Formal Modelling and Performance Analysis of Clinical Pathway

Rui Han, Xian Yang, Anthony Rowe & Yike Guo

Imperial College London

xian.yang08@imperial.ac.uk

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Introduction

Problem

Hospitals are required to serve more and more patients with limited medical staff and equipment.

Current Solution

Clinical pathway informatics applies information technology to the medical field to promote public health quality, facilitate medical data management and reduce treatment costs.

Our Method

This paper proposes a stochastic model to describe key features of a clinical pathway in a probabilistic way based on Performance Evaluation Process Algebra (PEPA).

Table of Contents

1. Motivation
2. Formal modelling method
3. Simulation and Results
4. Conlusion

Motivation

Clinical Pathway

A clinical pathway is a sequence of clinical actions performed by a multidisciplinary team. There are three key elements of clinical pathway:

- Process
- Time
- Resource

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All activities have time constraints such as execution durations and deadlines that form the completion time of the whole process.

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- Resource

A clinical pathway may include multiple resources and each resource has some constraints.

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- The formal model of its clinical pathway can optimize patient treatment process with constrained resources.
- The stroke clinical pathway discussed in this paper is extracted from the Hyper-Acute Stroke Unit (HASU) department of Charing Cross Hospital in London.

Case Study

Clinical Pathway of stroke

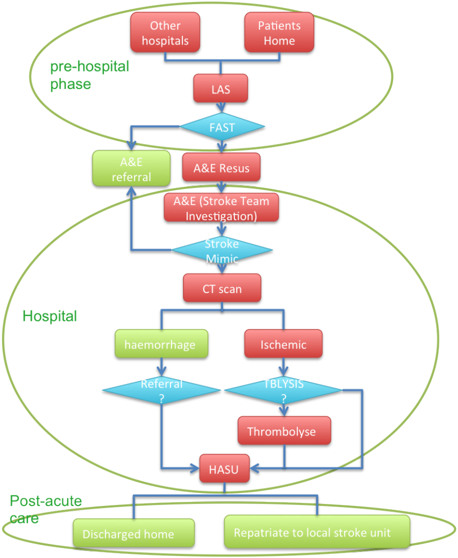

Table of Contents

1. Motivation
2. Formal modelling method
3. Simulation and Results
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PEPA

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- Both the system's behaviour and property can be described in the form of algebra, which facilitates the accurate definition and rigorous reasoning in mathematics.

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- Both the system's behaviour and property can be described in the form of algebra, which facilitates the accurate definition and rigorous reasoning in mathematics.
- PEPA is an enhanced process algebra mainly used to describe and analyse the performance of concurrent systems.
- Based on PEPA, the Clinical Pathway PEPA (CPP) describes the features of a clinical pathway in a probabilistic way.

Clinical Pathway PEPA

Definition1

In CPP, a clinical pathway is represented by a 5-tuple, $< S, R, Act, C, F_C >$, where:

- S is a finite set of states $s \in S$;
- R is a finite set of resources $r \in R$;
- Act is a finite set of activities $a \in Act$; Each application is represented by a two-tuple $(\alpha, rate)$.
- C is a set of constraints $c \in C$;
- F_C is a set of action rate functions that determine applications' action rate: $rate = f(c_{r1}, c_{r2}, \ldots, c_{rn})$ where $f \in F_C$, $c_{ri} \in C$ and $1 \leq i \leq n$.

Clinical Pathway PEPA

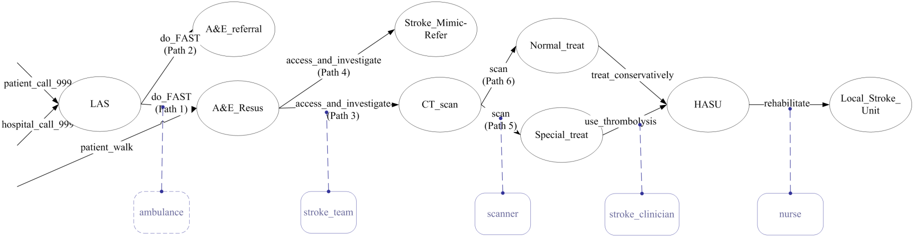
Definition2

In CPP, the set S and R are basic components. Given that, these components can be commonly denoted as P or Q, the syntax of the terms in CPP can be defined as follows: $P \stackrel{def}{=} (\alpha, rate).P|P + Q|P \bowtie Q$

- The sequential operator '.' defines the order of P and Q;
- The choice operator '$+$' indicates competition between P and Q;
- The cooperation operator '$\bowtie$' determines the interaction between P and Q.

Clinical Pathway PEPA

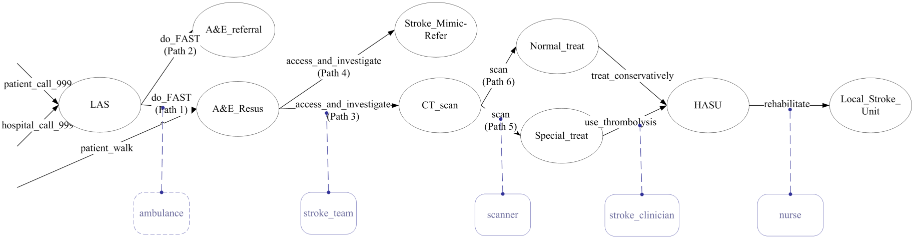
Example



The state set S has 9 states and the resource set R has 5 resources.

Clinical Pathway PEPA

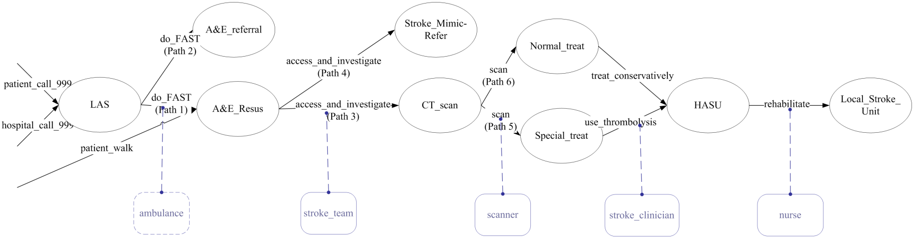
Example



Activities decide transitions among these states and each activity can rely on one or more resources. For instance, the activity '*do_Fast*' relies on one resource '*ambulance*'.

Clinical Pathway PEPA

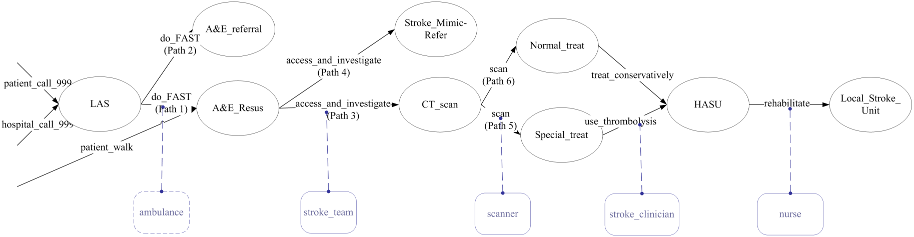
Example



In addition, each resource can have multiple constraints. For example, the '*ambulance*' resource's constraints are its cost per use and its service time.

Clinical Pathway PEPA

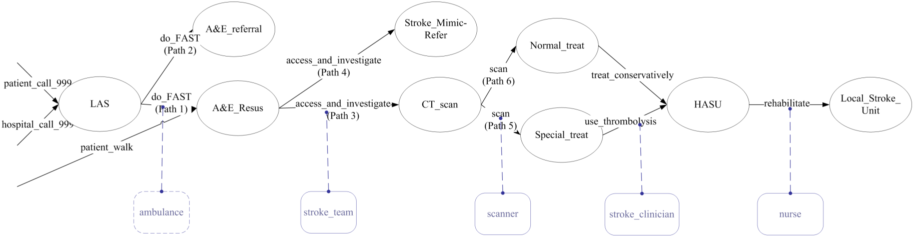
Example



The component 'LAS', for example, can be defined as '$LAS = (do\_Fast, \rho_{path1} * rate_{do\_Fast}).A\&E\_Referral + (do\_Fast, \rho_{path2} * rate_{do\_Fast}).A\&E\_Resus$'.

Clinical Pathway PEPA

Example



Moreover, for the '$\bowtie$' operator, '$LAS \underset{do\_Fast}{\bowtie} ambulance$' reflects that state '*LAS*' and the resource '*ambulance*' are synchronized. If two components share no activities (e.g., $Patients\_Home \bowtie Other\_Hospitals$), they can proceed in parallel without any interaction.

- Sate Definition
- Resource Definition
- System Description

Part 1: State definition

$Patient\_Home \overset{def}{=} (in, \Gamma).LAS;$

$LAS \overset{def}{=} (do\_FAST, \rho_{path1} \times \Gamma).A\&E\_Resus + (do\_FAST, \rho_{path2} \times \Gamma).A\&E\_referral;$

$A\&E\_Resus \overset{def}{=} (access\_and\_intestigate, \rho_{path3} \times \Gamma).CT\_scan +$
$(access\_and\_intestigate, \rho_{path4} \times \Gamma).Stroke\_Mimic\_Refer;$

$CT\_scan \overset{def}{=} (scan, \rho_{path5} \times \Gamma).Special\_treat + (scan, \rho_{path6} \times \Gamma).Normal\_treat;$

...

Part 2: Resource definition

//Ambulance

$Ambulance_{idle} \stackrel{def}{=} (in, rate_{in}).Ambulance_{busy};$

$Ambulance_{busy} \stackrel{def}{=} (do\_FAST, rate_{do\_FAST}).Ambulance_{idle};$

//stroke team

$Stroke\_team_{idle} \stackrel{def}{=} (do\_FAST, \Gamma).Stroke\_team_{busy};$

$Stroke\_team_{busy} \stackrel{def}{=}$
$(access\_and\_investigate, rate_{access\_and\_investigate}).Stroke\_team_{idle};$

...

Part 3: System description

$$
\begin{aligned}
& Patient\_Home[num_{patient}] \underset{in, do\_FAST}{\bowtie} Ambulance_{idle}[num_{ambulance}] \\
& \underset{do\_FAST, access\_and\_intestigate}{\bowtie} Stroke\_team_{idle}[num_{stroke}] \\
& \underset{access\_and\_intestigate, CT\_scan}{\bowtie} Scanner_{idle}[num_{scan}] \\
& \underset{CT\_scan, treat\_conservatively}{\bowtie} stroke\_clinician_{idle}[num_{clinician}] \\
& \underset{treat\_conservatively, rehabilitate}{\bowtie} nurse_{idle}[num_{clinician}]
\end{aligned}
$$

Table of Contents

1. Motivation
2. Formal modelling method
3. Simulation and Results
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Simulation

Table1: The action rates and resource numbers in the stroke clinical pathway

Action	do_FAST	access_and_intestigate	scan	treat_conservatively	rehabilitate
Action rate	8	12	8	4	2
Resource	ambulance	stroke_team	scanner	stroke_clinician	nurse
Number	2	2	2	2	10

Performance Evaluation

- Throughput denotes the number of patients the the hospital can serve per day.
- Resource utilization represents the fraction of time that the resource (e.g. ambulance) is busying servicing patients.

Results

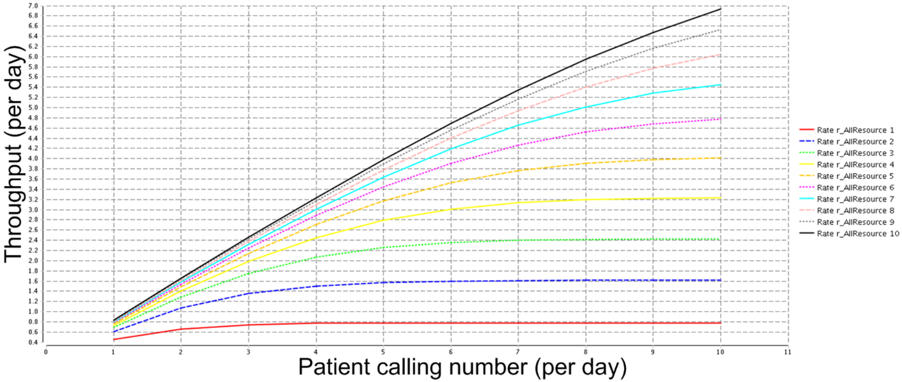


Figure 1: Relationship between throughput and number of resources

Results

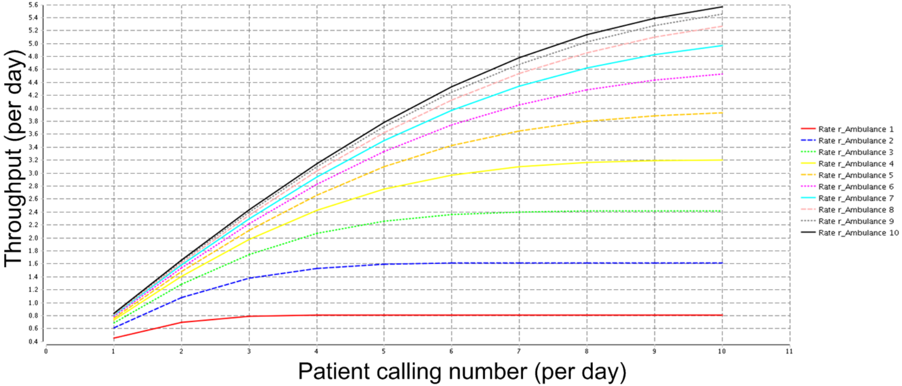
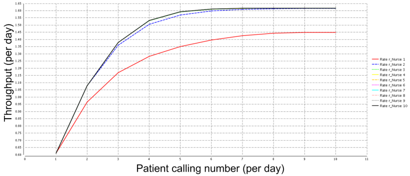
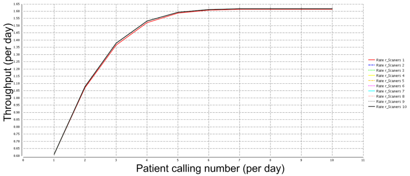


Figure 2: Relationship between throughput and number of ambulance

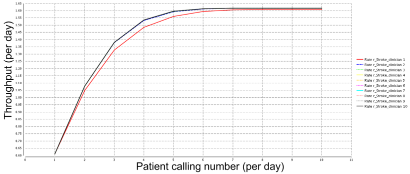
Results



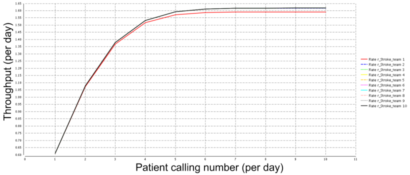
(a)



(b)



(c)



(d)

Figure 3: Relationship between the throughput and resources: a) nurse's number increases; b) scanner's number increases; c) stroke clinician's number increases; d) stroke team's number increases.

Results

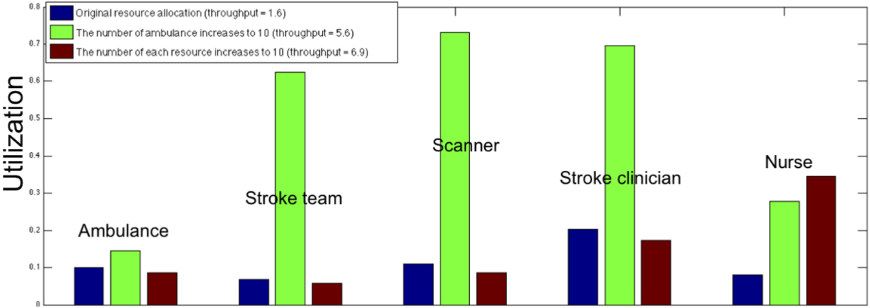


Figure 4: The utilization of each resource

Table of Contents

1. Motivation
2. Formal modelling method
3. Simulation and Results
4. Conlusion

Conclusion

- This paper has presented a novel stochastic model for quantitatively simulating and analysing performance of clinical pathways.
- Based on process calculus, this model can unambiguously describe different aspects of a clinical pathway, thus supporting the simulation and analysis of this pathway.
- A real-world stroke clinical pathway was employed to demonstrate the practical applicability of this performance analysis.
- The experiment shows that the analysis results can assist hospitals to detect the resource bottleneck of their clinical pathway and make an optimal resource selection.

Acknowledgement

- We really appreciate the help from St Mary Hospital for providing us the clinical data, especailly Professor Diana Bilton.
- This work is support by EPSRC ihealth project.