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Modeling of Ebola Surveillance Flow Diagram Using Coloured Petri Nets

***James Okpor and Foghor Tanshi**

Department of Electrical/Electronic and Computer Engineering, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.

*Corresponding authors' email: okpor.james@fupre.edu.ng

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ABSTRACT

The recent outbreak of Ebola virus Disease (EVD) in the Democratic Republic of Congo (DRC) and Uganda in May 2026 has shown that the Ebola virus is still a threat to the public health system globally after the 2014-2016 pandemic that claimed the lives of 11,325 persons. The containment of Ebola virus disease outbreaks depends largely on the correctness of the epidemiological surveillance systems. Thus, this paper used CPN Tools 4.0 to translate the Ebola Virus Disease surveillance flow diagram into an executable Coloured Petri Nets (CPN) Model. By utilizing CPN 4.0 Tools, we modeled various phases of the EVD surveillance flow diagram, such as case detection, symptom evaluation, laboratory testing, and referral, into an executable hierarchical CPN model. The developed EVD surveillance flow CPN model was analyzed using state space methods. Simulation results show that the developed CPN model effectively capture the various activities such as case detection, symptom evaluation, laboratory testing and referral module. This work will assist public health authorities to analyze and digitize EVD surveillance against future outbreak of the disease.

Keywords: Community-based surveillance, Coloured Petri Nets, Ebola Surveillance, Ebola Virus Disease, Infectious Disease Modeling

INTRODUCTION

Ebola Virus Disease (EVD) is a serious disease that affects humans. People contract the virus from wild animals, and then spread from person to person within the human population. The first outbreak of EVD was reported to have happened almost at the same time in South Sudan and the Democratic Republic of Congo in 1976 (Laupland & Valiquette, 2014). More than 25 Ebola cases have been reported since the first outbreak was reported in 1976. The biggest and most complicated Ebola outbreak occurred in West Africa from 2014 to 2016, affecting countries like Guinea, Liberia, Senegal, Sierra Leone, and Nigeria (Bobadoye & Aluko, 2025) . About 50% of Ebola cases often result in death. According to the World Health Organization (WHO), there are five different species of the Ebola virus. These include Sudan ebolavirus, Zaïre ebolavirus, Bundibugyo ebolavirus, Tai forest ebolavirus, and Reston ebolavirus, which have all been linked to significant outbreaks in Africa. The estimated incubation period for EVD is within two to twenty-one days after contact with the virus. Studies have shown that humans are not contagious with EVD until they exhibit symptoms. Common symptoms of EVD include fever, severe headache, fatigue, diarrhea, muscle pain, vomiting, weakness, and abdominal pain (Abah et al., 2024).

The recent outbreak of EVD in May 2026 in the Democratic Republic of Congo and Uganda calls for an urgent need to develop an effective disease surveillance and response system. This outbreak shows that Ebola remains a global threat and poses a major health challenge globally. The World Health Organization on May 17 declared the 2026 Ebola outbreak as a Public Health Emergency of International Concern. Thus, Nigeria and the international community must be on alert and ready to respond.

Effective disease surveillance has played a major role in the containment and eradication of infectious diseases globally. Thus, there is a need for a seamless flow of information from case detection to laboratory testing. Modeling has helped us to understand the spread of viruses and how they evolve with time (Peng et. al., 2021).

Several approaches have been used by different researchers to model health care workflow and systems. Coloured Petri nets have been an invaluable mathematical and graphical modelling tool in the health sector. Several researchers have published different work on the use of coloured Petri Nets in the health sector. For example, Ganiyu et al. (2015) developed a patient care flow process simulation model for the medical record and examination room section for Ladoke Akintola University of Technology Health Center Ogbmomso using Timed Colored Petri Nets. Peng et. Al., 2021, used Petri nets to model and simulate the epidemic transmission process of COVID-19 in a bid to ascertain the impact of the epidemic prevention method. Gehlot et al 2021, used Colored Petri Nets to model and simulate patient flow to an operating room. Coloured Petri Nets have one of the most powerful tools used in modelling dynamic and concurrent systems. CPNs have been used extensively in various areas to model and analyze systems in healthcare, manufacturing, embedded systems, business processes, cyber physical, industrial control, hardware, software, and communication protocols. CPN enables us to translate an Ebola surveillance flow diagram into a CPN model that we can simulate and analyze.

Colored Petri Nets (CPN) is a graphical language for distributed and concurrent system modeling and validation (Jensen & Kristensen, 2009). Coloured Petri Nets is a powerful modeling language because of its graphical representation, underlying formal semantics, executable nature, mathematical foundation, and analytical methods (Lumsden *et al.*, 2002). Colored Petri Nets combine Petri Net with functional programming language characteristics. Low-level Petri Nets (like Place/Transitions Nets) and high-level Petri Nets (such as Coloured Petri Nets) are the two categories of Petri Nets. The standard ML language served as the

foundation for the CPN ML language (Kristensen *et al.*, 1998). The states of the system and the events (transitions) that can change those states are described in CPN models, which are executable (Jensen & Kristensen, 2009). It also allows the use of hierarchical techniques to disintegrate complex processes, and the availability of state space tools to analyze and examine some useful CPN qualities such as reachability, liveness, boundedness, and home state (Kristensen *et al.*, 2002). A CPN model's ability to be constructed hierarchically makes it possible for a module to have sub-modules. The creation, simulation, and analysis of CPN models are all accomplished using CPN Tools. In CPN Tools, both non-hierarchical and hierarchical CPN models are supported (Jensen & Kristensen, 2009).
CPN Tools is employed to modify, simulate, and verify CPN models graphically. For the declaration of color set (data types), variables, constants, and functions, CPN Tools uses the CPN ML language. The net structure of a CPN model is represented graphically as a network of nodes (places and transitions) and arcs. It is not acceptable to make connections between two places or two transitions. Through directed arcs, places and transitions are joined. Places are indicated by circles (or ovals), and transitions are indicated by boxes and rectangles (or bars). In a CPN model, each location includes one or more tokens and serves as a way to indicate the system's state. Each token has a color that represents its data value, and the place of a token creates a mark at a certain location (Okpor & Apeh, 2021). The transition indicates possible system occurrences, and when a transition fires (occurs), tokens are moved from the input place to the output place in accordance with the arc expression connecting the two nodes (Jensen and Kristensen., 2009). A transition guard is a Boolean statement that places an additional restriction on the binding of a transition. The distribution of tokens among the places affects how colored Petri nets behave. If there is no enabled transition, a state is considered dead. State space analysis is employed to confirm the model's characteristics, and CPN Tools is utilized to study and validate the model utilizing simulation.

Ebola Virus Disease (EVD) Surveillance Flow Diagram
Figure 1 depicts the Ebola virus disease (EVD) surveillance flow diagram. The EVD surveillance flow diagram has four phases.

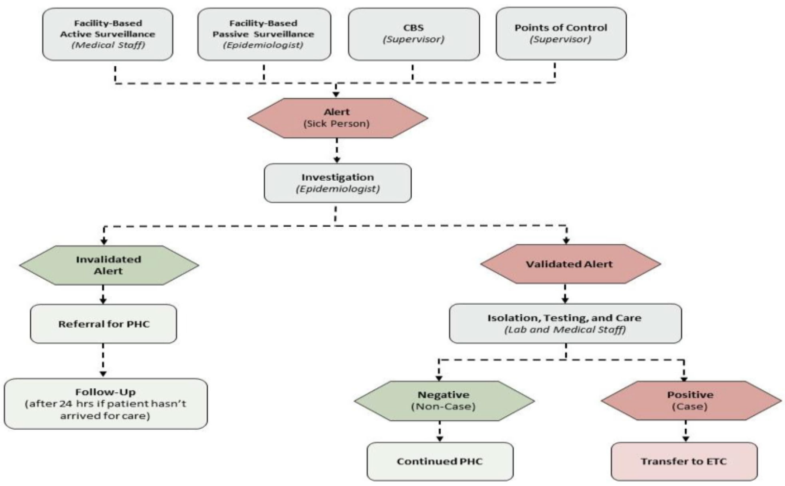

Figure 1: EVD Surveillance Flow Diagram (Okeeffe et al., 2023)

The EVD Surveillance Flow Diagram depicted in Figure 1 is centered on community-based surveillance (CBS). Where community health workers played a major role in Ebola case detection, collection of health information, and also provided surveillance coverage in the form of community-based surveillance within the area. Community Health Workers (CHW) were instrumental in stopping the 2014-2016 West Africa Ebola pandemic. CHW visited houses, identified sick people, and raised an alert if they fit the criteria for Ebola virus definition (Okeeffe et al., 2023). CHW reported daily to supervisors, while the supervisor immediately reported to the Ebola surveillance team for action. The supervisor gathered these alerts daily and sent them to the Epidemiologist/clinical staff who examined these alerts to determine whether they met the criteria for a suspect Ebola case. The patient was admitted immediately to the Integrated Treatment Center (ITC) for testing and isolation if the alert was confirmed as a suspect Ebola case. When an alert appears to be invalid, patients were sent to the primary health care, where investigators will critically examine the alert within 24 hours. CBS also adopted three other surveillance approaches, such as active, passive, facility-based, and point-of-control surveillance. Suspect cases were identified through visits by staff to health facilities, pharmacies, and traditional healers in active facility surveillance, while health care officers reached out to the surveillance team to report suspected Ebola in the passive facility-based surveillance approach. In point-of-control surveillance, selected staff were positioned in strategic areas to identify and report to the authority suspect Ebola cases. These networks, made up of members of the community, were very useful and instrumental in ending the 2014-2016 pandemic (Okeeffe et al., 2023).

MATERIALS AND METHODS

Coloured Petri Nets was used to model the EVD surveillance flow diagram. Following is a definition of a Petri net, hierarchical, and a non-hierarchical colored Petri net module:
Definition 1. (Petri net) A Petri net is a triple (Jensen and Kristensen, 2009)

$$PN = (P, T, F) \quad (1)$$

Where,

i. P is a finite set of places.
ii. T is a finite set of transitions ($P \cap T = \emptyset$).
iii. $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs.

The state of the Petri net, often referred to as marking denoted by M, is a distribution of tokens over places: $M \in P \rightarrow N$.

Definition 2: According to (Lalita and Wiwat 2019), a non-hierarchical colored petri net is a nine-tuple (Σ, P, T, A, V, C, G, E, I), where,

i. Σ is a finite collection of non-empty color sets (type) are described in CPN Tools by utilizing the CPN-ML.
ii. P is a finite collection of places that are shown as ovals or circles.
iii. T is a series of transitions that are represented as rectangles$P \cap T = \emptyset$.
iv. A is a collection of directed arcs such that $A \subseteq P \times T \cup T \times P$
v. V is a collection of typed variables with a finite set such that Type[v] ∈ Σ for all variables v∈V.
vi. C is a function that sets colors. It is characterized as $C : P \rightarrow \Sigma$
vii. G: T→$EXPR_V$ is a guard function that provides a guard for each transition t in order to ensure that Type [G(t)] = Bool.
viii. E: A→$EXPR_V$ is a function for arc expressions that gives each arc in a way that $Type\ [E\ (a)] = C\ (p)_{MS}$, where p is the place associated with arc a.
ix. I: P → $EXPR_{\emptyset}$ is a function that initializes each place p with an initialization expression so that $Type\ [I\ (p)] = C\ (p)_{MS}$.

Definition 3: According to Jensen and Kristensen (2009), a hierarchical Colored Petri Net Module is a four tuple
CPNM = (CPN, Tsub, Pport, PT) (2)
Where,

i. A non-hierarchical Colored Petri Net is defined as CPN = (P, T, A, V, C, G, E, I).
ii. ii. A group of substitution transitions is such that $T_{sub} \subseteq T$.
iii. iii. P_{port} is a collection of port places is such that $P_{port} \subseteq P$. iv. Port type function that designates a port type to each port place. PT : $P_{port} \rightarrow$ {IN,OUT,I/O}

Procedure for Creating the EVD Surveillance flow Diagram CPN Model

CPN Tools 4.0 was used to capture the various activities of the EVD surveillance flow diagram into a hierarchical colored Petri Net model.
i. Transitions were used to represent activities that occur in the EVD surveillance flow diagram. ii. Places were used to represent the state of the EVD surveillance flow diagram.
iii. A set of directed arcs was used to connect the transitions to the places in the EVD surveillance flow diagram CPN model. While the arc inscription specified the maximum number of tokens that may cause a transition to trigger in the CPN model.
iv. A guard was used to impose an additional constraint on the transitions used in the model. A guard is a CPN Boolean expression whose result evaluates to the Boolean value true or false.
v. The CPN ML language was used in the definition of data types (colorset), variables, constants, functions, and guards for describing the data manipulation.
vi. The EVD surveillance flow diagram model was divided into some modules with clearly defined interfaces made up of places, transitions, and arcs.
A top-down design methodology was used to construct the hierarchical EVD surveillance flow model. The process started with the creation of a page that shows the overview of the subpages and how they are connected. The move to subpage tool in CPN 4.0 Tools was used to create the super page by moving a group to a subpage and with a super tag added to the transition to create the substitution transition.
As the module and submodule of the EVD surveillance flow model were constructed, the simulation tool embedded in CPN 4.0 was used to investigate the EVD surveillance flow model and to detect flaws. To check that the module and submodule function as intended and to make sure the model achieves the terminal state, an interactive simulation was utilized. The developed EVD surveillance flow module and submodules were subjected to simulations. The developed EVD surveillance flow diagram CPN model's behavioral features, such as the boundedness, home, liveness, and fairness qualities, were verified using state space analysis.
The state space tool included in the state space tool palette of the CPN 4.0 Tools was used to generate the complete state space report, which contains vital details about the model's statistics, boundedness properties, homes, liveness properties, and fairness properties.

RESULTS AND DISCUSSION

The EVD surveillance flow CPN model is composed of case detection, symptom evaluation, laboratory testing, and referral submodules. Figure 2 shows the top-level module of the developed EVD surveillance flow CPN model. The top-level module consists of four substitution transitions and a substitution tag representing case detection, symptom evaluation, laboratory testing, and referral phases.

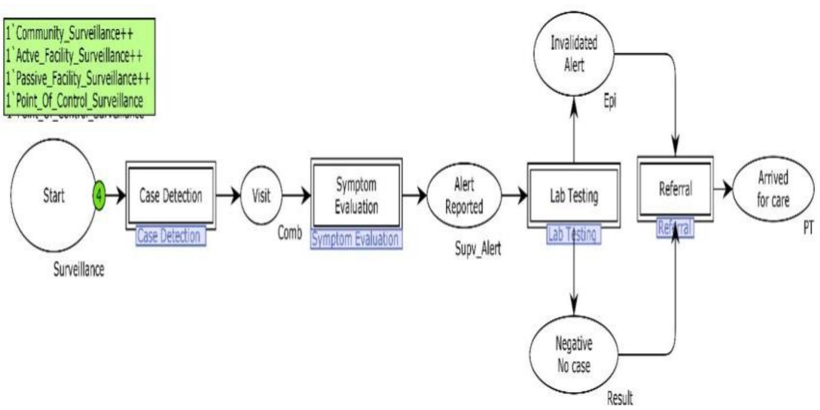

Figure 2: Top-level Module of the Ebola Surveillance CPN Model

Fig. 3 depicts the case detection sub-module. Color set *surveillance* is used to represent the initial activities such as community-based surveillance, Active-Facility-based Surveillance, Passive Facility-Based Surveillance, and Point-of-control Surveillance. It is an enumerated type color set. The immediate transition surveillance is enabled when place *start* contain a token. After transition *surveillance* is fired, the token will be moved to any of the 4 place *Community based Surveillance, Active Facility based Surveillance, Passive Facility based Surveillance, Point of control Surveillance,* as specified by the output arc expression. The transition attached to any of the place that received the token becomes enabled immediately. For instance, if place *Community based Surveillance* received the token, the model release a token *community health worker*.

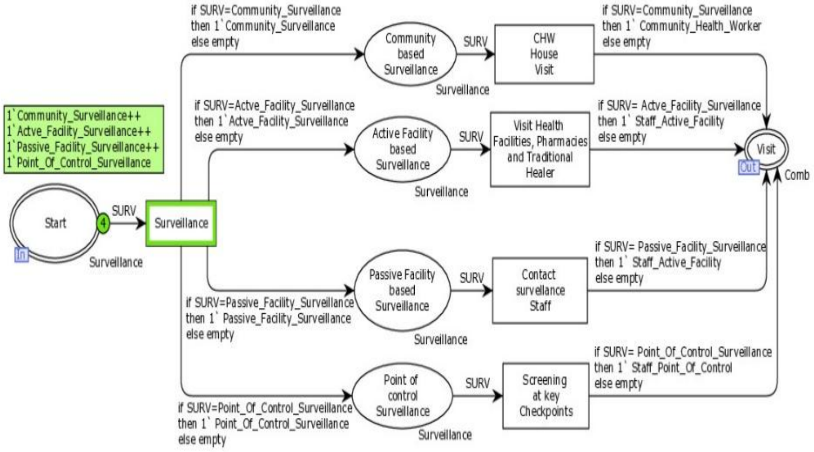

Figure 3: Case Detection Module

Fig. 4 shows the sub-module associated with the symptom evaluation substitution transition. There are three sets of activities in this phase, which include identify sick persons, check and raise alert, and collect alert modeled by three elementary transitions.

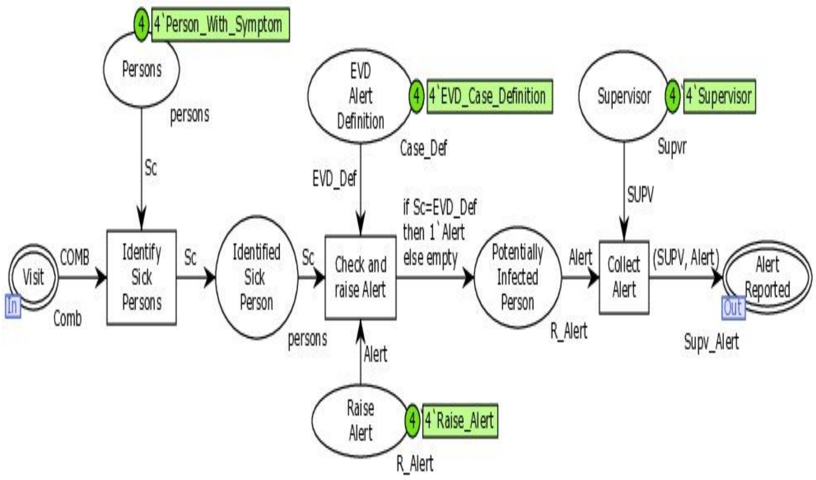

Figure 4: Symptom Evaluation Module

Place *visit* serves as a connection between the case detection Module, and the Symptom evaluation Module. Transition *identify sick persons* becomes enabled immediately when place *visit* receives an incoming token. When Transition *identify sick persons* fires, a token *person_with_symptom* will be transferred to place *identified sick person*. Transition *check and raise alert* becomes enabled immediately. If the condition of the output arc is met, an alert will be raised if he met the EVD alert definition as a potentially infected person with Ebola virus disease. Transition *collect alert* becomes enabled, and when it fires, it allows supervisors to collect alerts reported by community health workers daily.

Fig. 5 depicts the laboratory testing sub-module. Place *Epidemiologist or Clinical Staff* contains two tokens *validated alert* and *invalidated alert*. The epidemiologist or clinical staff examined the alert collected from supervisors to ensure they fall within the Ebola case definition. Place *validated alert* receives a token if the condition on the output arc expression to transition *investigation* is valid. Transition *Admit Patient for Isolate or Testing* becomes enabled if it is a validated alert. Place *Testing* contains the token for the test result, i.e either a positive case or negative case. If the result of the test is positive, the transition *Transfer to Ebola Treatment Centre* becomes enabled, and when it is fired, the patient is admitted to the Ebola Treatment Center (ETC). If the test result shows negative, the token is transferred to the place *Negative No case.*

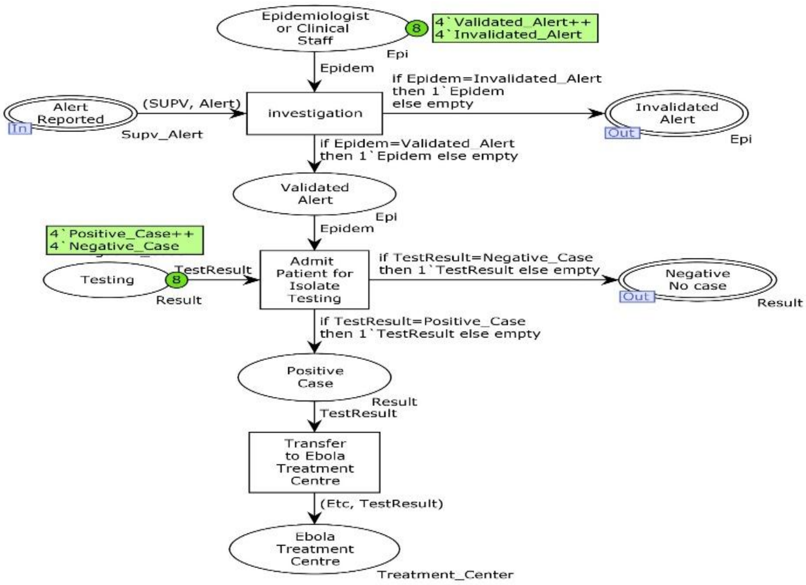

Figure 5: Lab. Testing Module

Fig. 6 shows the referral sub-module. When either place *invalidated alert* and place *Negative No case* received a token, the transition *refer to primary health care* becomes enabled. A patient is referred to the primary health care when the transition fires. When the transition Follow-up becomes enabled and fires, the investigator will be required to do a follow-up of the patient after 24 hours.

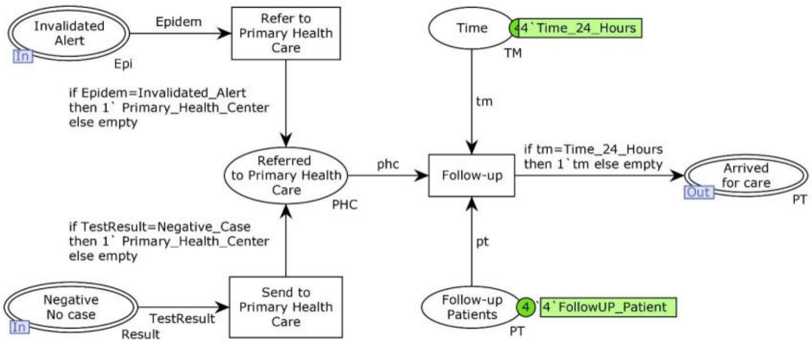

Figure 6: Referral Module

State Space Analysis

Fig. 7 shows the statistics, Home properties, Liveness Properties, and Fairness Properties of the EVD surveillance flow CPN model. The report of the state space shows that there are 10124 nodes, 35138 arcs, and it was generated in 9s, while the strongly-connected-component (SCC) graph has 10124 nodes, 35138 arcs, and was generated in 0 s.

```
CPN Tools state space report:

 Statistics
------------------------------------------------------------------
  State Space
     Nodes:  10124
     Arcs:   35138
     Secs:   9
     Status: Full

  Scc Graph
     Nodes:  10124
     Arcs:   35138
     Secs:   0

 Home Properties
------------------------------------------------------------------
  Home Markings
     None

 Liveness Properties
------------------------------------------------------------------
  Dead Markings
     15 [10124,10122,10121,10117,10114,...]
  Dead Transition Instances
     None
  Live Transition Instances
     None

 Fairness Properties
------------------------------------------------------------------
     No infinite occurrence sequences.
```

Figure 7: State Space Report of EVD Surveillance flow CPN Model

The report reveals that the SCC graph and state space contain an equal number of nodes and arcs. The Fairness Properties also show that no infinite occurrence exists, and hence the model will terminate correctly. The liveness properties show that there are 15 dead markings and no dead transitions. It was observed that the 15 dead markings are terminal state CPN model, and as a result, the model will produce the expected result when it terminates.

CONCLUSION

This study has shown the use of Coloured Petri Nets in modeling, simulating, and analysis of the EVD surveillance flow diagram. Through the use of CPN Tools, this model translates a static EVD surveillance flow diagram into an executable EVD surveillance flow CPN model using Coloured Petri Nets 4.0 Tools. The developed CPN model captures the four phases of the EVD surveillance flow diagram. The developed EVD surveillance flow CPN model was verified using simulation and state space analysis tools embedded in CPN software. The results obtained from the verification confirm the reliability and correctness of the developed EVD surveillance flow CPN model.

REFERENCES

Abah R.T., Abraham B.Z., Kayode O., Adejimi A. (2024), Mathematical analysis and simulation of Ebola virus disease spread incorporating mitigation measures, Franklin Open, 6, 1-16

Bobadoye A., Aluko O.J. (2025), Bridging Human, Animal, and Environmental Health for Sustainable Disease Control in West Africa, FUDMA Journal of Sciences (FJS), (9)11, 316 – 320

Ganiyu R.A, Olabiyisi S. O., Badmus T.A., 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, 4 (1), 9954-9961

Gehlot V., Jake R., Manisha T., Elliot B.S., Nilmini W. (2021), Toolkit for Healthcare Professionals: A Colored Petri Nets Based Approach for Modeling and Simulation of Healthcare Workflows, Proceedings of the 2021 Winter Simulation Conference, 1-12

Jensen K., and Kristensen M.L. (2009), Coloured Petri Nets and CPN Tools for Modelling and Validation of Concurrent Systems, Springer Dordrecht Heidelberg London New York, pp 1-382, DOI 10.1007/b95112

Kristensen, L.M., Søren, C. and Kurt, J. (1998). The practitioner's guide to coloured Petri nets. International Journal of STTT. Springer-Verlag. pp 98-132.

Kristensen, L.M., Mitchell, B., Zhang, L. and Billington, J. (2002). Modelling and Initial Analysis of Operational Planning Processes using Coloured Petri nets. In proceedings of Workshop on Formal Methods Applied to Defense Systems, Australian Computer Society volume 12 in Conferences in Research and Practice in Information Technology. pp 105-114.

Laupland B. K. and Valiquette L. (2014) Ebola virus disease, Adult Infectious Diseases Notes, Canadian Journal of Infectious Diseases and Medical Microbiology, 25(3):128-9

Lalita T., and Wiwat V. (2019), Formalizing Railway Network Using Hierarchical Timed Coloured Petri Nets, Conference ICIT 2019 IOT and Smart City, 338 -342

Lumsden, S., Smallwood, R., Mitchell. B. and Zhang. L. (2002). Modelling Operational Level Planning Processes with Coloured Petri Nets. 7th International Command and Control Research and Technology Symposium. 1-15.

Okeeffe J., Emi T., Otshudiema J. O., Malembi E., Ndaliko C., Mutimatonda M. N., Caleo G., and Antonio I. C. M. (2023), Strengthening community-based surveillance: lessons learned from the 2018–2020 Democratic Republic of Congo (DRC) Ebola outbreak, Conflict and Health, pp 1-11.

Okpor, J., Apeh, S.T. (2021). Modeling and Analysis of Framework for the Implementation of a Virtual Workplace in Nigerian Universities Using Coloured Petri Nets. In: Vasant, P., Zelinka, I., Weber, GW. (eds) Intelligent Computing and Optimization. ICO 2020. Advances in Intelligent Systems and Computing, vol 1324. Springer, Cham. https://doi.org/10.1007/978-3-030-68154-8_39

Peng Lie, Penghui Xie, Zhe Tang, Fei Liu (2021), Modeling and Analyzing Transmission of Infectious Diseases Using Generalized Stochastic Petri Nets. Applied. Sciences, Vol. 11, pp 1-18 https://doi.org/10.3390/app11188400

US Center for Disease Control (2026, June 28), Ebola Outbreak Current Situation, https://www.cdc.gov/ebola/situation-summary/index.html

Zaitsev A. D., Ghaffari P., Sanchez V.S. (2022), Modeling Ebola Virus Dynamics by Colored Petri Nets, Proceedings of CECNet 2021, 707 -715