Stochastic Petri net model with random time of Vietnamese ischemic stroke patient treatment process

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ABSTRACT

Simulation is a helpful preliminary step for implementing a patient workflow management system. Simulation is based on the process model (the clinical practice guideline) and the organization model (human and technological resources), permitting the detection of blockages in the care delivery organization and finding the optimal resource allocation. Our study uses stochastic Petri net (SPN) to illustrate part of the medical practice within a stroke unit. In particular, we modeled the medical activities following the guidelines for the ischemic stroke treatment adopted by the Thai Nguyen National Hospital Stroke Unit. Several parameters have been estimated using a database of about 100 ischemic stroke patients collected and eliciting knowledge from the neurologists. This is the first time we have applied SPN to model and analyze system performance for emergency stroke patients using the SPN model. We can apply it to any medical examination and treatment system if we need to survey the system's capacity. Thereby detecting barriers or limitations of the system to provide solutions to overcome and improve the system's efficiency.

Introduction

Strokes are a major health problem in Vietnam, but to date, there has been no epidemiology survey reporting data in this country.[1] The estimated population of Vietnam in 2021 was 98.32 million, of which the young population accounts for the majority. The proportion of people older than 65 years accounts for 7.7% of the total population. This phenomenon is the leading cause of death and disability in Vietnam. The incidence and prevalence of stroke were reportedly 161 and 415 per 100,000 people, respectively.[2] Stroke is classified broadly into three types: ischemic stroke, hemorrhagic stroke,

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and subarachnoid hemorrhage. Ischemic stroke happens due to blockage of blood vessels, which limits the blood pool to the brain. Approximately 60-80% of all strokes are ischemic. This article focused on acute ischemic strokes and their genetic features. Their unmodifiable risk factors include age, race, sex, ethnicity, history of migraine headaches, and fibromuscular dysplasia. The hereditary factors are family history of stroke or transient ischemic attacks. The modifiable risk factors include hypertension, diabetes mellitus, cardiac disease, high cholesterol, previous stroke, carotid stenosis, hyperhomocysteinemia, and lifestyle issues. The majority of the ischemic strokes seen in patients with cardiovascular disease are embolic.[3]

The most critical factor in the management of acute ischemic stroke is time. The ischemic stroke patient loses 190,0000 brain cells per minute, which means 14,000,000,000 nerve connections are eradicated, and 12 km (7.5 miles) of nerve fibers are lost every minute. The brain ages 3.6 years; it is deprived of blood supply every hour.[3]

Clinical pathways, in general, are usually expressed by means of workflow formalisms, providing healthcare personnel with an easy-to-understand, high-level conceptual model of medical steps in specific patient conditions, thereby improving overall healthcare process quality in clinical practice.[4] The key first step in stroke care is the early identification of patients with stroke and triage to centers capable of delivering the appropriate treatment as fast as possible.[5]

Due to the need for management, control, and monitoring of information in an efficient way, hospital automation has been the object of several studies involving technologies. Thus, numerous hospital processes are still manual in private and public hospitals, especially with stroke cases. So, it is essential to model and simulate the stroke unit using stochastic Petri nets (SPN), which opens the possibility of being applied in several automation processes.[6] SPN are also applied to improve the efficiency of the post-disaster emergency medical rescue, providing decision-makers with rescue strategies.[7]

Several studies have employed simulation and modeling techniques to assess the performance and facilitate the deployment of telemedicine in a variety of contexts. Modeling techniques such as Petri nets have been used to describe healthcare systems formally with the purpose of performance evaluation.[8]

In this paper, we apply a SPN with the random time of a Vietnamese ischemic stroke patient's treatment process. The simulation results of the cases can be referenced to compare and analyze the model's effectiveness. If it is not effective and satisfactory, we may have to set the time delay values and activation rates of each transition (representation of the execution behavior of the emergency stages).

Materials and Methods

Study design

Among 100 stroke patients in our convenience sampling study, both males and females aged 20 to 45 have had an ischemic stroke. Patients' medical history was classified according to TOAST regulations for acute stroke treatment. Exclusion criteria were patients with cerebral venous sinus thrombosis, intracranial hemorrhage, and subarachnoid hemorrhage. The collected information includes risk factors for stroke in the medical history of patients, such as hypertension, diabetes, coronary artery disease, history of stroke, atrial fibrillation, smoking, headache, hyperlipidemia, valve replacement, thyroid dysfunction, history of abortion, vascular disease, blood disorders, chronic alcohol consumption, and use of oral contraceptives. The patients should undergo routine biochemical and hematological tests, Doppler ultrasound of the carotid and vertebral arteries, magnetic resonance imaging and/or computed tomography angiography of the brain, coagulation tests, fibrinogen, and homocysteine.

Stochastic Petri net

We conduct the SPN with a random time of 100 stroke patients' treatment process in Thai Nguyen National Hospital. The unexpected time determined for the events of patients arriving at the emergency room is random, not sequential, and regular. The random time specified for the events of patients arriving at the emergency room is unexpected, not sequential, and periodic. In this SPN, places represent states, and timed transitions represent behaviors within intervals. Transitions T1, T2, T3, T4, T5, and T6 have average firing rates of λ_1, λ_2, λ_3, λ_4, λ_5, and λ_6, respectively. The average speed for a patient is an exponentially distributed function (Figure 1).

To simulate, choose a closed Petri network (consisting of patients coming to the emergency room are all considered to be one type of patient, so we apply the SPN model with a kind of data (class 1). To set up the class, we choose as in Figure 2A. There are two types of classes: closed and open. We choose closed so that all calculations refer to a node. For example, in Figure 1, we choose the reference node as location P1: Patient.

The average activation time or delay of these transitions is $1/\lambda_1$, $1/\lambda_2$, $1/\lambda_3$, $1/\lambda_4$, $1/\lambda_5$, and $1/\lambda_6$. These activation delays represent the complete processing (or service) time of doctors and nurses at each stage, from bringing the patient into the stage from a state (place) to having the processing results of the taking stage. The patient moves to the next place. The patient's stay in a preceding place, *e.g.*, P1: Patient, depends on the delay or activation rate of the output transition T1: Emergency.

The activation delay of the transitions depends on the resources (resource power) of each stage: the number and qualifications of doctors at each stage and imaging diagnostic equipment. With good resources, the activation delay will be small. We can specify what the standard activation delay (patient processing time) is: minimum or maximum through setting the values λ_i (i=1,2,3,4,5,6) can be set for each transition on the JMT tool, as shown in Figure 2B. For example, if the mean trigger time delay for transition T1: Emergency is set to 10 minutes (*i.e.*, recovery delay case of 1 emergency patient), we will have an average activation speed λ_1=0.1. To set up, we hover over the T1: Emergency transition and press the right mouse button; a window will appear, as shown in Figure 2C. On this window, we hover over the timing section and right-click, and a window will appear, as shown in Figure 2D. We select the average activation delay value (mean) and activation speed λ_1. A window will appear, as shown in Figure 1, on which we can set the values of mean and λ. In the same way, we set the average firing rate and time delay values for all transitions. The value taken in minutes or hours will give corresponding results on the simulation graph, depending on the simulation scenario. We end up with the SPN model of the stroke patient emergency system in Figure 2E.

Ethics approval and consent to participate

Informed consent from all participants or their legal representatives, ensuring they understood the study's purpose, risks, benefits, and procedures, was obtained.

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Thai Nguyen National Hospital (Reference No. #59/HĐĐĐ-BVTWTN# January 18th 2021). Written informed consent was obtained from the subjects regarding the use of the samples and information for research purposes.

Results

In the first scenario, we set the average trigger time delay in minutes, with the transition T1 to T6 as follows: T1: λ_1=0.1, 1/λ_1=10 minutes; T2: λ_2=0.05, 1/λ_2=20 minutes; T3: λ_3=0.025, 1/λ_3=40 minutes; T4: λ_4=0.025, 1/λ_4=40 minutes; T5: λ_5=0.05, 1/λ_5=20 minutes; T6: λ_6=0.05, 1/λ_6=20 minutes.

We set patient count values for locations as 5, 10, 20, 50,100 (Figure 3A). The remaining positions are similar. Thus, we will have five simulation results for all five cases with different numbers of patients. Simulation parameters

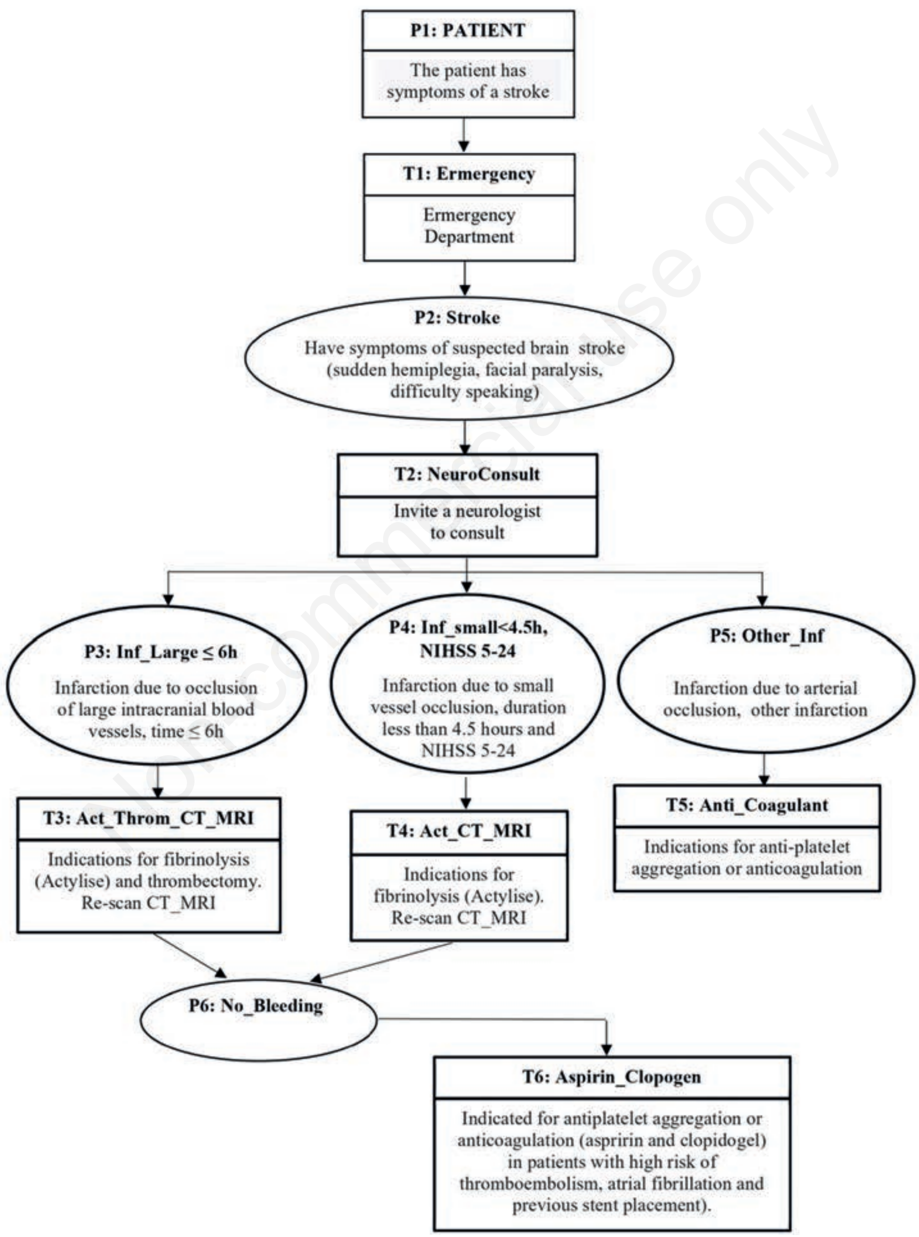

Figure 1. Careflow. In this stochastic Petri net, places represent states and timed transitions represent behaviors within intervals. Transitions T1, T2, T3, T4, T5, T6 have average firing rates of λ_1, λ_2, λ_3, λ_4, λ_5, and λ_6, respectively. The average speed for a patient is an exponentially distributed function. NeuroConsult, Neurologist Consultation; Inf, Infarction; Act, Actylise; Throm, Thrombectony; CT, Computed Tomography; MRI, Magnetic Resonance Imaging.

can be selected on the main window of the JSIMgraph tool (Figure 3B). All the performances could be set following Figure 3C.

After calculating the selected performance index, we need to select the reference node (Stat. Res) so that the performance indicators refer to the value. Figure 3C is an example of selecting performance indicators for locations and the entire emergency system. After setting the performance indicators, the simulation results will be automatically saved to the model file. The following figures are the graphs and result values of the cases where the number of patients 5, 10, 20, 50, and 100 are stored in the directory as a .isimg file. The simulation results of the cases can be referenced to compare and analyze the effectiveness of the model. If it is not effective and satisfactory, we may have to set the time delay values and activation rates of each transition (representation of the execution behavior of the emergency stages). The emergency system with human resources (doctors) and diagnostic and testing equipment ensures emergency care for 100 stroke patients with many options (greater probability) to serve the patients. Over a shorter period of time, the average response is relatively smaller (50.2068 minutes) than in the case of only five patients presenting to the emergency department (51.9389 minutes) (Figure 4). In the second scenario, we set the average trigger time delay in hours as follows: T1: λ_1=0.1, 1/λ_1=1 hour; T2: λ_2=0.05, 1/λ_2=2 hours; T3: λ_3=0.025, 1/λ_3=4 hours; T4: λ_4=0.025, 1/λ_4=4 hours; T5: λ_5=0.05, 1/λ_5=2 hours; T6: λ_6=0.05, 1/λ_6=2 hours.

This means that the response time values for one patient were obtained in hours, and the resulting graphs of the first scenario will receive hourly values.

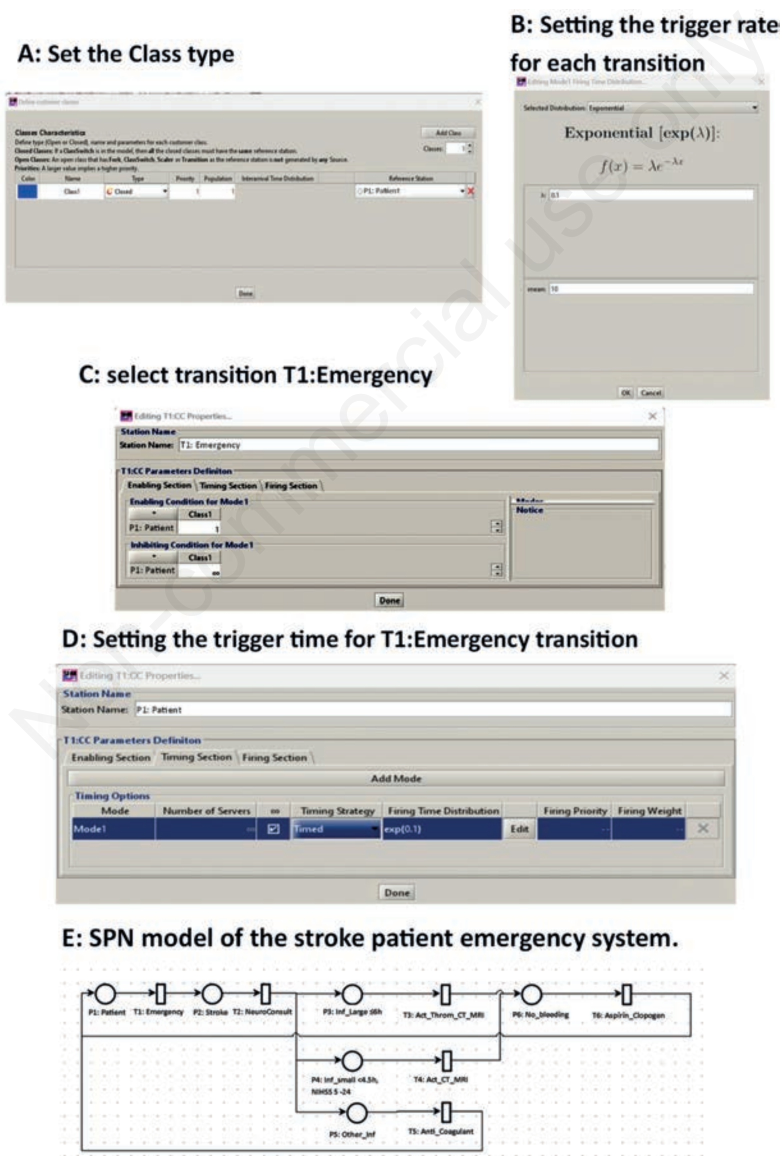

Figure 2. Setting up the Petri network. SPN, stochastic Petri net; NeuroConsult, Neurologist Consultation; Inf, Infarction,; Act, Actylise; Throm, Thrombectony; CT, Computed Tomography; MRI, Magnetic Resonance Imaging; NIHSS, The NIH Stroke Scale/Score.

Discussion

For the first scenario, the average service speed of a department patient (simulated as a relay node in the SPN model) is small (in minutes) in the system's patient service process. First aid with human resources (doctors) and diagnostic and testing equipment to ensure that performing emergency care for 100 stroke patients will have many options (greater probability) to serve patients in the future. Time is shorter, so the average response is smaller (50.2068 minutes) compared to the case where only five patients came to the emergency room (51.9389 minutes). However, in the second scenario, the average service speed for a patient of a department (SPN relay node) is high (in hours), possibly due to human resources (specialized doctors, equipment). medical facilities, hospital beds) is limited, the simulation results show that the average response per patient is high. So, to improve the average response per patient of the emergency system, it is necessary to reduce the activation delays $1/\lambda_1$, $1/\lambda_2$, $1/\lambda_3$, $1/\lambda_4$, $1/\lambda_5$, $1/\lambda_6$.

These activation delays of the relay nodes of the SPN model represent the complete processing (or service) time of doctors and nurses at each stage from bringing the patient into the stage from one state (place), and there are processing results of the step of moving the patient to the next place. Based on the two simulation scenarios, we can assume that if the corresponding activation delays for each relay are halved, the

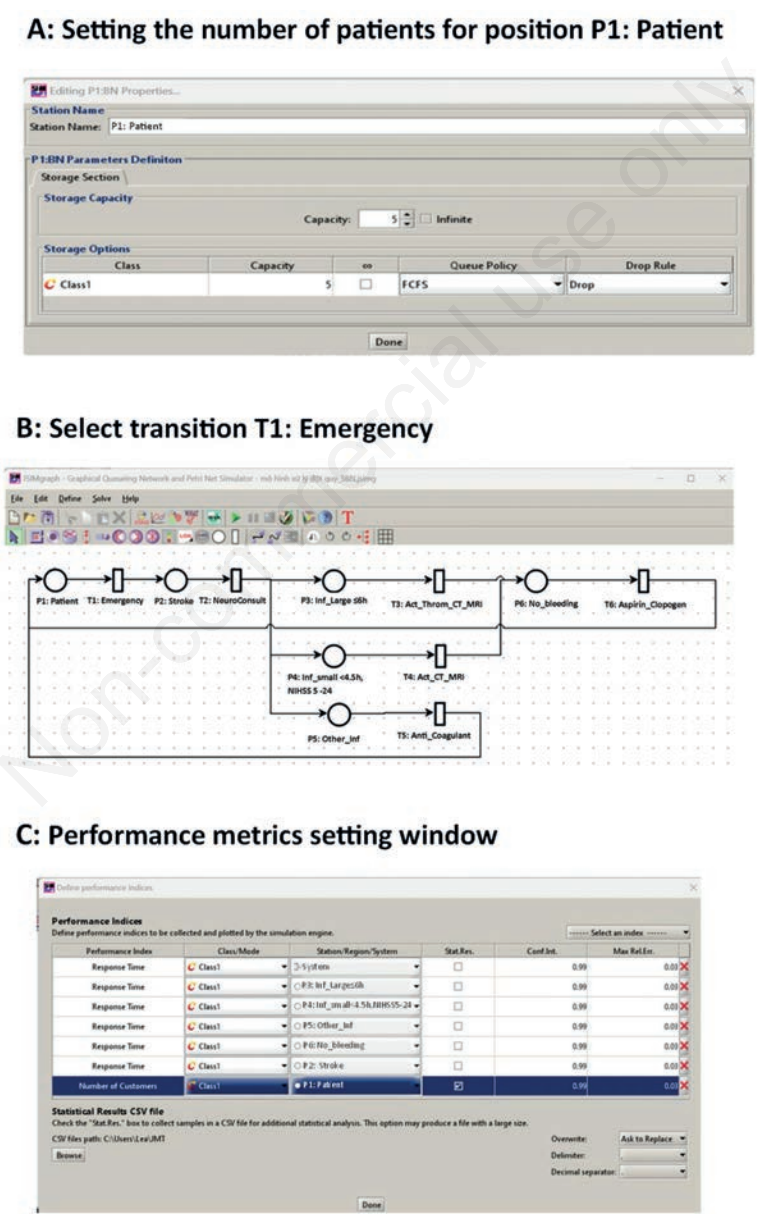

Figure 3. Setting up the patient count values for each locations and transition. NeuroConsult, Neurologist Consultation; Inf, Infarction; Act, Actylise; Throm, Thrombectony; CT, Computed Tomography; MRI, Magnetic Resonance Imaging; NIHSS, The NIH Stroke Scale/Score.

average patient response time will be halved. To do so, the emergency system needs to develop solutions to improve the necessary capacity (or performance of the SPN model). Keeping an optimal patient flow is crucial to improving the efficiency of stroke care practice and giving the optimal experience for patients and healthcare personnel. Patient flow is event-driven; thus, Petri nets are a good fit for modeling and analysis. Details of patient flow performance analysis based on stochastic timed Petri nets, such as the average patient waiting time, resource constraints modeling, task duration modeling, and patient flow hierarchical modeling that handles complexity, are essential to setting up a better care flow.[9] The same as patients moving through a healthcare facility to receive medical service from the patient flow. Optimizing patient flow is crucial to improving the efficiency of healthcare practice and providing a positive experience for patients and healthcare teams. Patient flow is event-driven, and thus Petri nets are a good fit for its modeling and analysis, as shown in the project of Wang (2022) or Quaglini *et al.* (2001) and Panzarasa *et al.* (2007), where the simulation has been able to find some of the causes of the delay in the patients' treatment, and accordingly, to suggest changes in the organization.[10-12]

Petri nets are a widely studied mathematical formalism for modeling systems. They provide a graphical notation for modeling concurrency, communication, synchronization, and resource-sharing constraints. For almost all of the diseases, each medical protocol can be modeled by a state machine Petri net. Various approaches of Petri nets can be achieved as system security and information flow in the healthcare record-

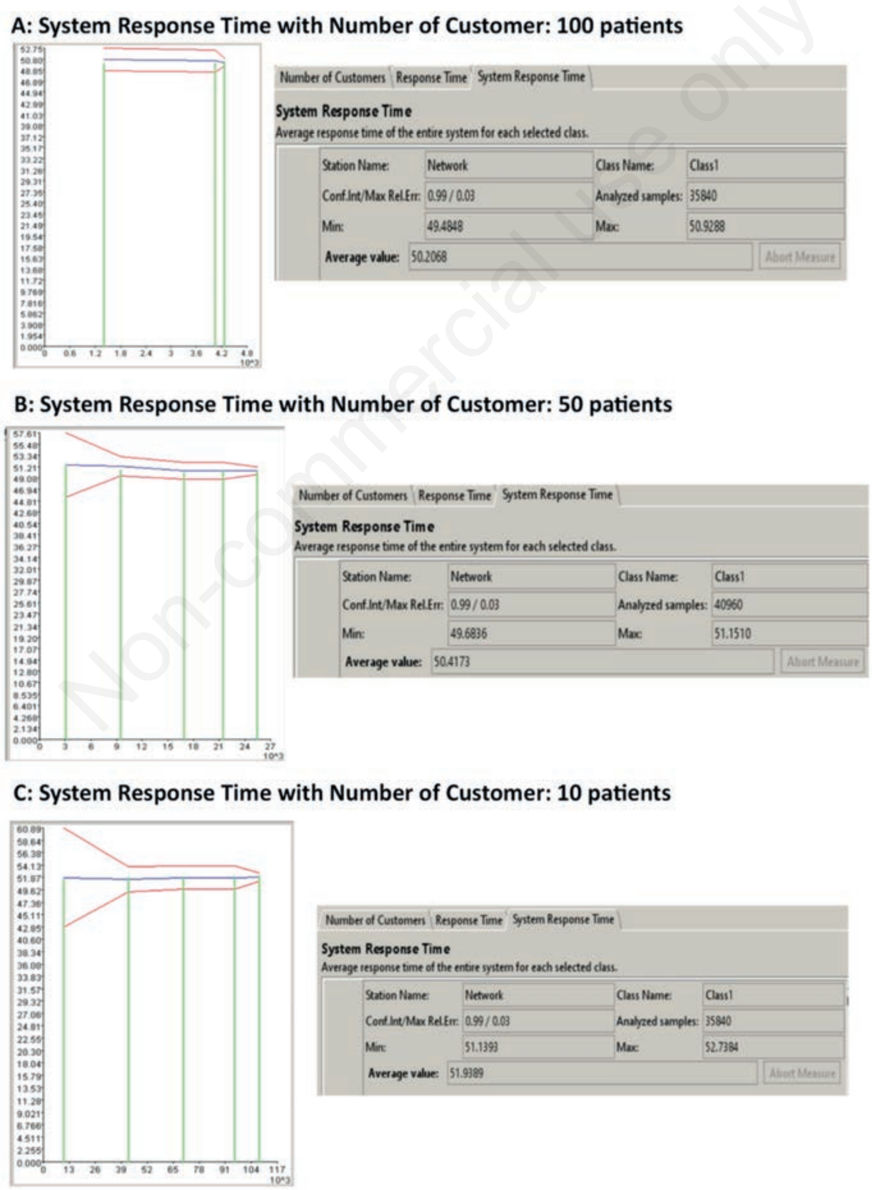

Figure 4. The simulation results.

ing system inside any medical or health-related business. However, it needs to be more performant for modeling and simulating large systems.

Conclusions

Simulation is a practical preliminary step for implementing a patient workflow or careflow management system. Simulation is based on the process model as the clinical practice guideline and the organization model as human and technological resources, allowing the detection of bottlenecks in the care delivery organization and finding the optimal resource allocation.

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