Safety and Reliability – Safe Societies in a Changing World – Haugen et al. (Eds)
© 2018 Taylor & Francis Group, London, ISBN 978-0-8153-8682-7

Evaluation of a community pharmacy dispensing process using a coloured Petri Net

M. Naybour & R. Remenyte-Prescott
Resilience Engineering Research Group, Faculty of Engineering, University of Nottingham, University Park Nottingham, Nottingham, UK

M. Boyd
Pharmacy Policy and Practice Research Group, Faculty of Science, University of Nottingham, University Park Nottingham, Nottingham, UK

ABSTRACT: UK customers visited community pharmacies to receive NHS prescriptions 1.104 billion times in 2016. One study of dispensing errors found an error rate of 3.3%. Severe dispensing inaccuracies often receive a high level of media attention, however, lower level errors could also be causing significant inefficiencies in the delivery of primary healthcare. This paper presents a modelling approach for analysing the reliability and efficiency of community pharmacies performance using a Coloured Petri Net (CPN) methodology. The model considers how single prescriptions are processed, the use of staff resources, and the occurrence of errors. The CPN evaluates performance over a set of key performance indicators. Results are validated, where possible, against published studies of community pharmacies.

1 INTRODUCTION

1.1 *Background*

Over the past 50 years there has been a growing awareness that healthcare systems are capable of inflicting harm to patients, and this harm should be reduced (Health Foundation, 2011). Two key reports by the US Institute of Medicine (Mullan et al, 2001) and the UK Department of Health (DoH, 2000) helped to spread the message that iatrogenic patient harm within healthcare systems is an important issue. Notably, if the community pharmacy dispensing error rate of 3.3% (Franklin & O'Grady, 2007) is considered, this could mean that around 36 million UK prescriptions per year contain errors.

As well as safety concerns, studies have shown that patient satisfaction with pharmacy services is linked to waiting times (Afolabi & Erhun, 2003). Extended waiting times have been given as a reason why patients will not return to a particular pharmacy (Somani & Daniels, 1982), and content customers are increasingly likely to return to their specific healthcare provider (Dansky & Miles, 1997).

1.2 *Reliability engineering*

Reliability engineering techniques are used by many industries and it has become common for complex systems to be subjected to risk assessment processes (Andrews, 2009). These assessments have historically been carried out in conventional high risk industries, such as the aviation (Netjasov & Janic, 2008), nuclear (Hsueh & Mosleh, 1996) and space sectors (Garrik, 1988), where effects of failure can be catastrophic.

Fault trees and event trees are an example of a widely used reliability engineering techniques. They use combinatorial logic to combine events to produce both qualitative and quantitative analysis of failures (Vesely et al, 2002). Fault tree analysis requires that the occurrence of events is independent.

Markov models are memoryless processes capable of modelling more complex systems, which might typically contain repair strategies and dynamic behavior (Boyd, 1998). A key limitation to implementing a Markov model for a given system, arises from the fact that the number of system states to consider grows exponentially with the number of components in the system.

Petri Nets are an effective tool for modelling processes or systems exhibiting concurrency (Schneeweiss, 1999). Since the publication of Carl Adam Petri's thesis in 1961, a number of extensions of the basic technique have been developed. Two important examples of Petri Net extensions are timed and Coloured Petri Nets (Jensen, 1996). Timed nets use either deterministic or stochastic delay timings, to control the timing of transitions. This gives the opportunity to model temporal processes. Meanwhile, incorporating token colour sets into Petri Net modelling enables token specific information to be propagated around the net. This can then be used to control and manipulate the nets behavior. Coloured Petri Nets have been utilized to model complex systems in a wide range of areas (Liu, 2017).

The healthcare sector, primary care especially, represents a relatively new area for reliability modelling. Previous healthcare modelling studies have been centred in secondary healthcare settings. In this field, Petri Nets have been used to model hospital departments (Dotoli et al, 2010), hospital information systems (Darabi & Galanter, 2009), and mental health care services (Dammasch & Horton, 2007). Michael R. Cohen et al utilized fault trees to conduct a risk assessment of dispensing in community pharmacies (Cohen et al, 2012), and their error probabilities are also used in this paper.

The novelty of the proposed approach in this paper is the ability to perform safety and efficiency evaluation within the framework of a single modelling technique. Therefore, a timed CPN model is developed and a wide range of performance indicators is obtained, using simulations. Model outputs can be used to support resource management and safety improvement decisions. The community pharmacy dispensing process is presented in section 2, section 3 outlines how the model is built, section 4 presents results and analysis and section 5 concludes the paper.

2 COMMUNITY PHARMACY DISPENSING PROCESS

2.1 *The main stages of dispensing*

A standard community pharmacy dispensing process is described in this section. The six key stages of the community pharmacy dispensing process are given in Figure 1 (Langley & Belcher, 2009 & NPSA, 2007 & Waterfield 2008).

To begin with, prescriptions must be received by a member of staff as and when patients bring them into the pharmacy. Prescriptions are then legally and clinically checked, to ensure that the prescription is clinically appropriate before continuing. After being received, the prescriptions' labels are generated. The labels include key information about the medicine. The next stage of the process is bringing the constituent parts of the prescription together to create the final product. First, the set of items included on the prescription is gathered together from the pharmacy stock. After this, an intermediate accuracy check is recommended, before applying the labels to medicines. After the prescription is fully assembled, it is passed onto either a pharmacist or an ACT (Accredited Checking Technician) to perform a final accuracy check on the prescription. The final accuracy check is the final opportunity for a pharmacy to intervene if a prescription has been dispensed incorrectly at some point in the process. The accuracy check involves making sure that the prescription being provided by the pharmacy exactly matches what has been written on the prescription form. This includes checking that the labels, items, doses, quantities and form of medication are all correct before handing the prescription out. Any mistakes that go unnoticed at the final accuracy check are likely to reach patients. Each stage of the process can be completed by a single member of staff, although, only pharmacists or ACTs are qualified to final accuracy check prescriptions.

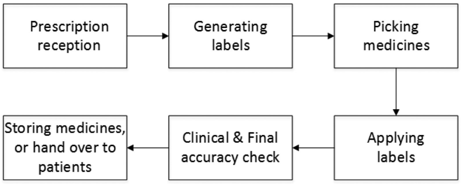

Figure 1. Dispensing process flow chart.

2.2 *Resources*

A typical community pharmacy staff team consists of a group of pharmacists, ACTs and dispensers, but the number of staff varies between pharmacies. Larger stores can have teams of up to 12 people, while the smallest independent store may be run by a single pharmacist. However, for a pharmacy to be allowed to dispense prescriptions, there must be a responsible pharmacist present during all hours of operation.

The full list of resources used in the dispensing process is as follows: prescriptions, dispensers, pharmacists, medicines, labels, labelling stations and a private room.

2.3 *Non-dispensing tasks*

As well as completing dispensing tasks, there are a number of non-dispensing tasks in pharmacies that members of staff are required to complete (Davies et al, 2014). These non-dispensing tasks include, stock management, patient counselling, advanced pharmacy services, non-prescription services, staff training, and general housekeeping. Advanced services are a set of 6 services offered in pharmacies, one example of which is the smoking cessation service.

In this study, the set of non-dispensing tasks requiring to be completed by staff is limited to stock management, advanced services and patient counselling. Although not strictly a task, lunch hours for dispensers are also included in the model.

2.4 *Failure modes*

Dispensing correct prescriptions reliably and in a time that is convenient for customers are the two main goals of community pharmacies. Therefore, the dispensing process can be considered to fail if either:

1. A prescription is incorrect when handed/delivered to a patient.
2. A prescription takes an extended amount of time to be dispensed, causing the patient to decide not to return in the future.

Prescriptions can be incorrect in a number of different ways, for example, the labels may indicate to take too much or too little of the medicine. This would be classified as a labelling error. Other examples include, items being included which are different to those prescribed. This would be classified as a contents error, and it can be due to wrong dose, wrong volume, or being a completely different medicine. Additionally, it may be the case that the labels and items were generated and picked correctly, but they are mixed up when applying the labels, this is classified as a label application error.

If one of the above errors makes it through the final accuracy check and is handed out to a patient, this is then classified as a dispensing error. If however, the error is spotted and rectified at the final accuracy check, this is classified as a near miss (Chua et al, 2003).

2.5 *Definitions: Process reliability and efficiency*

Reliability of the dispensing process, R, is defined in Equation (1) as:

$$R = \frac{p_{cc}}{p_{total}} \tag{1}$$

where p_{cc} is the number of prescriptions dispensed which are completely correct, and p_{total} is the total number of prescriptions dispensed.

Process efficiency is commonly defined as the ratio between an output gained and the level of resources needed to maintain the process. Since the cost of resources is not factored into this study, a set of efficiency indicators are used. Two examples of efficiency indicators are, the total number of prescriptions completed, and the average time to dispense walk-in prescriptions. Results for all performance indicators can be found in Table 4. The ideal outcome of the process in terms of efficiency is a high number of prescriptions completed quickly.

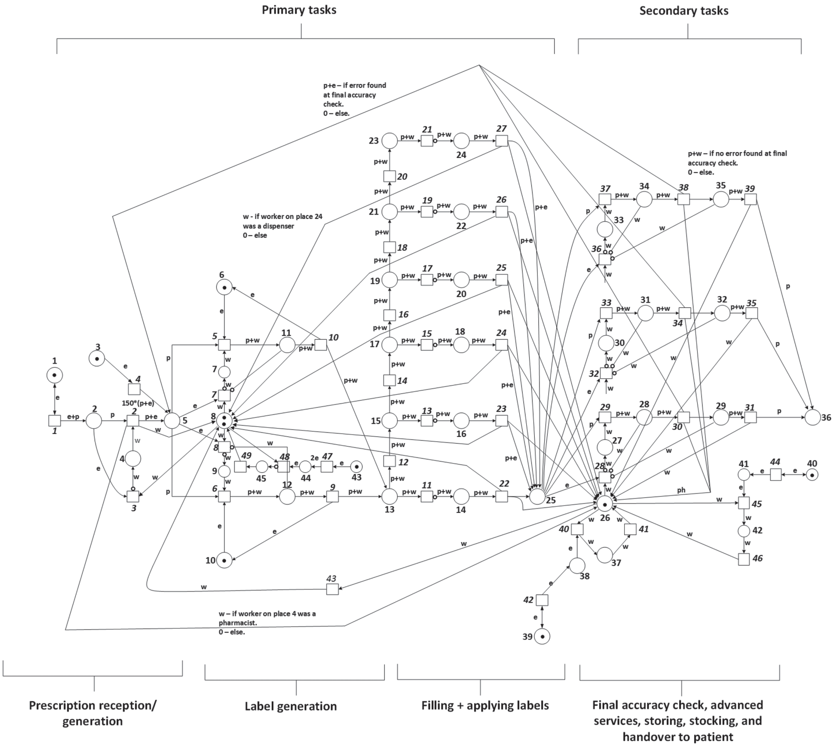

Figure 2. A CPN model for community pharmacy dispensing.

Table 1. Places.

Place	Description	Type
1	Walk-in task generator.	e
2	Customer at counter.	e
3	Delivery task generator.	e
4	Staff receiving.	w
5	Prescriptions to be dispensed.	p, e
6, 10	Labelling stations available.	e
7, 9	Staff member choosing prescription.	w
8	Staff available for primary tasks.	w
11, 12	Staff member generating labels.	w, p
13, 15, 17 19, 21, 23	These places are used to separate staff into parallel work streams.	w, p
14, 16, 18 20, 22, 24	Staff are assembling, and applying labels to prescriptions.	w, p
25	Prescriptions waiting for secondary dispensing tasks.	p, e
26	Pharmacists available to complete secondary tasks.	w
27, 30, 33	Pharmacist allocated to complete secondary tasks for a prescription.	w
28, 31, 34	Pharmacists is checking a prescription.	w, p
29, 32, 35	Pharmacist is handing out/storing for delivery.	w, p
36	All completed prescriptions.	p
37	Advanced service being completed.	w
38	Advanced service waiting.	e
39	Advanced service task generator.	e
40	Stocking task generator.	e
41	Stocking waiting.	e
42	Stocking task being completed.	w
43	Dispenser lunch break generator.	e
44	Lunch break ready to be taken.	e
45	A dispenser is on their lunch break.	w

Table 2. Transitions.

Transition	Description	(Y/N)*
1	Walk in generation: Exp(0.0033)	N
2	Receive a prescription: Uni(30, 60)	N
3	Move staff to counter: Det(0)	N
4	Delivery generation: Det(6000)	N
5, 6	Staff choose prescription: Uni(5,10)	N
7, 8	Allocate a staff member: Det(∈)	N
9, 10	Label generation: Det(15)	Y
11–21	Spreaders: Det(∈)	N
22–27	Filling & label application: N(50,10)	Y
28, 32, 36	Pharmacist allocation: Det(∈)	N
29, 33, 37	Choose prescription: U(10, 15)	N
30, 34, 38	Final accuracy check: Uni(5,10)	Y
31, 35, 39	Hand out and counsel: Exp(0.025)	N
31, 35, 39	Store for delivery: Exp(0.05)	
40	Allocate to advanced service: Det(∈)	N
41	Complete advanced service: Uni(300, 600)	N
42	Advanced service generator: Exp(0.00006)	N
43	Move pharmacist primary: Det(10)	N
44	Stocking task generator: Det(6600)	N
45	Allocate to stocking: Det(∈)	N
46	Finish stocking: Uni(300, 900)	N
47	Begin triggering of lunch break: Det(7200)	N
48	Allocate dispenser to lunch: Det(∈)	N
49	Dispenser finished lunch: Det(3600)	N

*This column designates transitions as processors.

3 MODELLING APPROACH

3.1 *Overview*

This section of the paper presents the development of a Coloured Petri Net (CPN) for modelling the dispensing process. The dispensing process being modelled in this study is that of manual dispensing pharmacy, as opposed to automated dispensing. Figure 2 shows the CPN model of a community pharmacy. Overall, the model is built according to the process flow, considering resources and errors. Model outputs are obtained after the CPN model is simulated.

3.2 *Places and transitions*

Table 1 shows the description of each place and the type of token that may occupy the places. Note that the net uses three token types: e (basic), w (staff), and p (prescriptions).

Overall, some places are used to keep track of resources, and others are used as task generators, controlling when new tasks arrive.

Table 2, shows the description and distribution of each transition. Note that Det(x) stands for a deterministic delay. Some transitions directly represent the community pharmacy dispensing tasks seen in Figure 1. Other transitions are purely used to move tokens around the net. The types of distributions and their parameter values have been assumed in this paper.

In Table 2 each transition is also designated as either a ‘processor’ transition, or not. A processor transition represents a task that is affected by the number of items in the prescription. For example, the transition, modelling generating labels, is a processor transition, since it will take longer to generate labels for a large prescription.

3.3 *Model assumptions*

Tasks in the model are separated into primary and secondary tasks, where primary tasks may be completed by all staff, whereas secondary tasks may only be completed by pharmacists. In addition a number of assumptions about staff behaviour and pharmacy specification are made. Below is a list of modelling assumptions about how staff behave.

- Staff complete tasks in an identical way, i.e. the same probability distributions are used to determine how long tasks take, and to generate error probabilities for different staff.
- Dispensers may only complete primary tasks, and pharmacists prioritise secondary tasks. Pharmacists are able to move to primary tasks if they are idle.
- Once primary work is begun on a prescription, the same member of staff continues working on it until the primary tasks are finished.
- Upon a customer arriving with a walk-in, the first member of staff to become available for primary tasks go to serve them.
- Dispensers have a lunch hour. It is assumed that pharmacists fit their lunch in during moments when they are not working.

Below are assumptions about the labelling stations, pharmacy opening hours, and prescriptions.

- The pharmacy is open from 9 am-5 pm.
- Walk-in prescriptions are prioritised over deliveries. Within the same type, there is a first come first served order. They arrive with increments of an Exponential distribution, as shown in Table 2.
- Delivery prescriptions arrive at the pharmacy in a single large bulk, at 10 am, 1 hour after the pharmacy opens.
- The pharmacy has 2 labelling stations capable of generating labels for prescriptions.
- Walk-ins taking longer than 15 minutes to be dispensed are classed as delayed.

3.4 *Prescription modelling*

In the CPN model, prescription tokens each have 8 colour fields which represent:

1. Delivery or walk-in
2. The number of items
3. Time taken to dispense
4. Number of iterations to compete
5. The overall outcome
6. Label error
7. Content error
8. Label application error

In particular the number of iterations to complete is determined by how many times a pharmacist has had to send the prescription to be corrected after a final accuracy check. The overall outcome is one of 3 outcomes: completely correct, near miss, or dispensing error. The last 3 colours, labels, contents and label application, are Boolean variables, which indicate whether an error of each type is contained within the prescription.

Upon arrival, every prescription is allocated a random number of items by sampling from a Geometric (0.35) random variable (mean = 2.86). This was chosen using two assumptions. Firstly, patients with a prescription will have at least 1 item on the prescription. Secondly, prescriptions with more items are increasingly less likely to occur than those with fewer. This number of items is then used to determine how long the processor transitions, designated in Table 2, take to fire. For example, a prescription containing 5 items will use the sum of 5 samples from the distribution that describes the duration of label generation.

Table 3. Error probabilities.

Task	Error probability
Labelling	0.06
Filling	0.05
Label application	0.03
Final accuracy check	0.05

3.5 *Failures*

Failures are modelled using Bernoulli random variables. At three points of the process, label generation, prescription assembly and label application, an error can occur. The error probabilities were taken from Cohen et al (Cohen et al. 2012), and are shown in Table 3.

The outcome of the final accuracy check depends on the state of the prescription being checked. It is assumed that prescriptions that are correct will always pass through the check. If there is an error present in the prescription, the pharmacist will spot it with probability 0.95, otherwise they will fail to spot it with probability 0.05.

4 PHARMACY SIMULATION SCENARIOS AND THEIR ANALYSIS

4.1 *Scenario specification*

This paper uses three pharmacy scenarios to demonstrate the ability to evaluate performance using the CPN model. These three scenarios have been chosen to demonstrate the impacts, or efficiency improvements, of adding an additional staff member.

a. Scenario 1

Staff – 1 pharmacist, 2 dispensers

Failures—Chance of failure in labelling, filling, label application and final accuracy check stages.

Advanced services—Included.

Stocking—Pharmacist must do 4 stints of stock management, each period lasting 5–15 mins.

Lunch hours – 1 hour for each dispenser, taken sequentially (only 1 dispenser may be off at the same time).

b. Scenario 2

Same as scenario 3, but with 1 pharmacist and 3 dispensers.

c. Scenario 3

Same as scenario 1, but with 2 pharmacists and 2 dispensers.

4.2 *Results and analysis*

A 9-5 day of pharmacy operation was simulated a total of 6000 times for each scenario. A test for convergence was conducted to find whether 6000 was a large enough number to reach convergence. A further 1000 simulations were carried out for each scenario, then the indicator values for the set of 7000 simulations were compared to the values calculated for 6000 simulations. Every field was the same between the two sets of data to 2 significant figures.

Results of key performance indicators for each scenario are shown in Table 4.

Since walk-in (WI) prescriptions are given priority over delivery prescriptions, walk-in prescriptions get completed first, but a smaller pharmacy which takes longer to dispense prescriptions is unable to complete all their deliveries. This can be seen in scenario 1, where 39 of the 150 delivery prescriptions are unfinished. In both scenarios 2 and 3, having an additional staff member of either type (pharmacist or dispenser) improved the efficiency of the pharmacy sufficiently so that on average almost all the deliveries were being completed. This suggests that the pharmacy may be able to complete a larger number of delivery prescriptions when employing 4 staff. The average time to dispense was also improved by more staff in scenarios 2 and 3. A large decrease (of 217s) in the average time to dispense walk-ins was seen when introducing an extra pharmacist in scenario 3. A smaller decrease (of only 75s) was gained by introducing an extra dispenser to the pharmacy team in scenario 2.

Previous studies have reported near miss rates of between 0.024% (Knudsen et al, 2007) and 1.84% (Sanchez, 2013), and dispensing error rates of between 0.014% (Knudsen et al, 2007) and 3.3% (Franklin & O'Grady, 2007). There are many more near misses occurring during the simulations than have been seen in previous studies of errors, i.e. all 3 scenarios had near misses occurring in over 10% of all prescriptions being dispensed. This may be due to underreporting of near-misses in self report based studies, or the final accuracy check failure probability is set too low in the model. The dispensing error rate produced by simulations fell within the reported range.

These simulations suggest that the simulated dispensing process has good reliability. The reliability for scenarios 1, 2 and 3 were as follows, $R_1 = 0.992$, $R_2 = 0.992$, $R_3 = 0.992$. The same reliability for tall three scenarios is due to the fact that the error rates do not depend on the type of staff and pharmacy set-up.

4.2.1 *Distribution of time to dispense*

Figure 3 shows how the distribution of the time to dispense walk-ins depends on the scenario. The duration of 600,000 walk-in prescriptions were used for comparison, i.e. around 100 walk-in prescriptions from each of the 6,000 simulations. It can be seen in Figure 3 that all scenarios have a similar underlying distribution. However the skewness decreases with each additional member of staff. A larger decrease in skew is seen when an additional pharmacist is added. Note that the dashed vertical line represents 15 min dispensing time limit.

4.2.2 *Causes of delays*

A prescription could be delayed due to one of many reasons, such as, prescriptions containing more items taking longer to dispense, delays due to a large amounts of walk-ins already being processed or waiting in the queue when a patient arrives, members of staff being busy with non-dispensing activities, or due to a near miss that has been picked up at the final accuracy check.

Table 5 shows how looking at single scenarios, for more increasingly delayed prescriptions, the average size, and number of iterations required to complete prescriptions increases. This appears to confirm the prospect that prescriptions which contain more items, or need to be dispensed multiple times are more likely to be delayed.

Table 4. Simulation results.

	Efficiency					Reliability		
Scenario	Deliveries completed	Total completed	Advanced services completed	Delayed	WI dispense time mean sec	R	Near misses	Dispensing errors
1	111.1	211	1.8	25.0	711	0.992	29.7	1.6
2	149.4	250	1.8	19.3	636	0.992	32.8	1.9
3	149.5	250	1.8	8.3	494	0.992	32.9	1.9

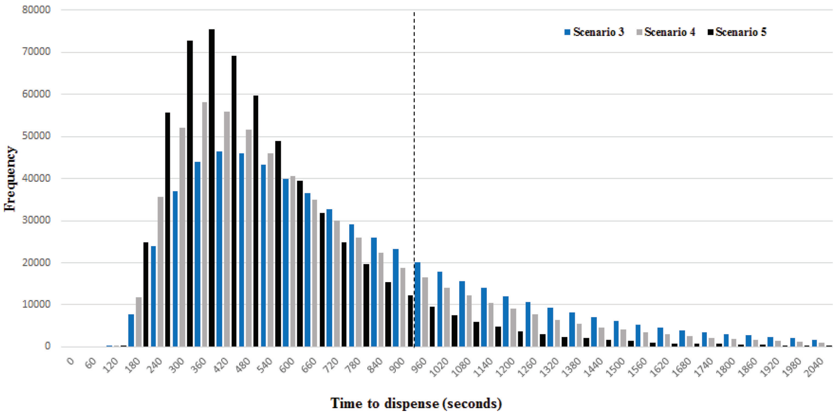

Figure 3. Distributions of the time taken to dispense walk-in prescriptions.

Table 5. Causes of delays.

		$t < 15$	$15 \leq t < 20$	$20 \leq t < 25$	$25 \leq t < 30$	$30 \leq t < 35$	$35 \leq t < 40$	$40 \leq t$
Scenario		mins	mins	mins	mins	mins	mins	mins
1	% of total	75.08	12.64	6.15	3.01	1.49	0.754	0.884
	Avg items	2.37	3.83	4.20	4.49	4.76	5.02	5.79
	Avg itts	0.074	0.226	0.349	0.498	0.673	0.838	1.24
2	% of total	80.66	10.40	4.72	2.17	1.03	0.495	0.533
	Avg items	2.40	4.10	4.52	4.88	5.25	5.70	6.70
	Avg itts	0.0803	0.276	0.425	0.606	0.796	0.997	1.33
3	% of total	91.74	5.27	1.77	0.66	0.295	0.141	0.122
	Avg items	2.50	5.70	6.46	6.57	7.33	8.21	9.51
	Avg itts	0.104	0.485	0.765	1.027	1.232	1.37	1.73

Comparing scenarios, it can be seen that scenarios 2 and 3 offer an improvement in the number of walk-in prescriptions being completed on time. Scenario 3 increased the percentage of prescriptions being completed on time by 16%, while scenario 2 managed an increase of only 5.5%.

5 CONCLUSION

In conclusion, this paper has demonstrated the use of CPNs as an effective tool for modelling the community pharmacy dispensing process. CPN is a suitable tool to evaluate efficiency and safety in one model. Pharmacy dispensing complexity is captured through: the inclusion of all major dispensing stages, their duration, and a variety of staff roles, errors and remedial action. Adding a pharmacist improved the pharmacy efficiency more than adding a dispenser. Dispensing errors are within the range reported in the literature, whereas near misses are overestimated.

Process reliability remained constant in all scenarios. By assigning staff wage costs to scenarios, this model could support decisions related to the cost-benefit of employing extra staff member.

Future work will focus on optimizing a pharmacy dispensing process. This would involve finding the optimal choice of how many staff should work in the pharmacy, given the working conditions and cost of staff wages. Metaheuristics such as, genetic or ant colony optimisation algorithms, are promising methodologies for this purpose. In addition, in-field data collection would be carried out, and ethical approval has been granted by the University of Nottingham. Other routes for future research could include constructing an alternative model capable of comparing the performance of automated and manual dispensing pharmacies. Future iterations of the model could be designed to include the dependency between the overall state of the pharmacy, and staff error rates. For example, if a pharmacy is busy, with many patients waiting for walk-ins to be dispensed, this could put pressure onto staff, who may be then more likely to make errors. Another possible improvement to the model could be to consider how errors of each type, labelling, contents or label application, can actually occur in each item in a prescription.

ACKOWLEDGEMENTS

The authors would like to acknowledge and thank the ESPRC for their support and funding, without which, this research would not be possible (Grant ref EP/M50810X/1).

REFERENCES

Afolabi, M. & Erhun, W. 2003. Patients' response to waiting time in an out-patient pharmacy in Nigeria. *Tropical Journal of Pharmaceutical Research.*

Boyd, M. 1998. An Introduction to Markov Modelling: Concepts and Uses. *Reliability and Maintainability Symposium.*

Chua, S. & Wong, I. & Edmondson, H. & Allen, C. & Chow, J. & Peacham, J. & Hill, G. & Grantham, J. 2003. A Feasibility Study for Recording of Dispensing Errors and 'Near Misses' in Four UK Primary Care Pharmacies. *Drug Safety.*

Cohen, M. & Smetzer, J. & Westphal, J. & Comden, S. & Horn, D. 2012. Risk models to improve safety of dispensing high-alert medications in community pharmacies. *Journal ofAmerican Pharmacists Association.*

Dammasch, K. & Horton, G. 2007. Active Tokens for Modelling Mental Health Care with Coloured Stochastic Petri Net. *2007 Innovations in Information Technologies (IIT).*

Dansky, K. & Miles, J. 1997. Patient Satisfaction with Ambulatory Healthcare services: Waiting and Filling Time. *Hospital and Health Services Administration.*

Darabi, H. & Galanter, W. & Lin, J. & Buy, U. & Sampath, R. 2009. Modelling and integration of hospital information systems with Petri nets. *IEEE/INFORMS International Conference on Service Operations, Logistics and Informatics.*

Davies, J. & Barber, N. & Taylor, D. 2014. What do community pharmacists do?: results from a work sampling study in London. *International Journal of Pharmacy Practice.*

Department of Health Chief Medical Officer, 2000. An Organisation with a Memory: Report of an Expert Group on Learning from Adverse Events in the NHS. *Stationary Office.*

Dotoli, M. & Fanti, M. & Iacobellis & Ukovich, W. 2010. Modelling and management of a hospital department via Petri nets. *Health Care Management Conference.*

Franklin, B. & O'Grady, K. 2007. Dispensing errors in community pharmacy: frequency, clinical significance and potential impact of authentication at the point of dispensing. *International Journal of Pharmacy Practice.*

Garrick, J. 1988. The approach to risk analysis in three indus-tries: nuclear power, space systems, and chemical process. *Reliability Engineering & System Safety.*

Health Foundation, 2011. Health Foundation Research scan: Levels of Harm. *The Evidence Centre.*

Hsueh, K. & Mosleh, A. 1996. The development and application of the accident dynamic simulator for dynamic probabilistic risk assessment of nuclear power plants. *Reliability Engineering & System Safety.*

Jensen, K. 1996. Coloured Petri nets: basic concepts, analysis methods, and practical use. *Berlin: Springer.*

Knudsen, P. & Herborg, H. & Mortensen, A. & Hellebek, A. 2007. Preventing medication errors in community pharmacy; frequency and seriousness of medication errors. *Qual Saf Health Care.*

Langley, C. & Belcher, D. 2009. Applied pharmaceutical practice. *London: Pharmaceutical Press.*

Liu, X. & Zhang, J. & Zhu, P. 2017. Modeling cyber-physical attacks based on probabilistic colored Petri nets and mixed strategy game theory. *International Journal of Critical Infrastructure protection.*

Mullan, Z. & Benham, L. & Cumber, H. & Dehnel, T. & Clark, S. 2011. To err is human. *The Lancet.*

Netjasov, F. & Janic, M. 2008. A review of research on risk and safety modelling in civil aviation. *Journal of Air Transport Management.*

NPSA. 2007. Design for patient safety: A guide to the design of the dispensing environment. *National Patient Safety Agency.*

Schneeweiss, W. 1999. Petri nets for reliability modeling: (in the fields of engineering safety and dependability). *Hagen: Liole-Verlag.*

Somani, S. & Daniels, C. & Jermstad, R. 1982. Patient satisfaction with outpatient pharmaceutical services. *American Journal of Hospital Pharmacy.*

Sánchez, M. 2013. Medication errors in a Spanish community pharmacy: nature frequency and potential causes. *International journal of clinical pharmacy.*

Vesely, W. & Dugan, J. & Fragola, J. & Minarick, J. & Railsback, J. 2002. Fault Tree Handbook with Aerospace Applications. *NASA Office of Safety and Mission Assurance.*

Waterfield, J. 2008. Community pharmacy handbook. *London: Pharmaceutical Press.*