Development of an Executable Model for a Hospital Medication Distribution Process using Hierarchical Timed Coloured Petri Nets

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ORIGINAL RESEARCH

Abstract— Medication distribution units offer one of the most sensitive services that determine the rate of quality service for patients' satisfaction in hospitals. In solving the issues of inefficient hospital medication distribution processes, a Hierarchical Timed Coloured Petri Nets (HTCPN) formalism was employed in this paper to model a decentralized hospital medication distribution process using Bowen University Teaching Hospital, Ogbomoso, Oyo State, Nigeria as a case study. The developed HTCPN model is made up of seven (7) modules conceptualizing medication distribution processes taking place in Children's ward, Men's ward, Women's ward, Private ward, Neonatal ward, Intensive care unit and Pharmacy. These modules modelled the prescription, checking and billing, transportation and administration of medications to the patients via urgent, daily and medicine cabinet requests. The developed HTCPN model can be easily modified through it associated modules to suit any future modification in the considered process or other related ones.

Keywords— Model, Hospital, Medication, Process, Modules, Petri Nets

1 INTRODUCTION

In hospital, the procedure of drug distribution may be categorized into two groups, namely outpatient services and inpatient services. Inpatients are those who get hospitalized for the purpose of treatment of the diseases, surgery and habitation. Drug distributions to inpatients falls within four categories, which include individual prescription order system, complete floor stock system, individual prescription order system/complete floor stock system and unit dose dispensing method. Outpatients refer to those patients who are not occupying beds in hospitals when they come for consultation, diagnosis and treatment. Drug distribution system is a sub-system in hospitals meant to supply medications prescribed for each inpatient. The system consists of all processes that occur between the prescription of a drug and the administration of that drug to the patient. The goal of drug distribution system is to ensure that each dose of medication administered to each patient is exactly that which was intended by the prescriber (Adigun, 2016).

The drug distribution procedure has various stages, starting with a prescription and ending with the administration of the drug to the patient. The prescription is the doctor's responsibility while 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.

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There are two basic known types of drug distribution systems: collective and individual (Filipe, 2010). 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 pharmacists that are professional 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. The types of pharmacy services include centralized and decentralized 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 (Rosa *et al.*, 2003; Adigun, 2016).

Modelling is a process of creating symbols or making graphical notations for abstract representation of real life system (Hussein, 2014). A model is an abstract representation and description of the operations of a real system either symbolically or mathematically and it can be classified into three; mathematical method, physical model and computer model, and the nature of each of the classes of the model can be either static or dynamic. Simulation is the experimentation of a system model. It involves subjecting the model to varying inputs in order to study the change in the system behavior for the purpose of improving the system performance (Akingbade, 2015).

Real systems such as hospital medication distribution system require the use of modelling approach in studying the various sub-processes of the system effectively due to the complexity it entails. Many modelling languages have been suggested and used for real systems modelling, but Petri Nets has proven to be a strong modelling language for different types of discrete systems, due to the fact that its formalism offers a clear means to present simulation and control logic. Coloured Petri Nets is a discrete-event modelling language that combines classical Petri Nets with the functional programming language Standard ML (Ganiyu *et al.*, 2013). 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 *et al.*, 2007). The inclusion of time in a CPN model resulted in a model called TCPN model (Akingbade, 2015; Ganiyu *et al.*, 2016; Odeniyi *et al.*, 2022). A TCPN which supports the modularity (hierarchy) is named HTCPN; a formalism used in modelling complex real systems which represent a system in a structured manner using substitution transitions which can also be modelled into details for effective representation of the real system.

In an attempt to proposed improvement that could reduce patients' dissatisfactions emanating from long waiting (1) time occasioned by inefficient hospital medication distribution processes, most existing works developed non-modular models. These models could not accommodate any future modification owing to the fact that they conceptualized on non-modular formalisms. Albeit, the objective of this paper is to employ a HTCPN formalism to develop an executable model for a decentralized hospital medication distribution process using Bowen University Teaching Hospital, Ogbomoso, Oyo State, Nigeria as a case study.

2 RESEARCH METHODOLOGY

2.1 The Modelling Approach

In this paper, a Hierarchical Timed Coloured Petri Net (HTCPN) formalism defined in [1] was utilized to develop an executable model for a decentralized hospital medication distribution process under consideration.

According to Odeniyi *et al.* (2021), the HTCPN is defined as a nine-tuple = (S, SN, SA, PN, PT, PA, FS, FT, PP) [1] where:

i. S is a finite set of pages,
   a. $\forall s \in S$: s is a non-hierarchical coloured Petri Nets.
   b. $\forall s_1, s_2 \in S : s_1 \neq s_2 \Longrightarrow (P_{s_1} \cup T_{s_1} \cup A_{s_1}) \cap (P_{s_2} \cup T_{s_2} \cup A_{s_2}) = \phi$ (2.13)

ii. $SN \subseteq T$ is a set of substitution nodes.

iii. SA is a page assignment function. No page is a subpage of itself.

iv. $PN \subseteq P$ is a set of port nodes.

v. PT is a port type function. $PT: PN \rightarrow \{in, out, i/o, general\}$.

vi. PA is a port assignment function. It is defined from SN into binary relations:
   a. $\forall t \epsilon S: PA(t) \subseteq X(t) x PN_{SA(t)}$
   b. $\forall t \epsilon SN, \forall (p1, p2) \epsilon PA(t): PT(p2) \neq general \Rightarrow ST(p1, t) = PT(p2)$
   c. $\forall t \epsilon SN, \forall (p1, p2) \epsilon PA(t): C(p1) = C(p2) \wedge I(p1) = I(p2)$

vii. $FS \subseteq P_S$ is a set of fusion sets
   $\forall fs \epsilon FS, \forall (p1, p2) \epsilon fs: C(p2) = C(p2) \wedge I(p1) = I(p2)$

viii. FT is a fusion type function. $FT: FS \rightarrow$ {global, page, instance}

ix. $PP \in S_{MS}$ is a multi-set of prime pages.

x. R is a set of time values, also called time stamps

xi. r_0 is an element of R called the start time

2.2 Description of the Case Study

In developing a Hierarchical Timed Coloured Petri Nets (HTCPN) model for a decentralized hospital medication distribution process, 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-patient Pharmacy department serves six wards, which include children's ward, men's ward, women's ward, neonatal/maternity ward, private ward and intensive care unit. There are three basic types of medication request identified in the medication distribution system of the Bowen University Teaching Hospital (BUTH). These include urgent request, regular (daily) prescription and medical cabinet request.

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. This type of order occurs on five hour or six hourly basis: preparation is within eight minutes while transportation takes up to five minutes - this depends on the distance between the ward and 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.

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.

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.

Fig. 1 shows the sequential steps of medication distribution process in BUTH. The process 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.

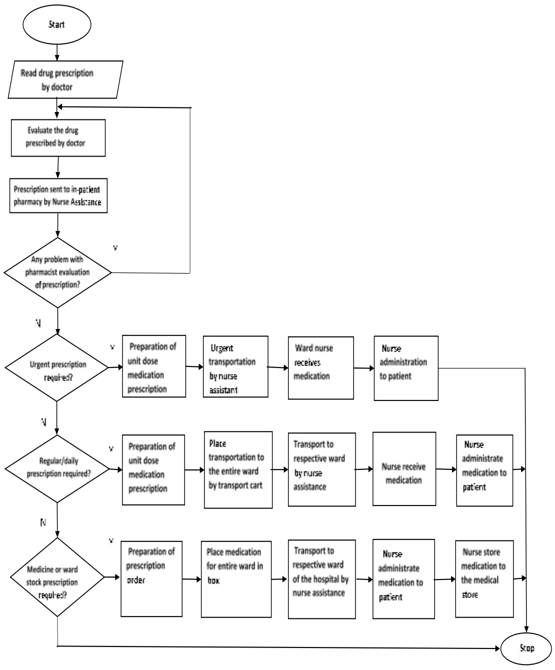

Fig. 1: Flow Diagram of the Medical Distribution Process in BUTH

2.3 Data Collection

Data collection is a vital stage because the results and findings of a simulation study are as important as the information inputted. The data used in developing the HTCPN model for the hospital medication distribution process, were collected primarily by direct observation from Bowen University Teaching Hospital (BUTH). The data acquired include the start and end time for each medical request, number of pharmacists, number of ward aids and nurses. Also, the numbers of medical requests observed within six (6) weeks for each type of prescription were obtained.

2.4 Development of a Model for the Decentralized Hospital Medication Distribution Process using HTCPN

The HTCPN model was developed consisting of seven (7) modules, namely Children's Ward Module (CWM), Men's Ward Module (MWM), Women's Ward Module (WWM), Private Ward Module (PWM), Neonatal/maternity Ward Module (NWM), Intensive Care Ward Module (ICWM), and Pharmacy Module (PM). Each module comprises transitions, places, directed arcs and tokens. Pictorially, transitions were drawn as rectangles and used to model events/activities in the considered medication distribution process. Places were drawn as ovals and used to model conditions or state of entities in the modelled system. Also, the places hold tokens which represent dynamic resources in the modelled process. In order to model the relationships between the various components of the considered medication distribution process, places and transitions were connected with directed arcs.

In the HTCPN model, the prescriptions of daily, urgent and medical cabinet requests by the Doctor meant for children's ward, women's ward, men's ward, private ward, neonatal/maternity ward, and Intensive Care Unit (ICU) were modelled by the transitions *Doctor creating CRequest*, *Doctor creating MRequest*, *Doctor creating WRequest*, *Doctor creating PRequest*, *Doctor creating NRequest* and *Doctor creating IRequest*, respectively. Similarly, the loadings of daily, urgent and medical cabinet requests meant for children's ward, women's ward, men's ward, private ward, neonatal/maternity ward, and ICU were modelled by the places *DRC URC MCC*, *DRM URM MCM*, *DRW URW MCW*, *DRP URP MCP*, *DRN URN MCN* and *DRI URI MCI*, respectively.

Each of the first six modules (CWM, MWM, WWM, PWM, NWM and ICWM) contains three transitions: *Joining Queue WTransport*, *Start of Transportation by Ward Aid*, and *end of WTransportation Ward Aid.* The functions of transitions being employed in Children, Men, Women and Private modules are as described in Table 1. Also, each of the modules consists of three main places: *Queue of Request*, *Ward Aid free* and *Ward Aid busy*. Furthermore, in each of the six modules, the place *DRC,URC MCC Preload* was designed to initially hold the prescribed medical request in the HTCPN model. The medical request emanated from the execution of the transition *Doctor creating CRequest* which deposited the request with arrival time of exponential function into arrival place named *Arriving CRequest*. The place *Arriving CRequest* was configured to be an input place to the Children's ward module. In the Children's ward module, the *Arrived request* would be moved to join the queue of requests by the execution of the transition *Joining Queue CWTransport*. The presence of *Arrived request* and the availability of ward Aid(s) in the place *CWard Aid Free* initialized the execution of the transition *Start of Transportation by Cward Aid*, which resulted in having the *Arrived request* deposited into the place *CWard aid Busy.*

Table 1: Description of the transitions employed in Children, Men, Women and Private modules

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Transition	Description
Joining Queue CWTransport	Models the children requests arrival from the doctor waiting for ward aid in Children's ward module
Start of Transportation by CWard Aid	Models the start of transportation of requests by ward aid in Children's ward module
End of Transportation by CWard Aid	Models the end of transportation of request by ward aids in Children's ward module
Joining Queue MWTransport	Models the men requests arrival from the doctor waiting for ward aid in Men's ward module
Start of Transportation by MWard Aid	Models the start of transportation of requests by ward aid in Men's ward module
End of Transportation by MWard Aid	Models the end of transportation of request by ward aids in Men's ward module
Joining Queue WWTransport	Models the women requests arrival from the doctor waiting for ward aid in Women's ward module
Start of Transportation by WWard Aid	Models the start of transportation of requests by ward aid in Women's ward module
End of Transportation by WWard Aid	Models the end of transportation of request by ward aids in Women's ward module
Joining Queue PWTransport	Models the private requests arrival from the doctor waiting for ward aid in Private ward module
Start of Transportation by PWard Aid	Models the start of transportation of requests by ward aid in Private ward module
End of Transportation by PWard Aid	Models the end of transportation of request by ward aids in Private ward module

The variable *pt1* associated with the time stamp *@++pt1* in the arc expression ((*n*, *RC*, *t*, *tpt*),*r*)*@++pt1* that runs from the transition *Start of Transportation by Cward Aid* to the place *CWard aid Busy* represents the transporting time as at the time of transporting the request into the place *CWard aid Busy*; and it randomly draws value from exponential distribution at the rate of 0.013333 in the code segment attached to transition *Start of Transportation by Cward Aid.* Execution of transition *End of Transportation by Cward Aid* would give rise to two conditions – the condition indicating the request the had been transported (deposition of token in the place *CWRequest Transported*), and the condition indicating that the two ward aids are no longer occupied and ready for next job (since the initial marking in place *CWard Aid free* is 2 staff).

The PM module contains places such as *MAX reception capacity, Queue of requests, Pharmacist free and Pharmacist busy:* the arrival of request (DR, UR and MCR) into the pharmacy was modelled by the place "*requestC*", the identity number of each request that entered the pharmacy was modelled by the place "*next request id*", request queues inside the pharmacy was modelled by the place "*queue of* request", indication that pharmacist was free was modelled by the place "*pharmacist free*", indication that pharmacist was busy was modelled by the place "*pharmacist busy*" and representation of requests being attended to was modelled by the place "*served*". *MAX reception capacity* modelled the available capacity in the Pharmacy. In modelling the PM, the transported requests emanated from Children'ward, Men's ward, Women's ward, Private ward, Neonatal ward and Intensive Care Unit modules, and deposited into the places CW*Request transported*, MW*Request transported*, WW*Request transported*, PW*Request transported*, NW*Request transported* and IW*Request transported*, respectively initiated the execution of transition *Joining Pharmacy Queue*. The output arc running from each of these places to the transition *Joining Pharmacy Queue* carries an expression *(n, TT, t, p1)*. The loading queue place was bounded by a place *Pharmacy Reception Capacity* which limited the number of ward aids in the Pharmacy reception to six (6). The requests then moved to join the place *queue of Pharmacy* by the execution of transition *Join Pharmacy Queue* if the Pharmacist were busy. The execution of transition *Start of Pharmacy service* enabled the free Pharmacist (Pharmacist staff) to start attending to the requests and also the execution of transition *End of Pharmacy service* represents the end of Pharmacist services.

3 Result - The Developed HTCPN Model

Fig. 2a and Fig. 2b show the developed HTCPN top model for the decentralized medication distribution process of the hospital under consideration while Figs. 3, 4, 5, 6, 7, 8 and 9 show its associated sub-models. The top model is structured into hierarchical levels to enhance clarity and modularity. It is the highest hierarchical level representing the entire medication distribution process in all the six wards and the pharmacy department in the considered case study. The seven sub-models (modules) depicted in Figs. 3, 4, 5, 6, 7, 8 and 9 represent the medication distribution processes taking place in children's ward, men's ward, women's ward, private ward, neonatal/maternity ward, intensive care unit and Pharmacy department, respectively. Time and hierarchy were used for scalability and reusability of the modules. The time delays named time stamps were derived from duration of each activity in the medication distribution process. Time stamps were added to arc expressions in the model to indicate the duration of time it took a process to finish as a result of an activity (execution transition). The time stamps were indicated by the notation @++d (where d is known as the delay). The arc expressions were written in the Coloured Petri Nets ML, and were built from typed variables, constants, operators, and functions.

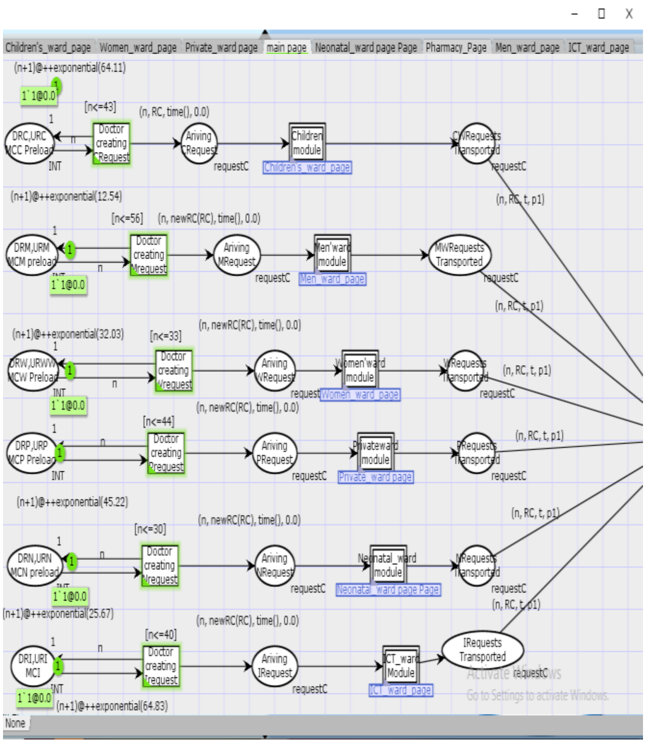

Fig. 2a: The Developed HTCPN Model for the Hospital Medication Distribution Process

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Fig. 2b: The Developed HTCPN Model for the Hospital Medication Distribution Process continued

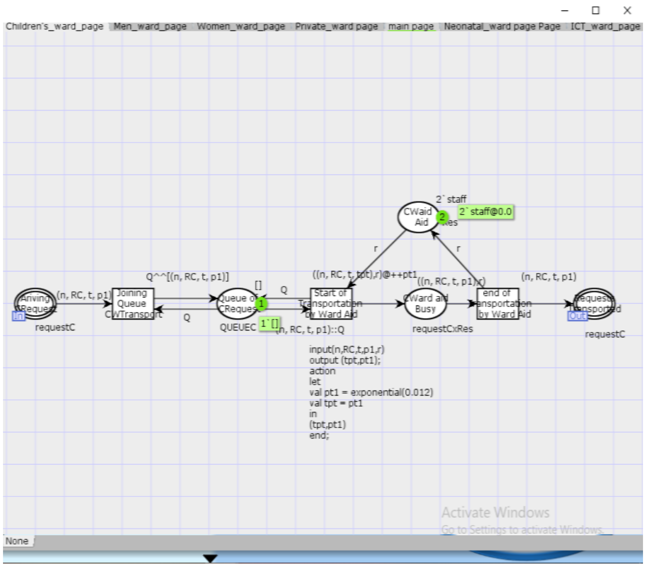


Fig. 3: The Children's Ward Module of the Developed HTCPN Model

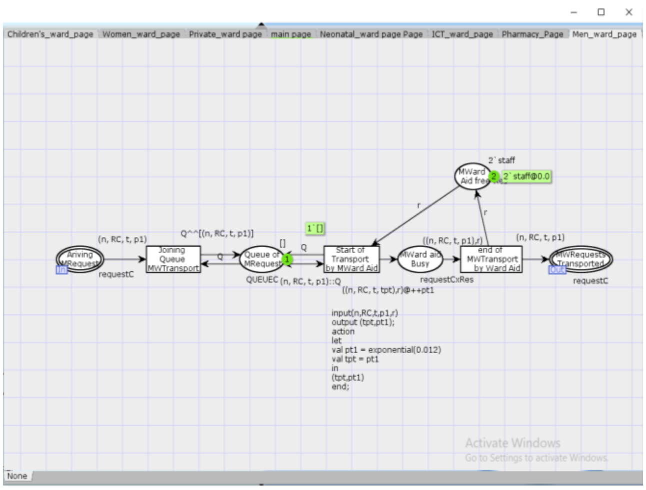


Fig. 4: The Men's Ward Module of the Developed HTCPN Model

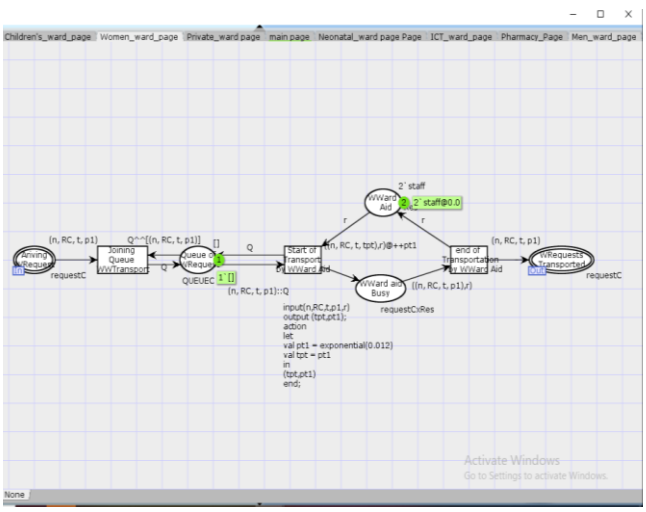
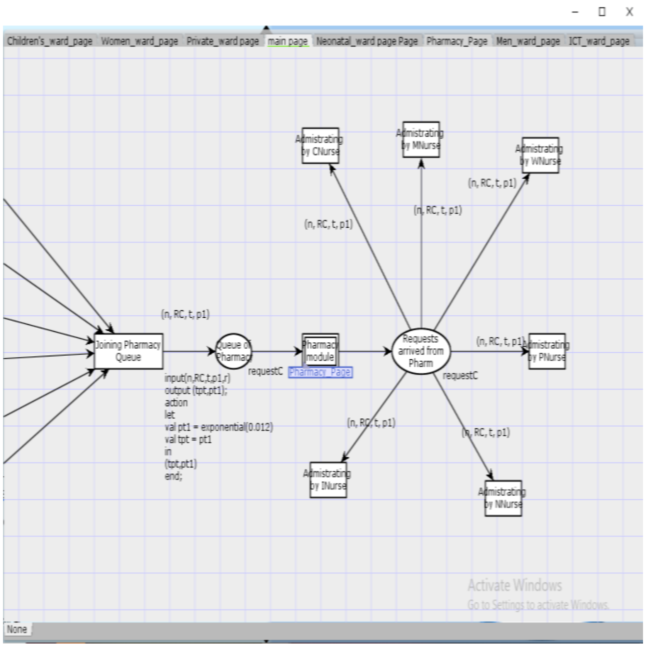


Fig. 5: The Women's Ward Module of the Developed



HTCPN Model

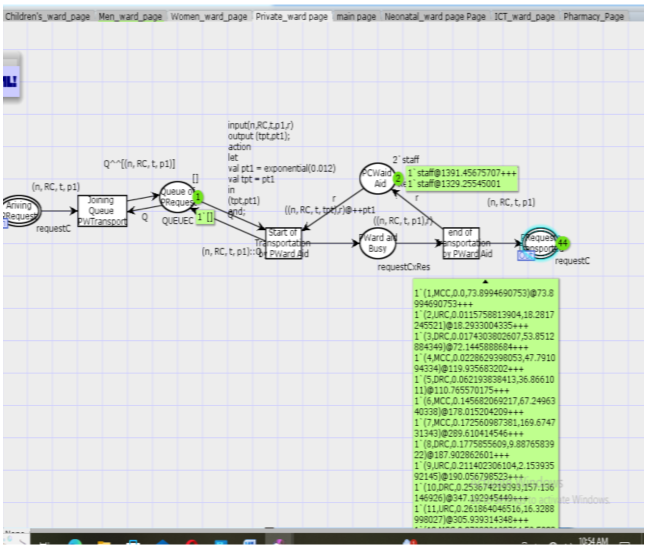


Fig. 6: The Private Ward Module of the Developed HTCPN Model

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Fig. 7: The Neonatal Ward Module of the Developed HTCPN Model

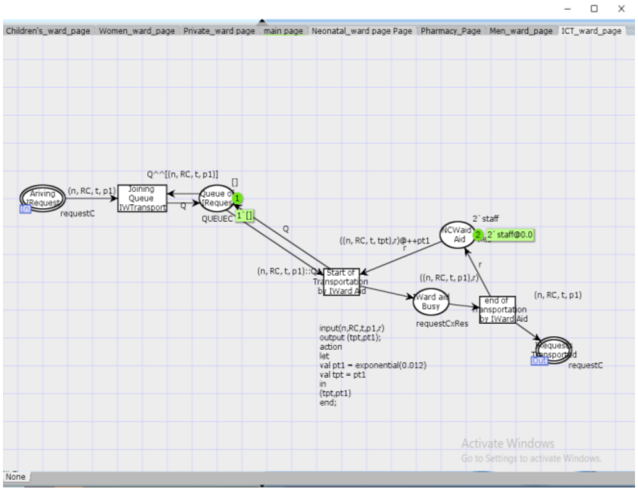

Fig. 8: The ICU Ward Module of the Developed HTCPN Model

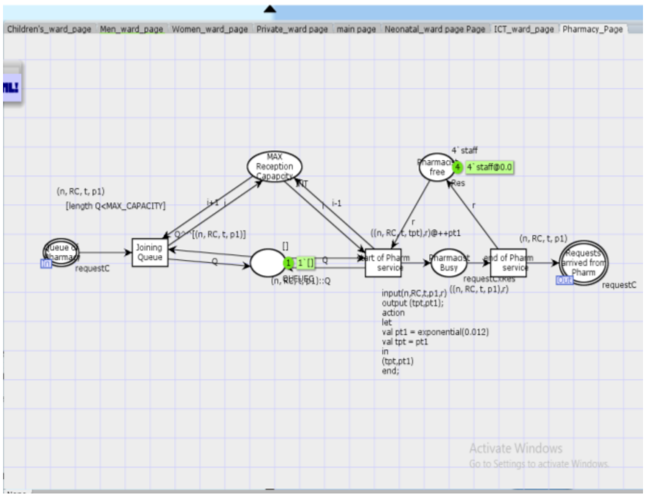

Fig. 9: The Pharmacy Module of the Developed HTCPN Model

4 CONCLUSION AND FUTURE WORK

In this paper, we have been able to develop a Hierarchical Timed Coloured Petri Nets (HTCPN) model for a decentralized hospital medication distribution process using Bowen University Teaching Hospital, Ogbomoso, Oyo State, Nigeria as a case study. The developed HTCPN model can be easily modified through its associated modules to suit any future modification in the hospital medication distribution process 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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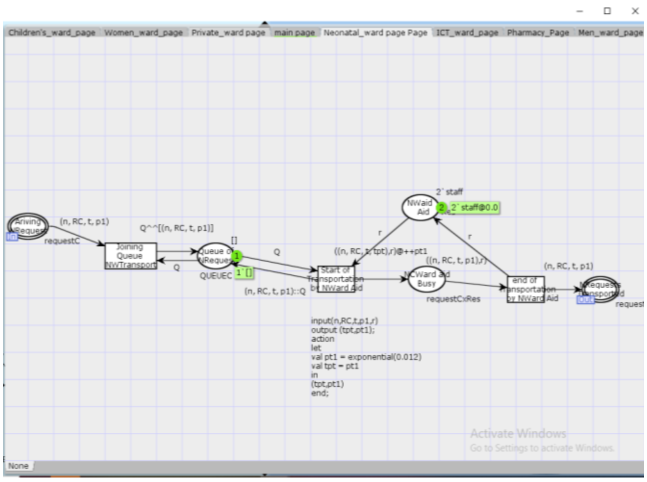

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