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Optimising the performance of an outpatient setting

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Summary

Background: An outpatient setting typically includes experienced and novice resident physicians who are supervised by senior staff physicians. The performance of this kind of outpatient setting, for a given mix of experienced and novice resident physicians, is determined by the number of senior staff physicians available for supervision. The optimum mix of human resources may be determined using discrete-event simulation.

Methods: An outpatient setting represents a system where concurrency and resource sharing are important. These concepts can be modelled by means of timed Coloured Petri Nets (CPN), which is a discrete-event simulation formalism. We determined the optimum mix of resources (i.e. the number of senior staff physicians needed for a given number of experienced and novice resident physicians) to guarantee efficient overall system performance.

Results: In an outpatient setting with 10 resident physicians, two staff physicians are required to guarantee a minimum level of system performance (42–52 patients are seen per 5-hour period). However, with 3 senior staff physicians system performance can be improved substantially (49–56 patients per 5-hour period). An additional fourth staff physician does not substantially enhance system performance (50–57 patients per 5-hour period).

Conclusion: Coloured Petri Nets provide a flexible environment in which to simulate an outpatient setting and assess the impact of any staffing changes on overall system performance, to promote informed resource allocation decisions.

Key words: Coloured Petri Net; concurrency; conflict; discrete-event simulation; outpatient clinic

Introduction

In an outpatient setting resident physicians are usually supervised by more experienced senior staff physicians. The resident physicians see new patients, record their history, and examine them. Having performed these steps, a resident physician usually consults an experienced senior staff physician who then joins him and discusses medical issues relating to the patient concerned. Resident physicians may be classified as novice and experienced. Experienced residents have undergone several years' training while novice residents have little professional experience. Senior staff physicians therefore spend more time with novice residents when discussing a clinical case. It is to be noted that staff physicians are meant to be clinically fully present and requires the ongoing presence of the team members indicated. This is important to emphasise, since senior staff members often have other duties as well. For example, in a teaching and referral hospital senior staff physicians are usually responsible for teaching and research activities in addition to their clinical duties.

One important question in an outpatient setting is the number of senior staff physicians needed to ensure an adequate turn-round of medical services. When a senior staff physician is being consulted by a resident physician, he is not available for other resident physicians who may need his advice. If there are too few senior staff physicians, the result is unnecessary delays and inefficiencies in clinic performance. It is therefore important to have methods for estimating the required number of senior staff physicians. This represents a human resource allocation problem which one may be tempted to evaluate in a practical study. However, such an undertaking may result in system inefficiencies and unnecessary costs. It would be much more convenient if there were a way to assess system performance without the need to actually implement different strategies in practice beforehand, i.e. a modelling approach that would allow

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us to evaluate the impact of varying the number of senior staff physicians, for a given mix of experienced and novice resident physicians, on overall system performance.

A modelling technique of this kind must fulfil several requirements. First, it must be able to handle concurrency or simultaneous events. For example, when two residents need the help of a senior staff physician and there are actually two staff physicians available, then consultation should occur simultaneously. Second, it must be able to handle conflicts, e.g. when two residents need the help of a senior staff physician and there is actually only one staff physician available, then a choice must be made and one resident physician must wait until a senior staff physician becomes available. Third, it must be able to handle time. That is, it must be able to determine at every point in time the number of resident physicians actually requesting professional advice and the number of senior staff physicians available at that point in time.

Coloured Petri Nets (CPN) is a graphically oriented language for discrete-event simulation which provides a means of modelling systems where concurrency and resource sharing are important. Typical areas of application include military systems, communication protocols, distributed systems and work flow analysis [1]. There are only a few examples which show how CPN can be used to analyse problems in medical sciences: they include the analysis of metabolic pathways or gene regulatory networks [2, 3]. Areas of application in health services research include analysis of careflow management systems [4–6]. However, their use in health care management science is still rare. One reason may be lack of awareness and knowledge of the technique. Another may be the scarcity of user-friendly CPN modelling software on common platforms. The aim of the present paper is to introduce CPN modelling to the medical community by addressing a resource allocation problem in a hypothetical outpatient setting. The question to be answered is: "How many senior staff physicians do we need to support an outpatient setting with ten resident physicians?"

Methods

The model

Our model describes the interaction between resident physicians and senior staff physicians in a hypothetical outpatient setting as shown in Figure 1. Novice residents often need more time to see a patient and experienced residents usually need less. Having seen the patient, the resident physician may call a senior staff physician. If not all staff physicians are already occupied, one of them immediately arrives and discusses the medical issues relating to the case presented. When all senior staff physicians are occupied, the resident physician who seeks professional advice must wait until a senior staff physician becomes available. Senior staff physicians usually spend more time with novice residents than with experienced residents. Moreover, we assume that experienced residents only present every third patient to a senior staff physician. Having consulted a senior staff physician, the resident physician starts seeing the next patient after a given delay representing the time needed to prepare for the new patient. This delay is usually longer for novice than for experienced residents.

Implementing the model

Discrete-event simulation can be used to model discrete changes at variable times in order to mimic a real-world system. The state of a system may change over time as a function of interactions between the simulated entities. We used CPN as a discrete-event modelling environment. For a comprehensive discussion of the pros and cons of CPN we refer to Jensen [1]. A comprehensive listing of available software packages is provided on the website www.daimi.au.dk/PetriNets/tools/. For our study we used the software package Design/CPN (Version 4.0.5 for Linux, Meta Software Corporation, MA, USA) which is provided free of charge.

A CPN model chiefly consists of states and actions. The states of a system are called *places* and are drawn as ellipses. Our model depicted in Figure 1 has four places. The actions in a system are called *transitions* and are drawn as rectangles. Our model has three transitions, as can be seen

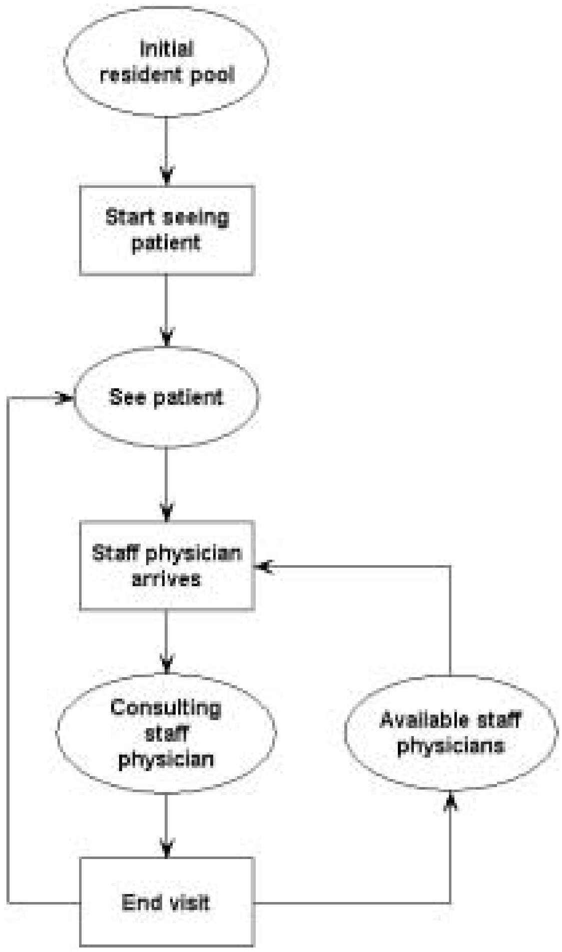


Figure 1

Coloured Petri Net model of an outpatient setting. The ellipses represent states (places) and the boxes represent ations (transitions).

from Figure 1. A CPN's place or transition is also called a node. In Figure 1 we also see arrows, which are called *arcs* and connect a place with a transition or vice versa. The direction of the arc indicates the action needed to convert one state of the system into another state.

The initial pool of available residents is described by the place "Initial resident pool". The transition "Start seeing patients" is used to model residents seeing patients, i.e. a resident who was in the place "Start seeing patients" moves to the place "See patient". The transition "Staff physician arrives" models a resident and a staff physician discussing a clinical case. The action "End visit" transfers the senior staff physician back to the state "Available staff physicians" where he becomes available for other resident physicians. At the same time the resident physician starts seeing the next patients and moves back to the state "See patient" (see appendix for a technical explanation).

In our model we assumed an outpatient setting with 10 resident physicians and analysed two possible mixes of novice and experienced resident physicians. First, we assumed that there were 5 novice and 5 experienced resident physicians. In a second analysis we assumed that there were 3 novice and 7 experienced resident physicians. The outcome of interest was defined as patient throughput, i.e. system performance expressed as number of patients seen over the period of 5 hours (half a day). The number of senior staff physicians varied between 1 and 10 in the analysis. To make our conceptual point, we did not explicitly model all possible mixes of resident and senior staff physicians, as this would only increase the computational burden (110 possible combinations of resident and senior staff physicians) without providing any substantial additional insights into the model.

To measure system performance we must extend the model with a time concept. We model the time required for the different processes as discrete uniform distributions. Novice residents and experienced residents need between 30–75 minutes and 20–50 minutes respectively to see a patient. Novice residents and experienced residents need between 7–45 minutes and 3–15 minutes respectively to discuss a case with a senior staff physician. Finally, novice residents and experienced residents need between 5–20 minutes and 2–10 minutes respectively to prepare for the next patient. The time ranges defined above are based on expert opinion. For simplicity, the time estimates above relate to new patients. More complex schedules could be introduced for a mix of new and follow-up patients.

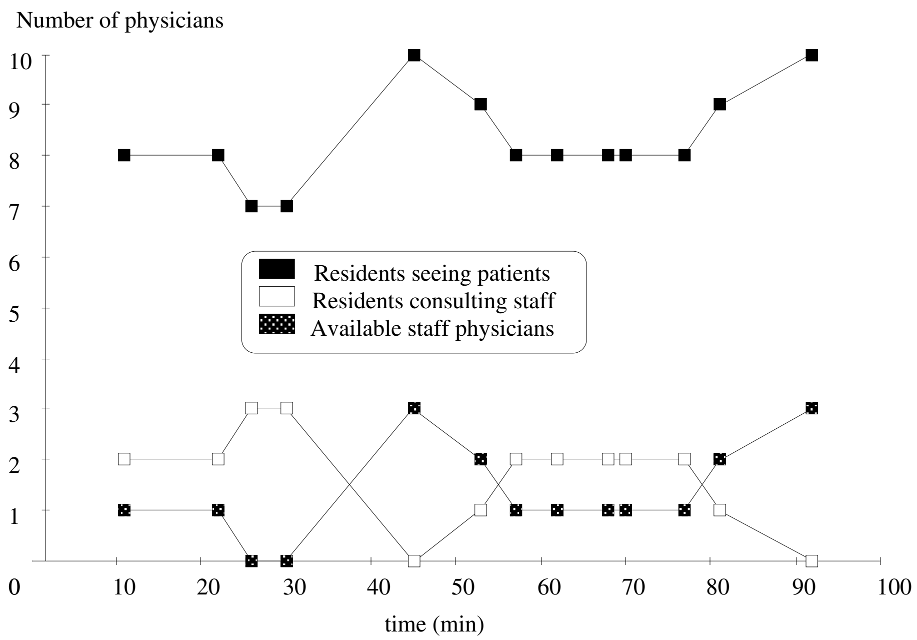
Results

The CPN modelling technique was used to generate Figure 2. It shows how the number of resident physicians and senior staff physicians in the different places change as a function of time. As expected, the curves behave synchronously. That is, whenever the number of resident physicians consulting a senior staff physician increases/decreases, the number of resident physicians seeing a patient decreases/increases and the number of available senior staff physicians decreases/increases.

The performance of the outpatient setting can be measured as the cumulative number of consultations over time (i.e., number of patients seen). If there were ten senior staff physicians available for ten resident physicians, we would achieve the highest possible performance because there would be a guarantee that a senior staff physician would be available at every point in time. However, this is obviously a waste of resources and the same performance may be achieved with a smaller number of senior staff physicians. The cumulative number of patients seen over 5 hours is shown in Figure 3 for a system with 5 novice and 5 experienced resident physicians and one, two, or three senior staff physicians. The time span of five hours reflects half a day where new patients are seen. The number of patients seen increases dramatically with two senior staff physicians compared to only one. The incremental gain with three senior staff physicians compared to two is still substantial. The curves in

Figure 2

The number of physicians in the different states as a function of time. The figure shows how the state of the system may change over time when the model is executed via simulation.



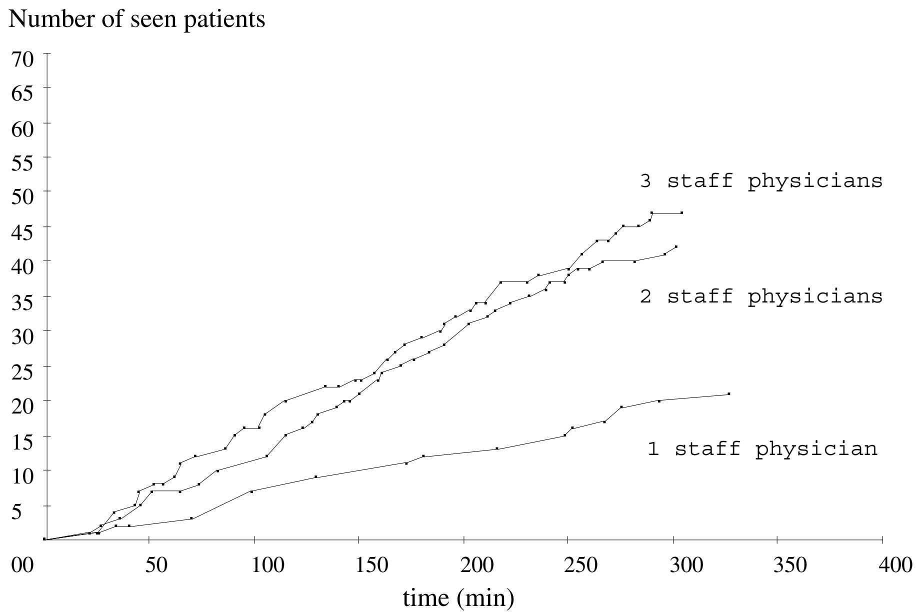


Figure 3

Simulating the number of patients seen in an outpatient clinic with ten resident physicians and one, two or three senior staff physicians. The example includes a mix of five novice and five experienced resident physicians.

Figure 3 are not smooth, since time has been modelled stochastically.

To achieve a stable estimate of the rate of patients seen, 1000000 minutes for the different mixes of senior staff physicians and resident physicians were simulated. The rates expressed as number of patients seen over 5 hours are shown in Table 1. From this table we can see that maximum system performance can also be achieved with four senior staff physicians. Two senior staff physicians are essential and three would be the optimum. A fourth senior staff physician does not seem to be necessary, since the incremental gain in the number of patients seen is only one. It should be emphasised, again, that in our model senior staff physicians are meant to be present solely for clinical duties. In an academic setting senior staff physicians are also engaged in research activities, so that our results actually represent an underestimate of the resources needed for this kind of setting.

Table 1

Performance of the outpatient setting expressed as number of seen patients per 5-hour period.*

Mix of resident physicians	Number of senior staff physicians (SSP)				
	1 SSP	2 SSP	3 SSP	4 SSP	10 SSP
5 novice residents 5 experienced residents	20	42	49	50	50
3 novice residents 7 experienced residents	29	52	56	57	57

* Time span represents a typical morning where new patients are seen

Discussion

In the present paper we have illustrated the basic techniques of CPN modelling using the example of a hypothetical outpatient setting. A body of literature exists regarding hospital staffing. For example, in a study of patient flow in an outpatient clinic by Hashimoto and Bell [7], bottlenecks were identified with the aid of sensitivity analysis, and subsequent operational changes led to a decrease in patient total time in the clinic [7]. Similarly, Clague et al., using computer simulation, examined the impact of varying the structure of an outpatient clinic on patient and doctor waiting times [8]. Other examples where simulation was used for resource planning include a study to determine the optimum capacity of a stroke unit and a recent study evaluating the structure of a family healthcare practice clinic with the aim of improving operating efficiencies and patient satisfaction [9, 10]. However, Coloured Petri Nets have not yet been used to address staffing issues at clinics and hospitals.

Our CPN model is based on several assumptions. It assumes that there are always patients in the waiting room. We ignored the possible temporary situation where no patients are actually seeking help. This assumption is realistic, since waiting rooms are usually filled with patients, i.e. patients usually wait for the doctor. That is, patients were not explicitly modelled in our hypothetical system. However, it would be possible to model incoming patients with time delays. Moreover, the model could be extended to include patient backlog, since CPN are particularly well suited to modelling of queuing systems. Such a model would also allow us, for example, to define patient waiting time as the objective function to minimise. The application of optimisation methods to discrete event simulation models in healthcare planning, however, is a separate matter and should undergo further research. Second, we assumed that a room is available for every resident physician. If the number of rooms is smaller than the number of resident physicians, then this additional constraint could be explicitly modelled as well. However, this would represent a different model and would introduce complexities that are beyond the educational nature of this article. Third, to make our point, consumption of time for the different tasks was based on expert opinion and modelled using discrete uniform distributions. This is useful as a first step and for model verification before a practical study is conducted to elicit the actual time intervals for input into the model. This could be done, for example, with the help of computerised forms. Some hospitals with clinical information systems may even have the input data already available in their computer systems. Fourth, we did not model how much time senior staff physicians spend on other activities when they are not supervising resident physicians. This may depend on the particular setting to be modelled (e.g. senior staff physician in a small hospital versus university hospital) and cannot be generalised. In addition, we have assumed that senior staff physicians do not see patients as resident physicians do, but rather supervise resident physicians. If senior staff physicians were simulated to see patients in the first place, the number of senior staff physicians available for supervision would be reduced, and this could have a negative impact on the performance of the outpatient setting. Moreover, it would represent a different model and would introduce complexities such as equity and differential scheduling, which might complicate the model beyond the educational nature of this article. Finally, one would need to assess model validity by checking whether the output data of the model (number of patients seen) closely resemble the data that would be observed from the actual system. In our study we did not address important aspects of complex systems, such as teaching and university hospitals where residents and in particular senior staff members perform a variety of different duties in teaching and/or research. Nevertheless, the modelling technique presented in this paper may be helpful in planning human resource needs for the clinical services of outpatient clinics.

We believe that CPN are capable of wide application in health services research. Potential areas of use include queuing systems, capacity planning, performance analysis and disease modelling. Discrete-event simulation techniques are becoming more prevalent in the medical literature and CPN in particular may gain in popularity as awareness of this technique increases.

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Appendix

The concept of tokens

In a CPN model, each place may contain markers, which are called *tokens*. The data value of a marker is called the *token colour*. A place may only contain tokens that belong to a specific type, called *colour set*. Colour set is therefore synonymous with data type in traditional programming, and token colour is synonymous with data vale. A colour set may represent data types of any complexity (from a simple Boolean expression to a combination of strings, integers, reals, Boolean, etc.). *Resident* is the colour set attached to the places "Initial resident pool" and "See patient". *Staff* is the colour set attached to the place "Staff physicians", and *Staff_Resident* is the colour set attached to the place "Consulting staff physician". We did not explicitly model patients as tokens, since we assumed that a backlog of patients is always available in the waiting room.

The colour sets of a CPN model must be defined beforehand. The declarations for our model are shown in Table 2. From Table 2 we see that the colour set *Resident* is an enumeration type with the two elements Novice and Experienced. The colour set *Staff* contains only the element staff, which indicates that a token of colour *Staff* bears no information apart from its presence or absence. The colour set *Staff_Resident* is defined as the Cartesian product of the two colour sets *Staff* and *Resident*. This does not mean that two elements are multiplied, but that two elements form a pair. It is also called a tuple construction. The first element of the pair is the constant staff and the second element is either the element Experienced or Novice (since these two elements are listed under the colour set *Staff*).

The distribution of tokens in a model is called a *marking*. The initial distribution of tokens in a model (i.e., the distribution of tokens before a model is executed) is called the *initial marking*. During execution, i.e. when transitions fire, the state of a system usually changes and hence the distribution of tokens will also change. For example, the place "Initial resident pool" only contains tokens (i.e., residents) that have not yet been moved. Once a token of colour *Resident* has entered the system (i.e., has started seeing patients), it will no longer return to the place "Initial resident pool" but to the place "Seeing patient", after a time lag and after the transition "End visit" has fired. The reason for modelling the place "Initial resident pool" is the assumption that there is no delay in time when the resident sees the first patient. Note

Table 2. Colour sets used in the model.

colour Resident = with Novice Experienced timed;
colour Staff = with Staff timed;
colour Staff_Resident = product Staff * Resident;

that the transition “Start seeing patients” is no longer enabled after all tokens of colour *Resident* have arrived for the first time at the place “Seeing patient”. However, simulation of the CPN model continues as long as other transitions are enabled (i.e., “Staff physician arrives” and “End visit”).

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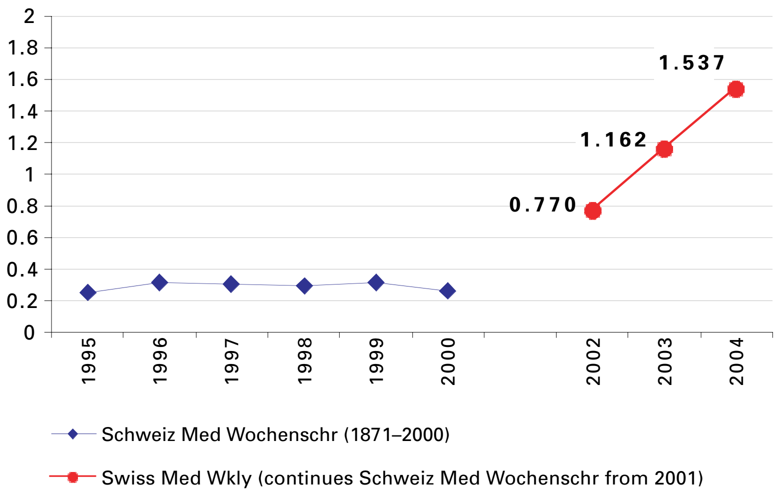

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