Science Forum (Journal of Pure and Applied Sciences)

Journal Homepage: https://atbuscienceforum.com.ng/index.php/jpas

Modeling and Simulation of Covid-19 Base Triage Algorithm using Coloured Petri Nets

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Abstract

The confirmation of a new coronavirus disease (COVID-19) case by the Cross River State Ministry of Health, Nigeria, on 17 April 2026 underscores the continued threat posed by emerging and re-emerging infectious diseases. Although there has been a substantial decline in global transmission since the 2019 pandemic. The confirmed case involved a Chinese national who arrived in Nigeria on 17 March 2026, subsequently developed symptoms, and tested positive for SARS-CoV-2, prompting the activation of emergency public health response measures. This incident highlights the persistent need for robust preparedness, rapid case detection, and efficient triage systems to prevent future outbreaks. During the 2019 pandemic, Nigeria recorded 3,155 COVID-19-related deaths, emphasizing the devastating impact of delayed detection and response. This study presents the modelling and simulation of a COVID-19-based triage algorithm using Coloured Petri Nets (CPN). It formally represents and validates patient screening, clinical decision-making, isolation, referral, testing, and treatment workflows. The proposed CPN model captures the dynamic behaviour, concurrency, synchronization, and resource-sharing characteristics inherent in hospital triage processes while enabling formal verification of workflow correctness. Through simulation, the model provides a reliable framework for evaluating patient flow, optimizing triage decisions, and minimizing delays that could facilitate disease transmission. The developed model serves as a decision-support tool for ministries of health, hospital management boards, emergency response teams, and frontline healthcare workers involved in outbreak preparedness, patient triage, and COVID-19 case management across Nigeria. Beyond COVID-19, the framework offers a scalable and adaptable platform for modelling and evaluating triage processes for future infectious disease outbreaks. This would strengthen national public health preparedness and emergency response capacity.

Keywords
COVID-19,
Coronaviruses,
Coloured Petri Nets,
Infectious Disease Modeling,
Pandemic

ISSN 1119-4618
JPAS
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Introduction

Coronaviruses are a family of enveloped RNA viruses that primarily infect the respiratory tract of mammals and birds. Before 2019, two coronaviruses had already shown epidemic potential in humans. The Severe Acute Respiratory Syndrome coronavirus (SARS-CoV) emerged in Guangdong Province, China, in late 2002 and spread to 29 countries before containment in 2003, causing roughly 8,000 confirmed cases and fewer than 800 deaths (World Health Organization 2003). The Middle East Respiratory Syndrome coronavirus (MERS-CoV), first identified in Saudi Arabia in 2012, caused a few thousand cases with a high case-fatality proportion but limited human-to-human spread (World Health Organization, 2019). Neither achieved the sustained global transmission later seen with COVID-19.

In December 2019, a cluster of pneumonia cases of unknown origin was reported in Wuhan, China, many linked to the Huanan Seafood Wholesale Market. The causative agent, a novel betacoronavirus named SARS-CoV-2, causes the disease designated Coronavirus Disease 2019 (COVID-19). The WHO declared a Public Health Emergency of International Concern on 30 January 2020 and characterized COVID-19 as a pandemic on 11 March 2020 following its rapid spread across continents (WHO, 2026a). The response included travel restrictions, lockdowns, mass testing, and accelerated vaccine and therapeutic development.

SARS-CoV-2 spreads predominantly through respiratory droplets and aerosols released when an infected person breathes, talks, coughs, or sneezes, with risk heightened in crowded, poorly ventilated, close-contact indoor settings. Airborne transmission over longer distances was increasingly recognized as the pandemic progressed (WHO, 2026b). Though fomite (surface) transmission is possible but comparatively minor. Transmission from symptomatic, pre-symptomatic, and asymptomatic individuals alike significantly complicated containment. The incubation period is generally two to fourteen days, with a median of about five. This varied across variants such as Alpha, Delta, and Omicron, some of which showed altered transmissibility.

The pandemic's scale far exceeded that of SARS and MERS SARS-CoV-2 spread to virtually every country and territory. By the end of 2021, more than 287 million confirmed COVID-19 cases and 5.4 million confirmed deaths had been reported to WHO, with totals continuing to rise substantially thereafter (Msemburi et al., 2023). Confirmed-death tallies are widely regarded as underestimates because of limited testing, inconsistent death-certification practices, and surveillance gaps (Mathieu et al., 2020). Excess-mortality modelling by Msemburi et al. (2023) gives a fuller picture, with an estimated 14.83 million excess deaths globally (ie., 95% uncertainty interval of 13.23 - 16.58 million) between January 2020 and December 2021 alone. This is 2.74 times the 5.42 million deaths officially reported for that period. Independent estimates using different methods have produced broadly consistent figures, with some placing the cumulative toll as high as 18 to 21 million once indirect and unreported deaths are included (Wang et al., 2022).

On April 17, 2026, the Government of Cross River State, Nigeria, confirmed a new case of coronavirus disease (COVID-19) in the state. The new case involved a Chinese national who arrived in Nigeria on March 17, 2026, before falling sick and testing positive for the COVID-19 virus (Eneji, 2026; Azu, 2026). The Cross River State Government swung into action by profiling and tracing persons in the state who had contact with a Chinese national who tested positive for the COVID-19 virus in a bid to curtail the spread of the virus. Contact tracing and triage are necessary to break COVID-19 transmission chains and reduce the spread within the community. According to the US Center for Disease and Control (CDC), Triage is "the sorting out and classification of patients or casualties to determine priority of need and proper place of treatment." Triage is especially crucial during infectious disease outbreaks such as COVID-19 in order to separate and classify patients infected with the particular pathogen according to various urgency levels (US CDC, 2024).

The World Health Organization report indicates that 80% of confirmed COVID-19 cases can be managed as outpatients, 20% need hospitalization, and 5% will be referred to intensive care units (WHO, 2020). Thus, the efficient triage of COVID-19 patients will help in management of cases and improve the national response. The use of computer simulation in health sector to model emergency department, and improve medical operation has been on the increase. This is due to the fact that simulation can easily be used to analyze problem and also present a complete view of the system. Coloured Petri Nets has been used extensively in health care modeling because of it graphical and executable nature.

Coloured Petri Nets Definition

Coloured Petri Nets (CPN) is a graphical and mathematical language that is used in the modelling and analysis of concurrent systems. CPN consists of three key components, namely places, transitions, and arcs (Okpor & Apeh 2021). Places are drawn as circles or ellipses and act as a data store or condition of the system. Transitions, drawn as rectangles, represent events or actions that will occur in the system (Lalita and Wiwat 2019). An arc is used to connect either a place to a transition or a transition to a place. The arc expression determines the token that will be added or removed from a particular place. CPN Markup Language (ML) is used in modelling and is based on the standard ML. Applications of CPN include embedded systems, communication protocols, and data networks. The system behaviours can be examined by using the simulation palette embedded in CPN Tools. The simulation palette also enables the modeler to observe different scenarios that the system can operate in and ensure that the system performs as expected.

A non-hierarchical colored petri net is a nine-tuple $(\Sigma, P, T, A, V, C, G, E, I)$, where Σ is a finite collection of non-empty color sets (type), P is a collection of places shown as ovals or circles, T is a set of transitions that are represented as rectangles $P \cap T = \emptyset$, A is a collection of directed arcs such that $\boldsymbol{A \subseteq P \times T \cup T \times P}$, V is a group of typed variables with a finite set such that $Type[v] \in \Sigma$ for all variables $v \in V$, C is a function that sets colors. It is characterized as $\boldsymbol{C : P \rightarrow \Sigma}$, $G: T \rightarrow EXPR_V$ is a guard function that provides a guard for each transition t to ensure that $Type[G(t)] = Bool$, $E: A \rightarrow EXPR_V$ 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, $I: P \rightarrow EXPR_{\emptyset}$ is a function that initializes each place p with an initialization expression so that $Type[I(p)] = C(p)_{MS}$ (Jensen & Kristensen, 2009

Review of Related Work

Salimifard et al., 2013 used Hierarchical Coloured Petri Nets to model emergency departments (ED) processes in a general hospital. The HCPN model captures ED care processes and patient flow. The simulation model was verified using past data, after which various scenarios were employed to evaluate, compare, and enhance key performance indicators in the emergency department, including patient wait times, length of stay (LOS), and resource utilization rates. The developed model will assist the hospital policymakers in setting up the ED to increase worker satisfaction and efficiency.

Masoomeh et al. (2020) conducted a study using timed coloured Petri nets in a bid to attain an optimum waiting time and also manage healthcare systems during the COVID-19 pandemic. The study used Sequence diagrams and a uniform modelling language (UML) to depict the cardiac clinic workflow. An executable Coloured Petri Nets model was created using a sequence diagram that shows the behavior of the system. The authors simulated three scenarios in order to arrive at the ideal waiting time, and the best was selected. Following the identification of the bottlenecks with the longest wait times, the planned scenarios were conducted to reach the optimal waiting time.

To maximize workflow and patient throughput, Gehlot et al. (2022) used the Hierarchical Colored Petri Net (CPN), an extension of classical Petri nets, to simulate, model, and optimize an episode of care using two key approaches, such as initial patient contact and triage procedures. The study examined two important patient triage programs, namely a specialized orthopedic surgical program in the United States and the generalized Australia health care system. The study developed an executable CPN model personalised to the US orthopedic program.

Zouaoui & Fatma (2023) use a coloured Petri net to model the emergency department to reduce patient waiting time. The model captures the triage process and medical observation. Particle Swarm Optimization algorithm was implemented numerous times to check the human and material resources in the emergency department. According to the results derived from the PSO algorithm, three distinct simulation models were constructed, with each model designed for its specific resources. The results obtained from simulations of the three models were compared with the Benchmark model.

Research Methodology

CPN Tools 4.0.1 version was applied to design the COVID-19 Base triage Coloured Petri net model. The developed model was also simulated and analyzed using the CPN Tools. CPN Tools is a powerful software tool for modeling and simulation of concurrent systems. The CPN markup language (ML) was used in describing the net elements. CPN Tools also allows for declarations of color sets (datatypes), variables, constants, and functions. Places drawn as circles (or ovals) were used to represent data stores or the state of the system, and transitions drawn as bars were used represent to action or events. Arcs were used to connect places to transitions or transitions to places. The arc expression determines the token to be added or removed from a particular place. The CPN model and the system properties were verified using the state space analysis method.

3.1. COVID-19 Base Triage Algorithm for clinical pathways

The COVID-19 Base Triage Algorithm for clinical care pathways of COVID-19 individuals is shown in Figure 1. According to Bartenschlager et al.. (2023), the COVID-19 Base Triage Algorithm was useful during the COVID-19 pandemic and serves as a standard for emergency departments during the pandemic in Germany. The process begins with screening of the patient by critically examining them for COVID-19 symptoms such as fever, dry cough, shortness of breath, and vital signs. Thereafter, the patient's clinical presentation is assessed. This will be strictly followed by examining the patient's blood counts and medical imaging such as Chest X-Ray (CXR), Computed Tomography (CT) Scan, and Lung Ultrasound (LUS). The patient is classified based on the results of the other steps as outpatient (i.e to be discharged), or referred to the ward unit, or intensive care unit (ICU). The classified pathways are Emergency department (ED) to ward unit, Emergency department (ED) to intensive care unit (ICU), or Emergency department (ED) discharge based on the doctor's recommendation (Bartenschlager et al.. 2023).

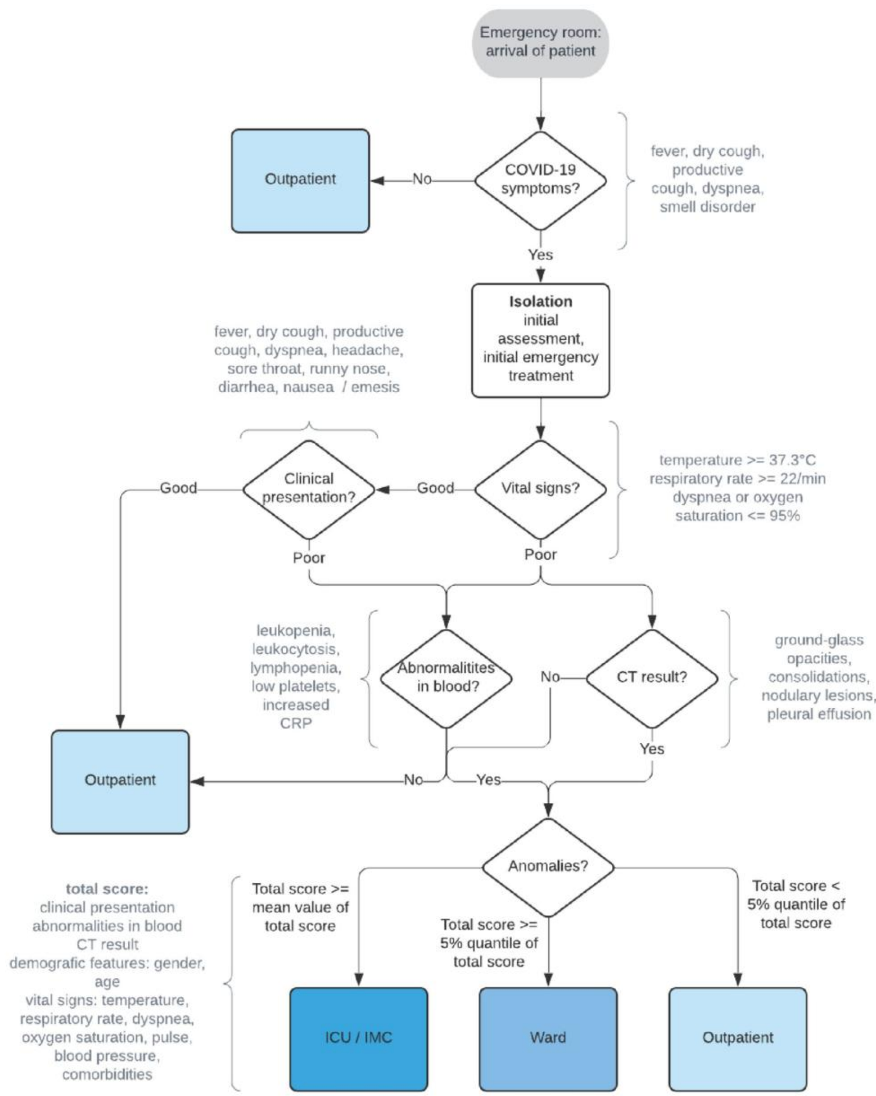

Figure 1 Base triage algorithm (TA) (Bartenschlager et al., 2023)

RESULT

Figure 2 shows the Coloured Petri Net model of the COVID-19 Base Triage Algorithm. The Base triage clinical pathway for COVID-19 starts immediately the patient enters the emergency room.

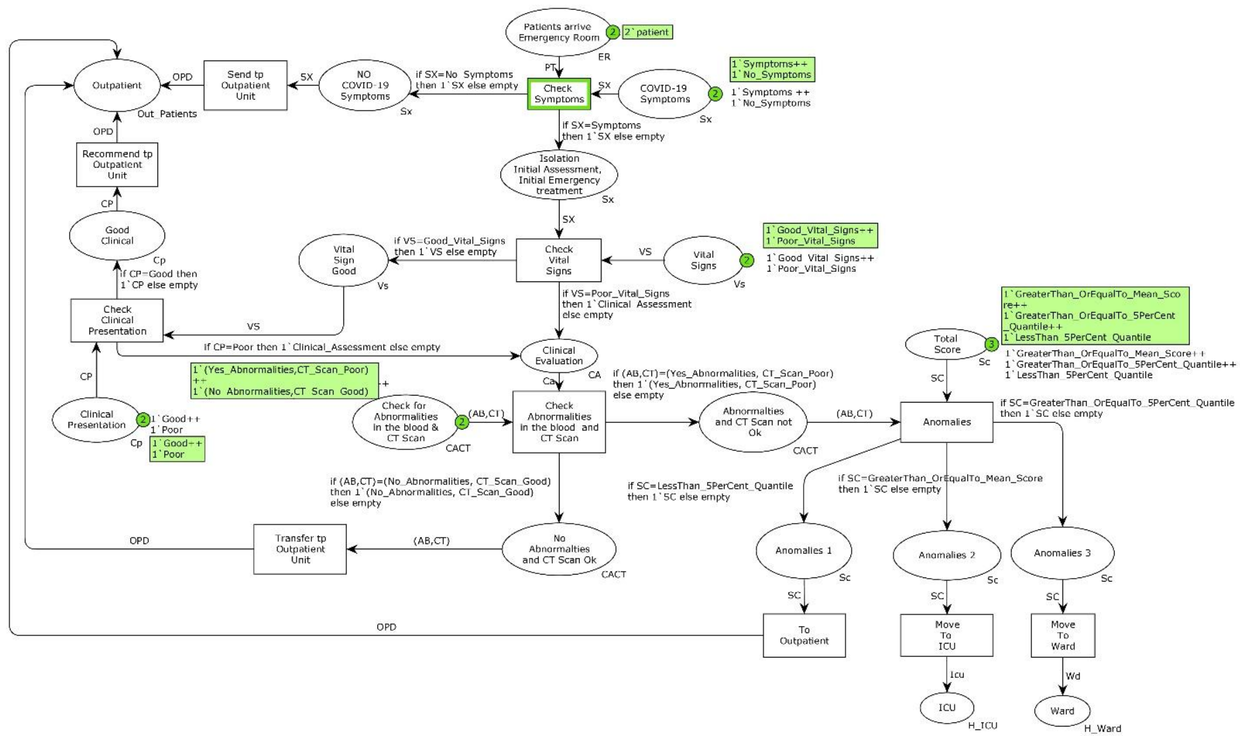

Figure 2: COVID-19 Base Triage CPN Model

Place *COVID-19 Symptoms* contains two tokens' *Symptoms* and, *No_Symptoms*. Transition *Check Symptoms* becomes enabled immediately when patient(s) arrive at the emergency room. When Transition *Check Symptoms* is fired, place *NO COVID-19 Symptoms* receives the token *No_Symptoms* if the output arc connected to place *NO COVID-19 Symptoms* is evaluated to be *No_Symptoms*. Transition Send to *Outpatient Unit* becomes enabled upon receiving the token, and when it fires, the patient will be transferred to place *Outpatient*. If the output arc attached to transition *Check Symptoms* is evaluated to be *symptoms*, place *Isolation, Initial Assessment, Initial Emergency treatment* receives the token *symptoms*, and transition *check vital signs* becomes enabled. When transition *check vital signs* occurs, and the output arc expression evaluates to be

Good_Vital_Signs based on the input from place *Vital Signs*, the token will be transferred to place *Vital Sign Good*. Transition *Check Clinical Presentation* becomes enabled immediately place *Vital Sign Good* receives the token. When the transition *Check Clinical Presentation* occurs, it extracts tokens from place *Clinical Presentation*, and if that token is *Good*, place *Good Clinical* receives the token and transition *Recommend to Outpatient Unit* becomes enabled. The patient is referred to the outpatient unit when the transition fires. When the output arc expression on transition *Check Clinical Presentation* evaluates to be *poor*, a token will be received by place *clinical evaluation,* and transition *Check Abnormalities in the blood and CT scan* becomes enabled.

A token will be transferred to place *No Abnormalities and CT Scan Ok*, if there are no Abnormalities and CT scan is okay. When transition *Transfer to Outpatient Unit* is enabled and it fires, the patient will be transferred to *outpatient unit*. If transition *Check Abnormalities in the blood and CT scan* evaluate to be *Yes Abnormalities, CT_Scan_Poor*. Place *Abnormalities and CT scan not Ok* will receive the token, and transition *Abnormalities* becomes enabled. When transition *Abnormalities* fires, if the expression on the output arc evaluates to total score >= 5% quantile of total score, place *Anomalies 3* receive the token, transition *Move To Ward* becomes enabled, and when it fires, the patient will be moved to the ward.

On the other hand, if the expression on the output arc evaluates to total score >= 5% mean value of total score, place *Anomalies 2* receives the token, transition *Move To ICU* becomes enabled, and when it fires, the patient will be moved to the ICU. If the expression on the output arc evaluates to total score < 5% quantile of total score, place *Anomalies 1* receives the token, transition *To Outpatient* becomes enabled, and when it fires, the patient will be moved to the outpatient. Fig. 3 below shows the Colour set definitions of the COVID-19 Base triage CPN model. The CPN model was developed using Unit, Boolean, Enumerated, and Product color set.

```
▼colset ER =unit with patient;
▼var PT:ER;
▼colset Sx=with Symptoms | No_Symptoms;
▼var SX: Sx;
▼colset Vs=with Good_Vital_Signs | Poor_Vital_Signs;
▼var VS: Vs;
▼colset Cp=with Good | Poor;
▼var CP: Cp;
▼colset CA = unit with Clinical_Assessment;
▼var Ca : CA;
▼colset Out_Patients=unit with Outpatients;
▼var OPD: Out_Patients;
▼colset Ab=with Yes_Abnormalities | No_Abnormalities;
▼var AB: Ab;
▼colset Ct=with CT_Scan_Good | CT_Scan_Poor;
▼var CT:Ct;
▼colset CACT=product Ab*Ct;
▼colset Sc=with GreaterThan_OrEqualTo_Mean_Score | GreaterThan_OrEqualTo_5PerCent_Quantile | LessThan_5PerCent_Quantile ;
▼var SC: Sc;
▼colset H_Ward =unit with ward;
▼var Wd: H_Ward;
▼colset H_ICU = unit with ICU;
▼var Icu: H_ICU;
```

Figure 3: Colour set definitions of the COVID-19 Base triage CPN model

```
State Space
    Nodes:  75
    Arcs:   122
    Secs:   2
    Status: Full
 Scc Graph
    Nodes:  75
    Arcs:   122
    Secs:   0

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

Liveness Properties
------------------------------------------------------------------------
 Dead Markings
    9 [75,74,73,66,65,...]

 Dead Transition Instances
    None
 Live Transition Instances
    None
Fairness Properties
------------------------------------------------------------------------
    No infinite occurrence sequences.
```

Figure 4: The state space report, which provides the basic information such as the state space statistics and standard behavioural properties of the developed CPN model.

The report shows that the state space and SSC graph of the model contain the same 75 nodes and 122 arcs, respectively. The fact that the state space and SSC graph contain the same number of nodes and arcs implies that no cycle exists. This implies the model will terminate properly because no infinite occurrence sequence.

Conclusion

The outbreak of different infectious diseases such as COVID-19, SARS, Middle East respiratory syndrome (MERS), and Ebola has negatively affected the lives of millions of people globally. No nation is immune to future outbreak of these infectious diseases. Thus, a robust triage and well-planned health surveillance system are key to containment of these diseases. In this study, a COVID-19 Base Triage CPN Model was developed. The developed COVID-19 Base Triage CPN Model was analyzed using state space. The CPN model being executable and graphical representation will provide guidance to healthcare workers during the triage of COVID-19 patients.

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