVAL OF ARRIVING CALLS CONT.

Location of Incident	Incident Location Code	Date	Time	Time Interval of Calls (min)
IWO	19	23- 11- 2013	5: 11 P.M	94
OBOKUN	02	23- 11- 2013	5: 27 P.M	16
IFE-NORTH	11	23- 11- 2013	5: 33 P.M	6
IFE-NORTH	11	24- 11- 2013	1: 33 P.M	
IKIRUN	20	24- 11- 2013	5: 33 P.M	240
EJIGBO	24	24- 11- 2013	5: 43 P.M	10
OSOGBO	10	26- 11- 2013	5: 07 A.M	
ILE-IFE	01	26- 11- 2013	2: 07 P.M	540
IKIRE	08	26- 11- 2013	2: 10 P.M	3
IKIRE	08	26- 11- 2013	2: 27 P.M	17
OSOGBO	10	26- 11- 2013	3: 07 P.M	40
ILE-IFE	01	26- 11- 2013	5: 07 P.M	120
ISOKAN	12	26- 11- 2013	5: 11 P.M	4
ILE-IFE	01	26- 11- 2013	5: 47 P.M	36
OKINNI	13	27- 11- 2013	2: 27 P.M	
GBONGAN	06	27- 11- 2013	5: 31 P.M	184

TABLE 6.TRANSITION NAME AND THEIR ACTIONS

Transition	Action
Arrival Call	Models arriving call
Victim Inform	A substitution transition that models operation of noncritical emergency call
Rescue Team Operation	A substitution transition that models operation of critical emergency call
startservice1	Models start of service by paramedic staff
Call dropped	Models end of service by paramedic staff
Start Examining Victim	Models examining activity by rescue team
end service	Models end of examining activity by rescue team
treatVictim	Models treatment of victim with noncritical condition at the incident location
end treatment	Models end of treatment operation at the incident location
TransferVictimtoHospital	Models transfer of victim with critical condition to the hospital

OSOGBO	10	29- 11- 2013	3: 13 P.M	253
OSOGBO	10	29- 11- 2013	4: 11 P.M	58
EDE-SOUTH	05	29- 11- 2013	5: 06 P.M	55
IKIRE	08	29- 11- 2013	5: 19 P.M	13
ERIN-IJESHA	03	29- 11- 2013	5: 33 P.M	14
IKIRE	08	29- 11- 2013	5: 33 P.M	0
IKIRE	08	29- 11- 2013	6: 02 P.M	29

TABLE 4(A). LOCATION OF INCIDENCE, AMBULANCE LOCATION CODE AND ITS RESPONSE TIME

Local Government	Possible Location of Incidence in the LGA	Ambulance Location Code	Ambulance Location Address Code	Ambulance Response Time (minutes)
IFE CENTRAL	ILE – IFE IFE-CENTRAL IFESOWAPO	01	IFC	Between 8 and 16
OBOKUN	ESA-OKE	02	OBO	Between 5 and 20
ORIADE	ILASE IBOKUN OBOKUN ERIN-IJESHA	03	ORI	Between 7 and 21
BORIPE	ORIADE IJEBU-IJESHA ADA	04	BOR	Between 10 and 18
EDE-SOUTH	IRAGBIJI AAGBA ORORUWO AKODA-EDE EDE-SOUTH OWODE-EDE EDE	05	EDS	Between 8 and 16
AIYEDADE	GBONGAN ODE-OMU	06	AYE	Between 6 and 20
IFE SOUTH	AYEOBA IFE SOUTH GARAGE-OLODE IFETEDO	07	IFS	Between 8 and 16
IREWOLE	IKIRE IKIRE JUNCTION IREWOLE	08	IRE	Between 5 and 15
ILA	ILA-ORANGUN ILA	09	ILA	Between 8 and 15
OSOGBO	OSOGBO	10	OSO	Between 5 and 10

TABLE 4(B). LOCATION OF INCIDENCE, AMBULANCE LOCATION CODE AND ITS RESPONSE TIME CONT.

Local Government	Possible Location of Incidence in the LGA	Ambulance Location Code	Ambulance Location Address Code	Ambulance Response Time (minutes)
IFE-NORTH	IFE-NORTH MORO MORO JUNCTION	11	IFN	Between 8 and 10
ISOKAN	APOMU	12	ISO	Between 8 and 15
EGBEDORE	ISOKAN EGBEDORE OLODE OKINI IDO-OSUN	13	EGB	Between 9 and 12
IREPODUN	ERIN-OSUN ILOBU	14	IREP	Between 8 and 12
AIYEDIRE	ILE-OGBO	15	AYEDI	Between 8 and 12
IFE-EAST	IFE-EAST MODAKEKE	16	IFE	Between 8 and 14
ATAKUMOSA-WEST	ATAKUMOSA-WEST	17	ATW	Between 8 and 10
ATAKUMOSA-EAST	OSU ATAKUMOSA-EAST	18	ATE	Between 9 and 12
IWO	IWO	19	IWO	Between 8 and 10
IFELODUN	IKIRUN	20	IFEL	Between 9 and 12
ODO-OTIN	ODO-OTIN	21	ODO	Between 5 and 12
ILESHA-EAST	ILESHA	22	ILE	Between 5 and 10
BOLUWADURO	BOLUWADURO	23	BOL	Between 5 and 8
EJIGBO	EJIGBO	24	EJI	Between 5 and 10

2.4 Development of the Timed Coloured Petri Net Model for Pre-hospital Emergency Care Network

CPN Tools (version 4.0) was used in constructing a Timed Coloured Petri Net (TCPN) model for the pre-hospital emergency care network under study. In the TCPN model, places were drawn as ovals while transitions were drawn as rectangles. Places and transitions were connected with directed arcs which modelled the relations among the individual elements of the TCPN model. The arcs with their arc expressions defined the flow of tokens in the net. The description of the places and transitions employed in the TCPN model are enumerated in Tables 5 and 6, respectively. The TCPN model consists of two modules which include Next Arrival Call and Process Emergency Call modules. The Process Call module was further sub-divided into Victim Informed and Rescue Team Operation sub-modules. The detailed activities associated with each of the modules and sub-modules are discussed in the following sub-sections.

2.4.1 Next Arrival Call Module

The arrival of emergency calls to the call centre of O'Ambulance management service is modelled in this module. Based on timed coloured petri nets formalism, each simulated call is assigned to a token. Each token is bind to four token elements: accType, aTime, ParmDecision,

TABLE 5.PLACE NAME, TYPE AND THEIR FUNCTIONS

Place	Place Type	Function
Next Call ID	INT	Hold the token for next calling number
Incoming Call	Calllist	Indicate lists of waiting calls
PARM FREE	CallReceiver	hold the token for call desk personnel (that is the Paramedic Staff)
PARM BUSY	CallerxCallReceiver	Indicate when paramedic staff is busy with caller
Dropped call	Caller	hold the token for lists of informed patients
Available Ambulance	LocIDxAmbulanceLocADDxnResTeam	Indicate number of emergency medical technician and list of available ambulance at their strategic location
Rescue team busy	CallerxAmbulanceLocADD	Indicate when Rescue Team is busy examining a patient at the scene
Rescue Team prepare to respond to call	RescueTeamOperation	Models preparation activity of the Rescue Team
Rescue Team in transit	RescueTeamOperation	Models transportation operation
Treatment in Progress	Caller	Indicate when Rescue Team is busy treating patient at the

incidentLocID and RescueTeamDecision. Interpretations of these binding elements are enumerated.

i. The token element accType denotes the type of accident reported by the caller
ii. The token element aTime denotes arrival time of call
iii. The token element ParmDecision represents decision made by the paramedic staff depending on the nature of incident reported by victim or eye witness.
iv. The token element incidentLocID denotes the assigned code for the location where the emergency case was reported.
v. The token element RescueTeamDecision represents decision made by the emergency medical technician of the rescue team either to treat the victim at the scene or transfer him to the hospital depending on the severity of the incidence.

2.4.2 Process Emergency Calls Module

When a call is made and the token element ParmDecision of the incoming call has the value "notserious", then the sub-module Victim Informed will be enabled as indicated by the guard function attached to the substitution transition VictimInformed in the Process Emergency Calls Module of the TCPN model. The implication of this is that the paramedic staff will only give medical health advice to the victim and no rescue team will be sent to the incident location. However, if the token element ParmDecision of the incoming call has the value serious, the sub-module Rescue Team Operation will be enabled as indicated by the guard function attached to the substitution transition Rescue Team Operation. Also, implication of this is that the incident occurred requires intervention of rescue team.

Besides, on getting to the incident location, the emergency medical technician of the rescue team has to make a decision on whether to treat the victim at the scene or transfer the victim to the hospital. In this case, the token element RescueTeamDecision was used to achieve this operation. However, based on the interview conducted with the rescue team, the probability of transferring victim to the hospital is 10%.

The simulation of the proposed TCPN model was carried out in CPN tools environment using the data obtained from the O'ambulance management service. According to the data obtained, the estimated frequency of emergency calls arrival is described by Table 7. The data for days 7, 9, 10, 18, 20, 25 and 28 were not included in Table 7 because no cases of emergency calls were reported on these days. Other input parameters for the simulation of the TCPN model are revealed in Table 8. Due to the fact that the simulation is stochastic, it is necessary to execute several simulations runs with the TCPN model in order to obtain the mean value. Hence several replications were run. Thirty simulation runs was carried out such that the number of patients that require non-urgent intervention as well as the numbers of patients that require urgent intervention was experimented. Besides, the Timed Coloured Petri Net model was validated by carrying out a statistical analysis (T-Test) between the output of the simulation model and the obtained rescue team average response time and turn-around times depicted in Table 9.

For any process improvement project, establishing quantitative measures to implement changes and develop monitoring system for continuous improvement is crucial. Hence, in this work, the following three key performance metrics were investigated in the TCPN model.

i. **Average Call Waiting Time**: The mean value of the interval between the time the emergency call arrive and the time the call receiver responds to the call.
ii. **Rescue Team Response Time**: Interval between the time the response team responds to call receiver (paramedic) request and the time it arrives at the scene.
iii. **Rescue Team Turn-around Time**: Interval between the time the response team received order from the call receiver and the time the recue team return back to its location.

TABLE 7.SIMULATION PARAMETER

Day (*i*)	Frequency of Emergency Calls	Arrival Distribution Function of Emergency Calls
1	1 call per 71.8 minutes	EXPO(71.8)
2	1 call per 54 minutes	EXPO(54)
3	1 call per 108 minutes	EXPO(108)
4	1 call per 65.8 minutes	EXPO(65.8)
5	1 call per 28.6 minutes	EXPO(28.6)
6	1 call per 90 minutes	EXPO(90)
8	1 call per 45 minutes	EXPO(45)
11	1 call per 63.3 minutes	EXPO(63.3)
12	1 call per 43 minutes	EXPO(43)
13	1 call per 84.8 minutes	EXPO(84.8)
14	1 call per 119 minutes	EXPO(119)
15	1 call per 49.4 minutes	EXPO(49.4)
16	1 call per 58.4 minutes	EXPO(58.4)
17	1 call per 68.6 minutes	EXPO(68.6)
19	1 call per 36 minutes	EXPO(36)
21	1 call per 85 minutes	EXPO(85)
22	1 call per 34.8 minutes	EXPO(34.8)
23	1 call per 38.7 minutes	EXPO(38.7)
24	1 call per 125 minutes	EXPO(125)
26	1 call per 109 minutes	EXPO(109)
27	1 call per 52.5 minutes	EXPO(52.5)
29	1 call per 64.6 minutes	EXPO(64.6)

TABLE 8. OTHER SIMULATION PARAMETER

Input Parameter	Value
Number of Call Receiver (Paramedic)	1
Call Receiver (Paramedic) Processing Time for very serious incident case	Between 5 to 10 minutes
Call Receiver (Paramedic) Processing Time for not very serious incident case	Between 1 to 3 minutes
Number of ambulance in Operation	24
Number of emergency medical technician attached to each ambulance vehicle	2
Rescue Team Preparation Time to leave for the scene	Between 3 to 5 minutes
Rescue Team Travelling Time to the scene	Between 5 to 10 minutes
Rescue Team Examining Time at the scene	Between 2 to 3 minutes
Rescue Team Treatment Time at the scene	Between 10 to 15 minutes
Rescue Team Transportation Time from the scene back to the location	Between 5 to 8 minutes
Rescue Team transportation Time of victim to the hospital	Between 5 to 7 minutes
Rescue Team Transportation Time from the hospital back to the location	Between 5 to 10 minutes

TABLE 9.OBTAINED RESCUE TEAM RESPONSE TIME AND TURN-AROUND TIMES

Ambulance Location Address Code	Rescue Team Average Response Time (ART) in Minutes	Rescue Team Turn-around Time (TTC) in case of critical condition (Minutes)	Rescue Team Turn-around Time (TTNC) in case of non-critical condition (Minutes)
IFC	12	32	40
OBO	14	28	38
ORI	14	33	35
BOR	14	31	40
EDS	12	30	37
AYE	13	29	39
IFS	12	27	41
IRE	10	30	37
ILA	11.5	33	39
OSO	8	28	36
IFN	7.5	32	38
ISO	12	30	35
EGB	6.5	26	39
IREP	11	29	36
AYEDI	10	30	35
IFE	10	32	39
ATW	11	28	37
ATE	8	26	36
IWO	7	30	39
IFEL	7.5	31	35
ODO	8.5	33	40
ILE	8	29	37
BOL	7	28	39
EJI	7.5	31	35

3 RESULTS AND DISCUSSION

Figure 2 shows the developed TCPN model for pre-hospital emergency care network of the O'ambulance service under consideration. The developed TCPN model is made up of two modules. These are (1) Next Call arrival module and (2) Process Emergency Call module shown in Figures 3 and 4, respectively. The Next Call arrival module models the arrivals of emergency calls to the emergency call centre. The Process Emergency Call module was further categorized into Victim Informed sub-module and Rescue Team Operation sub-module. The Victim Informed sub-module as depicted in Figure 5 shows the response operation of the paramedic staff on patient whose condition is not very serious. Also, the sub-module Rescue Team Operation as shown in Figure 6 reveals activities of the rescue team at the distress scene.

The results obtained from the simulation as shown in Table 10 revealed that the minimum average call waiting time of 0.15 minutes was experienced on day 5 while the maximum average call waiting time of 1.65 minutes was experienced on day 24. The maximum average call waiting time experienced on day 24 was due to high rate of call received by the paramedic staff on this day. Due to the long waiting time experienced on day 24, an alternative scenario was proposed and this entails the use of two call agents (receivers) on this day. The result shown in Table 11 revealed that using an additional call agent has considerably reduced the call average waiting time from 1.65 minutes to 0.35 minutes (that is by 78.79%). Also, from Table 12, it is evident that the minimum value for average response time (ART), rescue team turn-around time (TT) in case of critical and non-critical situation were 7.05, 26.17 and 35.13 minutes, respectively. Likewise, the maximum value for average response time(ART) and rescue team turn-around time(TT) in case of critical and non-critical emergency situation were 15, 34 and 41.62 minutes respectively. Thus, it can be concluded that the rescue team operation time in the case of critical emergency situation is approximately 18.31% (7.62 minutes) more than its operation time in the case of

TABLE 11.SIMULATION RESULT OF AN IMPROVEMENT SCENARIO

Day (*i*)	Call Average Waiting Time (AWT) in Minutes
1	0.45
2	0.24
3	0.15
4	0.42
5	0.65
6	0.27
8	0.55
11	0.40
12	0.51
13	0.42
14	0.45
15	0.59
16	0.40
17	0.57
19	0.35
21	0.48
22	0.65
23	0.75
24	0.35
26	0.23
27	0.45
29	0.21

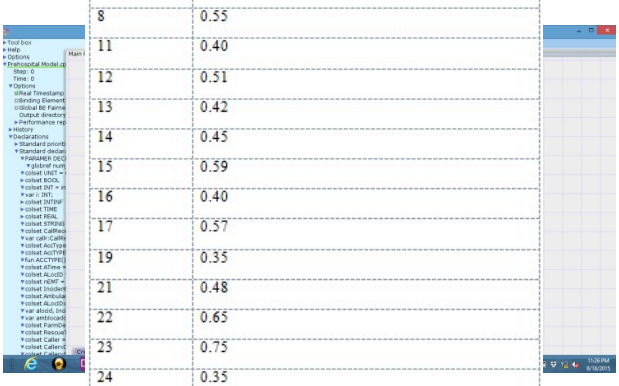

FIG. 2 ...EL OF O'AMBU... ...TWORK

TABLE 12.SIMULATION RESULT OF RESCUE TEAM RESPONSE TIME AND TURN-AROUND TIMES

Ambulance Location Address Code	Rescue Team Average Response Time (ART) in Minutes	Rescue Team Turn-around Time in case of critical (TTC) condition (Minutes)	Rescue Team Turn-around Time in case of non-critical (TTNC) condition (Minutes)
IFC	13.05	31.05	40.01
OBO	15.00	28.20	38.25
ORI	14.10	33.35	35.13
BOR	14.05	31.75	40.05
EDS	13.00	30.21	37.03
AYE	13.55	29.80	39.18
IFS	12.10	27.52	41.62
IRE	10.20	30.25	37.19
ILA	11.50	34.00	40.00
OSO	8.20	28.28	36.16
IFN	8.15	32.22	38.24
ISO	12.10	30.18	35.71
EGB	7.05	27.01	39.52
IREP	11.20	29.10	36.18
AYEDI	10.65	30.03	35.56
IFE	10.17	32.40	39.19
ATW	11.04	28.34	37.48
ATE	8.05	26.17	36.89
IWO	7.12	30.29	39.65
IFEL	7.55	31.77	35.13
ODO	8.55	33.90	40.85
ILE	8.17	29.72	37.45
BOL	7.25	28.18	39.45
EJI	7.55	31.49	35.72

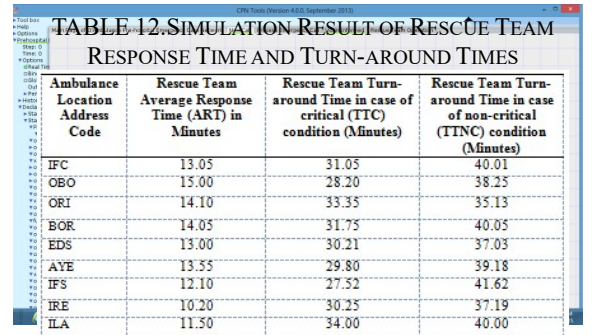

FIG. 4.PROCESS EMERGENCY CALL MODULE OF THE DEVELOPED TCPN MODEL

non-critical situation.

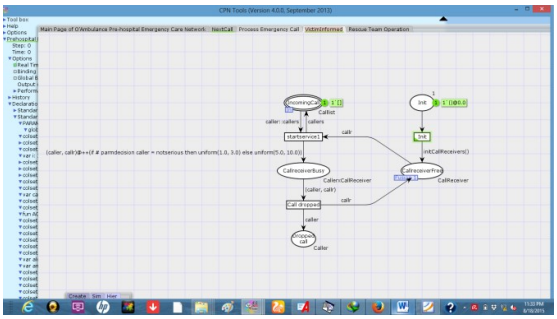

FIG. 5.VICTIM INFORMED SUB-MODULE OF THE DEVELOPED TCPN MODEL

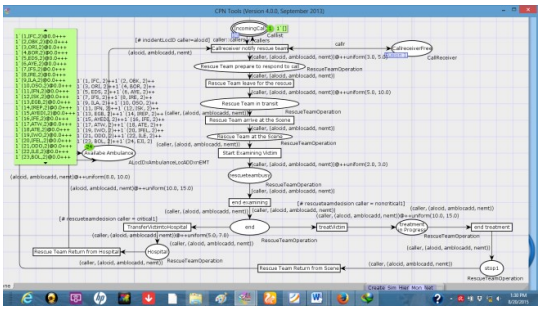

FIG. 6.RESCUE TEAM OPERATION SUB-MODULE OF THE DEVELOPED TCPN MODEL

TABLE 10.SIMULATION RESULT OF CALL AVERAGE WAITING TIME

Day (*i*)	Call Average Waiting Time (AWT) in Minutes
1	0.45
2	0.24
3	0.15
4	0.42
5	0.65
6	0.27
8	0.55
11	0.40
12	0.51
13	0.42
14	0.45
15	0.59
16	0.40
17	0.57
19	0.35
21	0.48
22	0.65
23	0.75
24	1.65
26	0.23
27	0.45
29	0.21

Figure 7 shows the results of the validation of the developed TCPN model. It compares the simulated and the obtained rescue team average response time and turn-around times of

the rescue teams in operation at the considered case study. The statistical analysis of the validation results carried out through statistical package for Social Sciences software (version 20.0) revealed that there were no significant differences between the simulated and the obtained data values at 5% significance difference level.

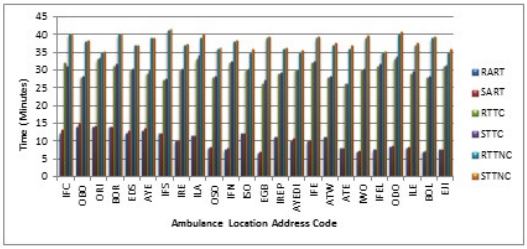

FIG. 7. VALIDATION RESULT OF THE DEVELOPED TCPN MODEL

Legends:

RART: Real Average Response Time
SART: Simulated Average Response Time
RTTC: Real Average Turn-around Time in the case of Critical Condition
STTC: Simulated Average Turn-around Time in the case of Critical Condition
RTTNC: Real Average Turn-around Time in the case of Non-critical Condition
STTNC: Simulated Average Turn-around Time in the case of Non-critical Condition

4 CONCLUSION AND FUTURE WORK

In this paper, a TCPN model, which is characterized by ambulance localization, security agencies and processing of emergency calls, has been developed. The developed TCPN model validly represents the considered pre-hospital emergency care flow process. This is evident from the result of the statistical analysis, which shows there were no significant differences between the simulated and the real number of patients making calls to the emergency call centre at 5% level. The TCPN model, through its simulation, can be used to predict the amount of manpower needed for efficient and effective pre-hospital emergency care services. Also, it can as well serves as a reference model for studying and improving pre-hospital emergency care flow process in a named ambulance centre. However, it is recommended that future research may be geared towards investigating the associated properties of the developed TCPN model using occurrence graph (O-graph) analysis method.

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