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Development of an Executable Model for the Nigerian Voting System using Hierarchical Timed Coloured Petri Nets

Ganiyu R. A., Omidiora E. O., Okediran O. O., Alo O. O., Olaoluwa A. O.

Abstract— Voting systems are complex systems that involve activities that take place before, during and after election. The world over, automation of voting systems has attracted the attention of academia and industry because voting system is fundamental to the success of any democratic process. In this paper, Hierarchical Timed Coloured Petri Nets (HTCPN) formalism is explored to develop an executable model for the Re-Modified Open-Secret Ballot System (REMOBS) adopted in Nigerian 2015 general election. The developed HTCPN model for REMOBS is made up of two modules representing the Accreditation Process and the Voting Process. Each of the modules comprises two sub-modules (voting_station and voting_booth). These sub-modules are made up of another layer of sub-modules that abstract key activities while each sub module in this layer is made up of several transitions and places. Thus, the developed HTCPN model can be easily modified through its associated modules to suit any future modification in voting systems.

Index Terms— Voters, Election, INEC, Petri Nets, modularized-model, voter arrival rate.

1 Introduction

Voting is the bridge between the governed and government. From the birth of democracy in Athens in sixth century BC and the first form of electoral laws, electoral systems have been designed and developed according to country particularities in democratic governments worldwide [1]. The last few years have brought a renewed focus onto the technology used in the voting process and a hunt for voting systems that engender confidence [2]. Elections allow the populace to choose their representatives and express their preferences for how they will be governed. Naturally, the integrity of the election process is fundamental to the integrity of democracy itself. The election system must be sufficiently robust to withstand a variety of fraudulent behaviors. It should be transparent and comprehensible that voters and candidates can accept the results of an election. There are a number of voting systems adopted all over the world with each of them having its peculiar problems [3]. In times past, different voting systems that are based on traditional paper ballots, mechanical devices, or electronic ballots were developed for election. However, these voting systems have littered history with example of elections being manipulated in order to influence their outcomes [4].

Nigeria as a nation is at the brink of breaking up with the political gladiators at each other’s throat, due to suspicion and counter suspicion of each other as regards electoral fraud. Rigging of election is threatening the present fragile nature of democracy in Nigeria and as well as the peaceful co-existence of the various geo-political region of Nigeria. It is therefore imperative to consider an alternative method of doing election without running fowl of the law of the land and putting the country in a more tensed situation [5]. Much time is wasted each time as Nigerians exercise the limitations of their patience by standing in line waiting for their turn at the poll centers to vote. Protracted voters’ waiting time is widely accepted to be a major impediment to voters’ turnout at elections [6]. Voting systems are complex systems that involve activities that take place before, during and after election. Candidates nominated by any political party to contest elections are elected through a voting system. A lot of voting system models had been presented in literature. A non-modular simulation-optimization model was developed by [6] for determining voting material requirements at the polls. Similarly, with no emphasis on modularity, [7] simulated the voting process using a simulation model that allows the use of non-stationary arrivals and non-steady-state queues. Thus, most existing voting system models are not flexible to abstract any future modification in voting systems owing to the fact that they conceptualized on non-modular formalisms. Albeit, Petri Nets are 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 [8]. The inclusion of time and hierarchy concepts into a Coloured Petri Net model results in a model called Hierarchical Timed Coloured Petri Net (HTCPN) model [9]. However, the objective of this paper is to employ a HTCPN formalism to develop an executable model for a voting system using the Nigerian Re-modified Open-Secret Ballot System as a case study.

2. Research Methodology

- Ganiyu R. A. E-mail: raganiyu@lautech.edu.ng
- Omidiora E. O. E-mail: eoomidiora@lautech.edu.ng
- Okediran O.O.,Email: oookediran@lautech.edu.ng
- Alo O.O., E-mail: ooalo@lautech.edu.ng
- Olaoluwa A.O.Email: yinkani@gmail.com
- Department of Computer Science and Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria.

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2.1 OVERVIEW OF THE MODELLING APPROACH

In this paper, a Timed Coloured Petri Net (CPN) formalism stated in (1) was used to develop an executable model for the voting system under consideration. A Coloured Petri Nets and Timed Coloured Petri Nets are tuples defined as [10,11,12];

$CPN = (\Sigma, P, T, A, N, C, G, E, I)$

Where:

(i) Σ is a finite set of non-empty types, called color sets.

(ii) P is a finite set of places.

(iii) T is a finite set of transitions.

(iv) A is a finite set of arcs such that: $P \cap T = P \cap A = T \cap A = \emptyset$.

(v) N is a node function. It is defined from A into $P \times T \cup T \times P$.

(vi) C is a colour function. It is defined from P into Σ.

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

$\forall t \in T: [Type(G(t)) = Bool \wedge Type(Var(G(t))) \subseteq \Sigma]$.

(viii) E is an arc expression function.

(ix) I is an initialization function.

A timed Coloured Petri Net is a tuple;

$$TCPN = (CPN, R, ro) \quad (1)$$

such that:

(i) CPN satisfying the above definition.

(ii) R is a set of time values, also called time stamps. It is closed under + and including 0.

(iii) ro is an element of R called the start time.

2.2 DESCRIPTION OF THE CASE STUDY

In this paper, a voting system known as the "Re-Modified Open-Secret Ballot System"(REMOBS) presented by the Independent National Electoral Commission Nigeria was used as a case study. This is a political party-based system as candidates run for elective offices on the platform of political parties [13]. The voting system is made up of the accreditation and voting exercise. These two takes place in a day; accreditation is scheduled to be between the hours of 8:00am and 1:00pm, while voting should start at 1:30pm of the Election Day and ends when the last person has voted. Voters arrive in a random manner. The two processes witnessed voters on queue at startup. If the queue length is above 100, the voter could choose to balk. A voter that has spent over 4800 seconds on queue also could choose to renege.

2.2.1 ACCREDITATION

The accreditation process assumes the following procedure. The voter shall present himself/herself to the APO III (Assistant polling officer III) who works as the queue controller officer at the Polling Unit or Voting Point. The APO III shall determine if the voter is at the correct Polling Unit or Voting Point and, if satisfied, directs the voter to the APO I(Assistant polling officer I) who does the verification and statistics collation.

The APO I (Verification and Statistics officer) shall request for the voters permanent Voters' Card (PVC) from the voter; match the photograph on the PVC to the Voter; read the PVC using the Card Reader to authenticate the PVC as that of the voter and that the Polling Unit details in the PVC correspond with those of that Polling Unit; request the voter to place the appropriate finger in the place provided on the Card Reader for authentication; on verification by the Card Reader, proceed to document the gender of the voter, and indicate where applicable, any physically challenged person, using the Voter Information and Statistics Form. Authentication means that the finger prints of the holder match the finger prints read by the Card Reader.

The verified voter shall then present himself/herself to the APO II who shall request for his/her Permanent Voter's Card; check the Register of Voters to confirm that the voter's name, details and Voter Identification Number (VIN) are as contained on the Register of Voters; tick the left side of the name of the voter, if the person's name is on the Register of Voters; apply indelible ink to the cuticle of the specified finger-nail on the left hand and issue him/her with an accreditation tag, bearing the signature of the PO or the APO II as delegated by the PO, date of election and the voter's serial number on the Register of Voters; advise the voter to be available not later than 1:30p.m. for commencement of voting [13].

2.2.2 VOTING PROCESS

Voting which is the second process of the election that takes place the same day follows the procedure as presented by INEC and stated below: On presentation of the PVC by a voter, the APO II shall check the cuticle of the appropriate finger/thumb-nail of the voter to confirm that he/she has been accredited and received the number tag for easy location of voter's name on the Register; stamp, sign and date the back of the ballot papers; issue the endorsed ballot papers to the voter, tick the Register of Voters in the appropriate box against the voter's name, indicating that he/she has been issued with ballot papers for the elections; apply indelible ink on the cuticle of the voter's appropriate thumb/finger nail according to the type of election; request the voter to proceed to the voting cubicle to thumb-print the ballot papers in secret, in the space provided beside the logo of the party of the voter's choice; advise the voter to fold the ballot papers vertically and proceed to the APO I (Overseer) [13]. The APO I (Overseer) shall ensure that the voter deposits the thumb-printed ballot papers into the appropriate ballot boxes placed in the open view.

These steps are represented in Fig. 1 and 2

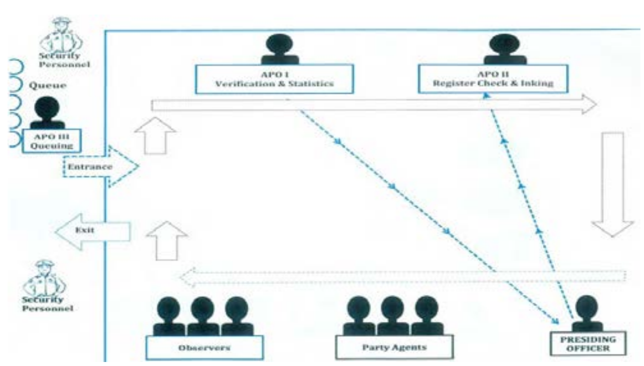

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Fig. 1: INEC’s Set-Up for Accreditation in Stand-Alone Polling Unit [13]

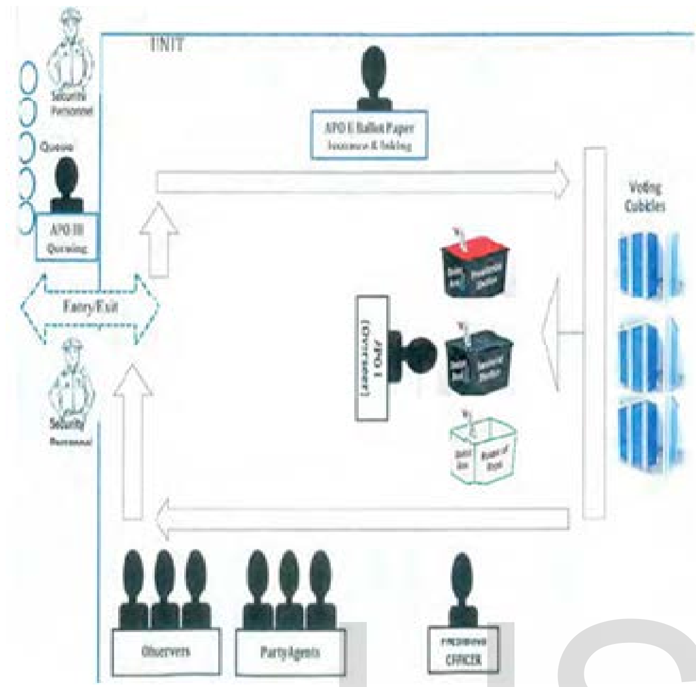

Fig. 2: INEC’s Set-Up for Voting in a Stand-Alone Polling Unit [13].

2.3 DATA COLLECTION AND ANALYSIS

Data acquisition is crucial because the results and findings of a simulation study in the best case are as good as the input information. In this study, different methods were used to collect data, the historical data used to obtain the arrival pattern and validate the developed HTCPN model of the voting system were obtained from secondary data sources. The input data used are those obtained from [6], [13] and [14]. The voter arrival pattern data obtained happened to be the only available option since these types of data are not readily available with the INEC and in the media. The data obtained from [6] is presented in Tables 1(observed arrival pattern during accreditation for 561 voters) and 2 (observed and simulated arrival pattern during voting exercise for 551). The arrival of the voters to the voting booth for both the accreditation and voting is a non-stationary arrival process and it is difficult to predict due to some variables such as time of day, traffic and working hours for voters. There is difference in arrivals during the different hourly time of the day. Mean arrival rate was calculated for each period of 3600 seconds of the whole voting day.

TABLE 1
Arrival pattern Data for Accreditation Process with a Population of 561 Voters

Time Interval	% of Voter's Turnout	Observed population	$1/\lambda$
Before 8 am	18.0	107.0	Preload
8.00-9.00	37.0	207.0	17.4
9.00-10.00	7.0	39.0	92.3
10.00-11.00	25.0	136.0	26.5
11.00-12.00	13.0	72.0	50.0

TABLE 2
Arrival pattern Data for Voting Process with a Population of 551 Voters

Time Interval	% of Voter's Turnout	Observed population	Simulated Population	$1/\lambda$
Before12 noon	15.0	83.0	83.0	Pre-load
12.00-1.00pm	21.0	116.0	116.3	31.0
1.00-2.00pm	12.0	66.0	63.7	54.6
2.00-3.00pm	28.0	154.0	149.3	23.4
3.00-4.00pm	8.0	44.0	43.0	81.8
4.00-5.00pm	10.0	55.0	56.7	65.5
5.00-6.00pm	6.0	33.0	33.7	109.1

2.4 MODELLING OF THE NIGERIAN VOTING SYSTEM USING HTCPN

CPN Tools (version 4.0.0) was used in constructing a HTCPN model. The developed HTCPN model is a hierarchical model that is made up of two main modules. The top module is the first level of the hierarchy that houses every other module. It has socket places and sub transition drawn with double walled rectangles. Each sub transition is a sub

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module which has completely defined operations. These are the voting_station module (models arrival and departure of voters) and voting_booth module (models queuing of voters, the operation the presiding officers and voters behavioral pattern). The hierarchical model was further broken it into different sub modules vis: arrival module, voting process module, queue module, departure module and voter behavioral module that modelled reneging and balking of disenfranchised. The descriptions of the major places and transitions used in developing the HTCPN model are as described in Tables 3 and 4, respectively. Also, the color sets, variables, initial parameters and functions employed in developing the HTCPN model of the voting system are depicted in Fig. 3.

TABLE 3
Description of Major Places in the HTCPN Model
Place Description

PLACES	COL-SET	DESCRIPTION
Chk_Register	voter	This socket place represents newly arrived voters checking for their names on the pasted voters list
Go_out	voter	This are balked voters in the state going-out as disenfranchised voters
Counter2	Tint	This is set to count the number of times transition Disfranchised voter is fired indicating the number of voters that left the voting booth as balked and to stop the transition. It is timed
Counter1	Tint	This is set to count the number of times transition Renege is fired indicating the number of voters that left the voting booth as reneged and to stop the transition. It is timed
Queue	Queue	Models queuing state by APOIII in a first in first out order.
Reneged	voter	This is for collecting another copy of the detailed data about the voter that balked and the time they left.
Limit	unit	This is to bound the maximum number of voters in place Renege?
Free_officer	vbooth	This indicated the availability of APOI, it was sent to two when two APOI officers were used but to one when only one was used but zero means all officers are engaged.
Validated	voter	Voters in this state are already through with the card reader and are waiting for the enabled transition to fire
Officer_free	vbooth	This indicated the availability of APOII, it was sent to two when two APOII officers were used but to one when only one was used but zero means all officers are engaged.
Renege?	voter	Voters in this state are set to decided to quit the voting if the time spent on queue is more than a set time and the population reneged is above a set value.
Officer1_desk	voter	This is a state on officer 1 desk. This indicate that the voter is waiting to use up the time allocated to it by the arc inscription (cid,t)@+discrete(60,90)
Officer2_desk	voter	This is a state on officer 2 desk. This indicate that the voter is waiting to use up the time allocated to it by the arc inscription (cid,t)@+discrete(50,75)
Finish	voter	Voter who have been properly accredited leave the voting booth through this place

TABLE 4
Description of Major Transitions in the Model
Transition Description

TRANSITIONS	DESCRIPTION
APO_III put_in_queue	This models the operation of the queue supervisor that puts voters into queue in a first in first out manner. It takes tokens from places Chk_Register and Queue and puts voters in queue in place Queue using arc inscription q^^[c]
Disfranchised voter	This models the behavior of the voter by becoming enabled when the condition len(q)>=100, i<50 is true. This says balk(fire) when queue length is above 100 and number balked is less than 50.
Leave_queue	This is to enable the monitoring of waiting time on queue and to model leaving the queue to a state(place) of decision making, do I renege?
Renege	This models the behavior of the voter by becoming enabled when the condition [(intTime()-t)>4800,i<50] is true.
APO_I	This models the card reader operator APOI verifying voters with the card reader and spending between 60-90seconds per voter. It is bounded with free-officer to limit the number of officer to 1
End1	This models the completion of operation by APOI and makes the officer APOI available.
APO_II	This models the manual data officer (APOII) verifying voters with the voters register and spending between 50-75 seconds per voter. It is bounded with place free-officer to limit the number of officer to 1
End 2	This models the completion of operation by APOII and makes the officer APOII available.

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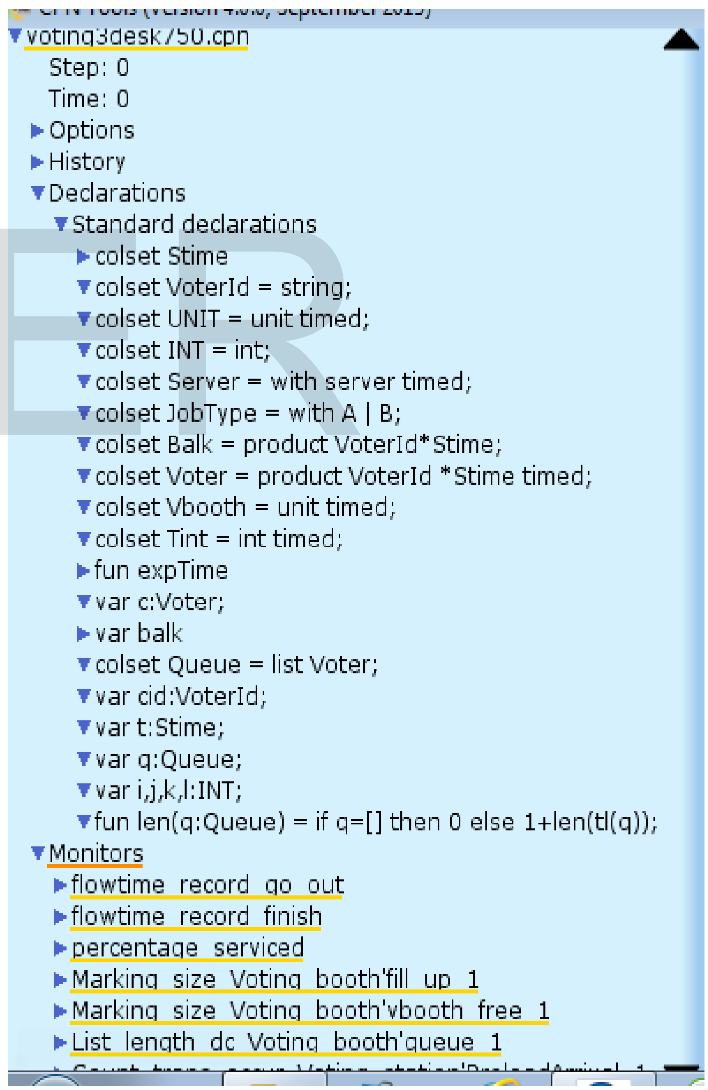
PO_ADDRESS	This models the activity of the presiding Officer who takes some minutes to address the voters on queue already and declares exercise opened. It is only enabled once.
Preload Arrival	This models the arrival of voters before the 8.00am. The limiting value is obtained from the voters' turnout rate statistics. i<54
Arriva1l	This models the arrival of voters from 8.00a. to 9.00am as a Poisson process obtaining arrival time distribution from negative exponential distribution with a coefficient of 1.0/32.4. It is set to become enabled only after all the early arrivals have been attended to using the guard [time()<=3600,i>54] and arc inscription [1+i@round(exponential(1.0/32.4))]. When it fires, it updates place counter, Cont and presents properly labeled voters to the voting station sub model through the socket place Che_register.
Arriva2l	This models the arrival of voters from 9.00a. to 10.00am as a Poisson process obtaining arrival time distribution from negative exponential distribution with a coefficient of 1.0/171.4. It is set to become enabled only after all the early arrivals have been attended to using the guard [time()>=3600,time()>=7200] and arc inscription 1+i@round(exponential(1.0/171.4)). When it fires, it updates place counter, Cont and presents properly labeled voters to the voting station sub model through the socket place Che_register.
Arriva3l	This models the arrival of voters from 10.00am. to 11.00am as a Poisson process obtaining arrival time distribution from negative exponential distribution with a coefficient of 1.0/48.0. It is set to become enabled only after all the early arrivals have been attended to using the guard [time()<=7200,time()>=10800] and arc inscription 1+i@round(exponential(1.0/48.0)). When it fires, it updates place counter, Cont and presents properly labeled voters to the voting station sub model through the socket place Che_register.
Arriva4l	This models the arrival of voters from 12.00noon to 11.00am as a Poisson process obtaining arrival time distribution from negative exponential distribution with a coefficient of 1.0/92.5. It is set to become enabled only after all the early arrivals have been attended to using the guard [time()<=10800,time()>=14400] and arc inscription 1+i@round(exponential(1.0/92.5)). When it fires, it updates place counter, Cont and presents properly labeled voters to the voting station sub model through the socket place Che_register.

Fig. 3: Declarations of Color sets, variables and functions

3 THE DEVELOPED HTCPN MODEL

Fig. 4 shows the developed HTCPN top model for the Remodified open-secret ballot system under consideration while Fig. 5,6,7,8 and 9 show its associated sub-models. The developed HTCPN model of the voting system has three pages of global varieties. The APOI and APOII was assumed to use an average of 75 and 60 seconds for accreditation respectively, these were chosen according to data released during field trials carried out by the INEC. The Nigerian Re-modified Open-Secret Ballot System was modelled by breaking it into different sub modules vis: arrival module, voting process module, queue module, departure module and voter behavioral module that modelled reneging and balking of disenfranchised voters. Time and hierarchy were used for scalabil-



ity and reusability of the modules. The arrival rate of voters for voting and accreditation were observed to differ notably between different hours of the day. Five different hourly blocks were considered for accreditation (preload before 8:00am, 8:00-9:00am, 9:00-10:00am, 10:00-11:00am, 11:00-

12:00noon) while seven different periodic blocks (preload before 1:30pm, 1:30-2:00, 1:00-2:00, 2:00-3:00, 3:00-4:00, 4:00-5:00, 5:00-6:00) were considered for voting according to the remodified scheme of INEC for 2015 polls. The inter-hourly distributions of voters' arrival rate were obtained from a negative exponential distribution extracted according to the observed arrival rate for each hour considered in the 2011 National election.

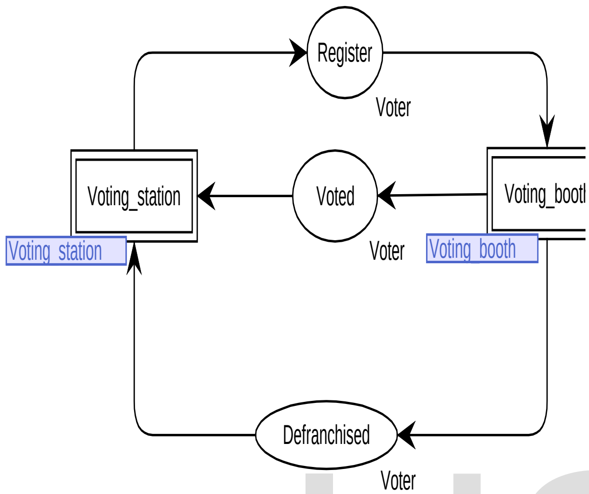


Fig. 4: Top Level Module of the Developed HTCPN Model for Voting Process

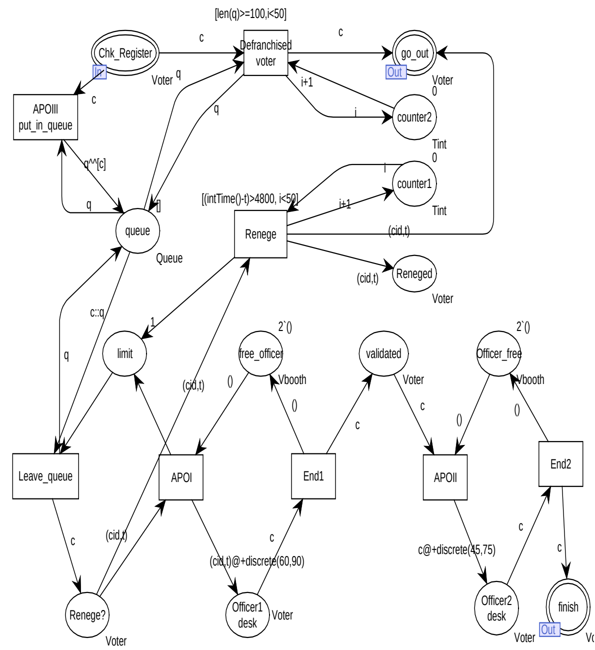


Fig. 6: The Voting Booth (Internal Operation) Subpage of the Developed HTCPN Model for Accreditation Process

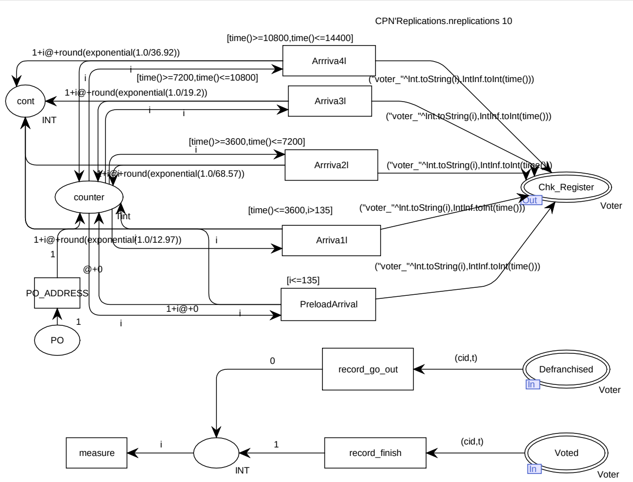


Fig. 5: The Voting Station (Environment) Subpage of the Developed HTCPN Model for Accreditation Process

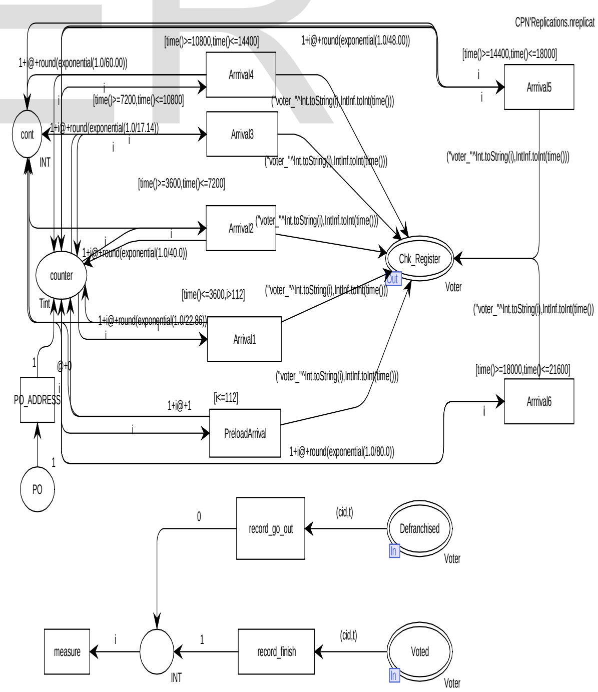


Fig. 7: The Voting Station (Environment) Subpage of the Developed HTCPN Model for Voting Process

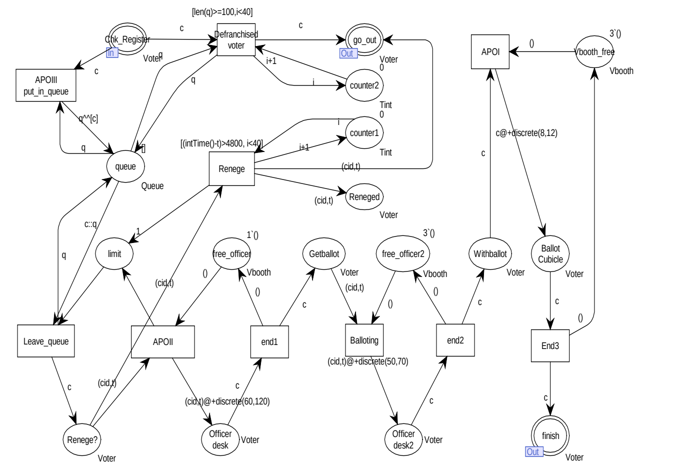


Fig. 8: The Voting Booth (Internal Operation) Subpage of the Developed HTCPN model for Voting Process

4 Conclusion and Future Work

In this paper, we have been able to develop a Hierarchical Timed Coloured Petri Net (HTCPN) model for a voting system using the Nigerian Re-modified Open-Secret Ballot System (REMOBS) adopted for 2015 National election as a case study. The developed HTCPN model can be easily modified through its associated modules to suit any future modification in the voting system under consideration. Furthermore, it is recommended that future research may be geared towards validating and analyzing the performance of the developed HTCPN model through simulation based analysis technique.

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