International Journal of Clinical Pharmacy (2024) 46:881–888
https://doi.org/10.1007/s11096-024-01722-0

RESEARCH ARTICLE

Optimisation of medication reconciliation using queueing theory: a computer experiment

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Received: 24 December 2023 / Accepted: 4 March 2024 / Published online: 10 May 2024

Abstract

Background Medication reconciliation (MedRec) in hospitals is an important tool to enhance the continuity of care, but completing MedRec is challenging.

Aim The aim of this study was to investigate whether queueing theory could be used to compare various interventions to optimise the MedRec process to ultimately reduce the number of patients discharged prior to MedRec being completed. Queueing theory, the mathematical study of waiting lines or queues, has not been previously applied in hospital pharmacies but enables comparisons without interfering with the baseline workflow.

Method Possible interventions to enhance the MedRec process (replacing in-person conversations with telephone conversations, reallocating pharmacy technicians (PTs) or adjusting their working schedule) were compared in a computer experiment. The primary outcome was the percentage of patients with an incomplete discharge MedRec. Due to the COVID-19 pandemic, it was possible to add a real-life post hoc intervention (PTs starting their shift later) to the theoretical interventions. Descriptive analysis was performed.

Results The queueing model showed that the number of patients with an incomplete discharge MedRec decreased from 37.2% in the original scenario to approximately 16% when the PTs started their shift 2 h earlier and 1 PT was reassigned to prepare the discharge MedRec. The number increased with the real-life post hoc intervention (PTs starting later), which matches a decrease in the computer experiment when started earlier.

Conclusion Using queueing theory in a computer experiment could identify the most promising theoretical intervention to decrease the percentage of patients discharged prior to MedRec being completed.

Keywords Medication reconciliation · Medication errors · Patient safety · Pharmacy service, hospital · Quality improvement · Quality of health care · Waiting lists

Impact statements

- Queueing theory, the mathematical study of waiting lines, or queues, can be used in the safe environment of a computer experiment to test various interventions to optimise the medication reconciliation process in the hospital pharmacy.
- Strategic decisions on priorities and goals in the medication reconciliation process should be the starting point before choosing interventions to be tested.
- Efficiency measures in the logistic system of medication reconciliation or other pharmaceutical activities and medical implications are closely connected, queueing theory can help to unravel this interaction in future applications.
- A post-hoc intervention due to the COVID-19 pandemic in real-life did not increase the percentage of finalised discharge medication reconciliation, which was also predicted by the queueing model in the computer experiment, although it increased the quality of care.

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Introduction

Medication discrepancies during care transitions, such as hospital admission and discharge, are common and linked with adverse events, such as readmissions [1, 2]. Therefore, medication reconciliation (MedRec) has been implemented [3–5]. MedRec involves building a complete list of a patient's medications, checking it for accuracy, and reconciling and documenting any changes. MedRec was found to effectively reduce medication discrepancies, thereby improving patient safety by reducing clinically relevant medication errors [6, 7]. The aim of MedRec matches that of the World Health Organization's global initiative to reduce severe, avoidable medication-associated harm in all countries by 50% by 2022, with "transition of care" as a key area [8]. Approximately half of the medication errors that occur in hospitals are estimated to occur upon admission or discharge, and approximately 30% of these errors have the potential to cause patient harm.

Several studies have shown that trained pharmacy technicians (PTs) are valuable for MedRec and reducing medication errors [9–13]. However, the implementation of MedRec has been shown to be challenging [10, 11, 14–17]. To collate a thorough medication history, information should be collected via at least 2 different sources [11]. Health records from the community pharmacy are retrieved, and patients or their caregivers are interviewed thereafter. At hospital discharge, medication changes that were initiated during the hospital stay were communicated with the patient. This discharge conversation is often limited before the patient is discharged: patients are sent home before the discharge MedRec is finalised. New methods to improve the MedRec process, especially at discharge, are welcomed.

Queueing theory involves the mathematical study of waiting lines or queues and was first applied in health care in 1952 [18–20]. For example, the effects of no-shows on reducing appointment delays, staff allocation at different points of the patient trajectory in the outpatient clinic, efficiency improvement of an accident and emergency department (A&E), and queue lengths in an outpatient pharmacy system have been investigated [1, 20–23]. There are no publications describing an approach for improving MedRec by using queueing theory. This theory could be valuable for comparing MedRec workflow interventions in pharmacies. The application of queueing theory for this comparison requires modelling assumptions of different promising interventions, such as adjusting the start time of PTs or replacing in-person conversations with traditional or video telephone calls. When applying queueing theory to optimize pharmacy staff allocation, the focus is on the comparison of proportional differences in interventions instead of precise numerical values.

Aim

The aim of this study was to investigate whether queueing theory could be used to compare various interventions to optimise the MedRec process and ultimately reduce the number of patients discharged prior to MedRec completion. Queueing theory has not been used previously in hospital pharmacies but enables comparison without interference with the baseline workflow. Due to the COVID-19 pandemic, it was possible to add a real-life post hoc intervention to the theoretical interventions.

Ethics approval

This study is theoretical and mathematical, and only retrospective anonymous patient data concerning admissions and discharges were used. Individual patient or medication data were not extracted from the hospital information system; therefore, informed consent was not needed from the patients. According to Dutch legislation, this is not required for studies that do not affect patient integrity [24]. Patient data were obtained and handled in accordance with privacy regulations.

Method

Setting

The admissions and discharges data at Hospital Group Twente, a 700-bed general teaching hospital in the Netherlands, were retrospectively studied from November 1, 2019, to January 31, 2020. Individual patient or medication data were not consulted.

Usual care

Usual care and patient trajectories are shown in Fig. 1. Admission MedRec took place in 3 departments: the A&E department, the ward and the preanaesthesia evaluation clinic (PAC). Most nonsurgical patients were admitted to the A&E department. Due to the mental or physical state of the patient upon arrival, time of day or remaining questions, MedRec might be finalised in the ward. Patients awaiting planned surgery are generally assessed in the PAC 1 week to 3 months prior by an (assistant of the) anaesthetist and a PT. After this assessment, MedRec of some patients is repeated once they are admitted because of remaining questions or to check for changes since the first MedRec in the PAC. After treatment on the ward, a discharge MedRec is prepared, and a discharge conversation is held. Patients who did not use medication filled by their outpatient pharmacy or included in the hospital

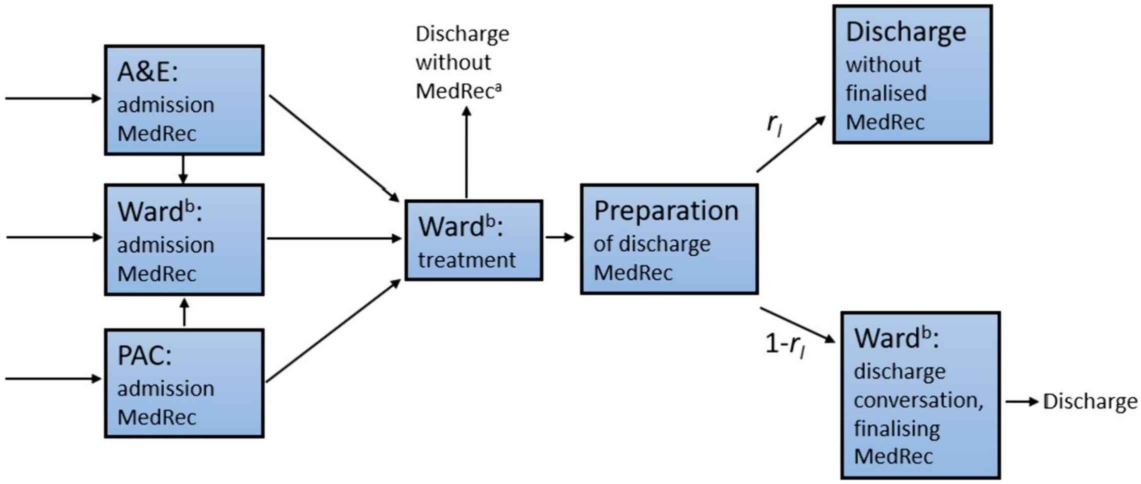

Fig. 1 Model of the medication reconciliation (MedRec) process. A&E: accident and emergency department. PAC: preanaesthesia evaluation clinic. r_l: proportion of the patients leaving the hospital without finalised MedRec. [a]patients excluded from discharge MedRec, e.g. they do not use medication or have given birth. [b]any ward is included

information system, who were admitted for delivery by a primary care midwife, or who were in a severe state that prohibited a conversation were excluded.

All MedRec conversations were held in-person. PTs perform various tasks during the day, for MedRecs altogether 12 full-time PTs (8:00 until 17:30 seven days a week) are needed (see Fig. 1). Four PTs were positioned in the wards for admission MedRec for all eligible patients and completion of discharge MedRec. Three PTs perform admission MedRec to the PAC, 2 PTs admission MedRec at the A&E department and 3 PTs prepare discharge MedRec. Patients are served in order of arrival, i.e., “first come, first served”.

Possible interventions

In a computer experiment, baseline S_0 was compared with 5 possible (what-if) interventions without increasing the number of PTs or working hours.

In intervention S_1, MedRec conversations with patients are replaced by telephone calls under the assumption that telephone calls are less time-consuming than in-person conversations. Three submodels are tested: replacement of all, 75% or 50% of MedRec conversations.

In intervention S_2 a PT is moved from the ward or PAC and assigned to prepare the discharge MedRec. With additional PTs assigned to prepare MedRec, ad hoc discharges can be performed as well. Three submodels are considered for the reallocation of PTs: a PT is moved from the PAC and assigned to prepare discharge MedRec, or a PT is moved from the ward and reassigned to prepare discharge MedRec. In the third submodel a PT is moved from the PAC and assigned to prepare discharge MedRec and not recheck the MedRec form again at the ward. For continuity and quality of care, it is important to treat A&E patients as soon as possible; therefore, reallocation from the A&E is not considered.

Intervention S_3 combines interventions S_1 and S_2: a percentage of in-person conversations are replaced by telephone calls, and PTs are reallocated.

Intervention S_4 tests three submodels, namely, adjusting the working schedule of PTs, starting their shift 1 h later to finish discharge MedRec, or 1 or 2 h earlier for admission MedRec before discharge MedRec starts to queue up.

Intervention S_5 is a combination of interventions S_2 and S_4: adjust the working schedule of PTs and moving a PT from the PAC or ward and assign them to prepare the discharge MedRec; additionally, do not recheck the MedRec of a patient from the PAC at the ward.

Intervention S_6 will be referred to as post hoc intervention, as this intervention was introduced in a later phase as a consequence of changing working conditions due to the pandemic. Based on favourable preliminary results from computer experiments and at the request of the A&E department, the working schedule of the PTs in the A&E department was changed from 8:00–17:30 to 10:30–20:00. This intervention was also compared with the baseline in the computer experiment.

Data collection and classification

Anonymized admission and discharge data were extracted from the hospital information system between November 1, 2019, and January 31, 2020. These data included the admission and discharge dates and time stamps, whether admission and discharge MedRecs were performed, and the age of the patients. Admission and discharge dates and time stamps were used to determine the mean and variance of the length of stay of patients and combined with the working hours of the PTs. Patients were categorised into age classes: children (0–17 years), adults and elderly individuals (75+ years). The adult group, which included the majority of patients, was split into two subgroups (18–49 years and 50–74 years) to facilitate possible calculations in the future. Seventy-five years of age was chosen as the cut off because almost all patients in this group used medication [25].

The age groups were used to determine the time required for MedRec and subsequently to construct the queueing model. The MedRec time needed in each age group was estimated by 3 PTs with more than 30 years of experience each in MedRec. The time required for each patient consisted of 3 parts: preparation for MedRec, walking to the patient and the MedRec conversation, including the correction of the medication in the hospital information system. For a telephone call, the required time decreases as walking is not included, assuming that the patient could be reached on the first attempt.

For the post hoc intervention, additional admission and discharge data were collected 3 months before and 3 months after the intervention: August 2020 until January 2021.

Queueing theory

A queueing model is constructed to predict queue lengths and waiting times. Patients' MedRec requests arrive in the queue, wait until they are processed, and depart from the queue thereafter. In a network of queues, the patient may then enter the next queue on its route, where a new MedRec request may be generated, e.g., a discharge conversation. Patient arrival may be characterised by the theoretical probability distribution of the interarrival times and the MedRec process by the theoretical distribution of the durations of processing patients' MedRec requests. Alternatively, these processes may be characterised by their empirical distributions or by their empirical means and variances.

For numerical evaluation of this queueing model, a queueing network analyzer (QNA) was developed [18, 22]. The QNA is implemented in a computer program and allows for analysis of possible interventions within the safe environment of that computer program. More information on the queueing theory methods is provided in the Supplementary material.

Outcome measures

The outcome measure was the proportion, r_l, of patients who left the ward prior to the completion of the discharge MedRec. PTs start to prepare the discharge MedRec for the next patient after the MedRec for the previous patient is completed. Hence, requests are queued, causing a delay. If the sojourn time (waiting time plus preparation time for MedRec) exceeds the time for patient discharge, then the patient leaves before the MedRec is finalised at hospital discharge (adding to r_l). The computer experiment calculates r_l.

For the post hoc intervention, the overall proportions of admission MedRec and finalised discharge MedRec were calculated for both periods by consulting the hospital information system. Descriptive analysis was performed.

Results

The general characteristics of the patients are shown in Table 1. These data were extracted from the hospital information system and used to construct the computer model. R_l was the lowest in the 50–74 years old age group. The mean length of stay was between 1.9 days (children) and 4.9 days (patients 75 years and older). The r_l almost halved with increasing age, with a mean r_l = 36.9% across all age groups, indicating that 63.1% of patients had MedRec performed at hospital discharge. The time needed for MedRec is shown in Table 2.

Table 3 displays the r_l values obtained from the queueing model for all the scenarios. R_l decreases under all interventions S_1–S_5. It varied between 37.2% for baseline S_0 and 16.0% for the intervention in which the PTs started 2 h earlier and 1 PT was moved from the PAC assigned to prepare the discharge MedRec (S_5). The mean r_l decreased for intervention S_1, ranging, between 32.8% and 35.1%, and for intervention S_2 between 22.8% and 23.3%. In S_3 r_l decreased even further, especially when all conversations were replaced by telephone calls (r_l = 18.6%). The actual value of r_l, 36.9%, is just outside the 95% confidence interval (37.0–37.3%, mean 37.2%) obtained from the queueing model for the baseline scenario S_0.

Intervention S_4 considers the effect of changing the working hours of PTs who perform MedRec. R_l decreases to approximately 30%. Combining interventions S_4 and S_2 further reduced r_l: if PTs start their shift 2 h earlier, r_l decreases to approximately 16%, as observed in the scenario in which 1 PT is removed from the ward or PAC and assigned to prepare the of discharge MedRec.

Post hoc intervention

The additional data gathered for post-hoc intervention S_6, shifting PT working hours to start 2.5 h later in the A&E department, led to an increase in the percentage of admission MedRec, from 50.1 to 61.2%, while r_l increased from 25.7 to 30.4%. The r_l calculated in the queueing model was 37.0%, without an improvement compared to the baseline (Table 3). The real-world percentages calculated in the post-hoc intervention (30.4%) were comparable to those calculated in the modelled scenario (37.0%).

Table 1 Patient characteristics (Nov 2019-Jan 2020)

Age group (years)	0–17	18–49	50–74	≥75	All ages
Number of patients	476	1915	3054	1750	7195
Mean length of stay (days, s.d.)	1.9 (2.8)	2.1 (3.6)	3.4 (4.8)	4.9 (5.7)	3.3 (4.8)
r_l	64.9%	43.1%	33.0%	37.0%	36.9%

r_l: proportion of the patients leaving the hospital without finalised medication reconciliation

Table 2 Estimated time needed for medication reconciliation in minutes

Age group (years)	0–17	18–49	50–74	≥75
Admission A&E department	0.5–22	6–24	13–23.5	13–23.5
Admission ward	1–22	6–24	13–24.5	13–24
Admission PAC	2–18.5	13.5–17.5	13–30	15–30
Discharge				
Preparation	1–14	2–14.5	9–15	7–16
Conversation and processing	2–10.5	5–11.5	6–13	7–15

Time needed for medication reconciliation by telephone is 1 min less

A&E: accident and emergency department

PAC: preanaesthesia evaluation clinic

Discussion

Statement of key findings

In all interventions, the r_l improved from the original situation (37%), varying from approximately 33% for scenarios in which conversations with patients were held via telephone to approximately 16% for combinations of PT reallocation and work hours adjustment. The real-life post hoc intervention showed an increase in r_l, which corresponded with its decrease in the computer experiment when PTs started earlier.

Strengths and weaknesses

The strength of this study is that queueing theory proved to be useful in terms of a decrease in r_l when various scenarios were compared in a computer experiment to thereby support decision-making regarding the MedRec process.

A limitation is the lack of thorough data on the duration of MedRec and the separate components of the process. Medrec duration data were gathered based on the expert opinion of 3 PTs. We assumed that all patients could be reached by phone on the first attempt, which could overestimate the impact of telephone calls compared to in-person MedRec. The time stamps for admissions and discharges were obtained from the hospital information system, and primarily used to support patient care, but are insufficient for mathematic optimisation of the MedRec process, such as actual time stamps. However, r_l is accurately captured by the queueing model: the actual value from the hospital information system is slightly beyond the 95% confidence interval obtained from the queueing model. Note that the focus is on the relative ordering of r_l under different interventions and not on its precise numerical value. Our queueing model approach captures this relative ordering. The workflows before and during the pandemic cannot be adequately compared for various reasons, such as changes in patients ratio.

Interpretation

The most promising intervention should be selected objectively and be well established, for example, queueing theory could be used instead of intuitive arguments. The implementation of the intervention also has practical limitations, such as conversations before 8:00 are unpleasant for patients. For older patients, video calls might be too complicated, while traditional telephone calls lack nonverbal communication. The assumption that telephone calls are less time-consuming has not been proven.

Because of the pandemic, various instantaneous modifications had to be made in the MedRec process. More patients visited the A&E department, and reduced patient contact was pursued temporarily by delegating MedRec to the nursing staff. Telephone call conversations were introduced for MedRec by PTs [26], and in-person conversations were reintroduced later. Based on favourable preliminary results from the computer experiment as well as at the request of the A&E department, the working hours of the PTs in the A&E department were shifted to later. This last modification provided a good opportunity to validate a part of the computer model. This post hoc intervention did not yet prove to be successful at increasing the percentage of finalised discharge MedRec but instead created time in the morning for the preparation of discharge MedRec and thereby possibly improved the quality of care as medication information was available sooner.

Other publications have described the difficulty of optimising the discharge MedRec process [11, 14, 16, 27–29]. Factors that play a role could be distributed across 3 categories: design of the MedRec process, digital infrastructure and resource intensity of the process. The latter can be overcome partly by employing trained PTs, although the

Table 3 Interventions and % unfinalised discharge medication reconciliation

				r_l (95% C.I.)
S_0 original situation				
All MedRec conversations are performed in person				37.2 (37.0–37.3)
Allocation of PTs:				
Ward: 4	PAC: 3	A&E: 2	Discharge preparation: 3	
S_1 in-person conversations with patients are replaced by telephone calls				
50% of the conversations are replaced by telephone calls				35.1 (35.0–35.3)
75% of the conversations are replaced by telephone calls				33.7 (33.5–33.8)
100% of the conversations are replaced by telephone calls				32.8 (32.7–33.0)
S_2 the allocation of the PTs is changed				
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	23.3 (23.1–23.4)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	22.8 (22.7–23.0)
Ward: 3	PAC: 3 Without rechecking patients from PAC at the ward	A&E: 2	Discharge preparation: 4	23.1 (22.9–23.2)
S_3 combination of intervention S_1 and S_2				
50% of the conversations are replaced by telephone calls				21.1 (20.9–21.2)
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	
50% of the conversations are replaced by telephone calls				19.8 (19.6–19.9)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	
50% of the conversations are replaced by telephone calls				21.2 (21.0–21.3)
Ward: 3	PAC: 3 Without rechecking patients from PAC at the ward	A&E: 2	Discharge preparation: 4	
75% of the conversations are replaced by telephone calls				19.8 (19.6–19.9)
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	
75% of the conversations are replaced by telephone calls				19.4 (19.3–19.6)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	
75% of the conversations are replaced by telephone calls				19.7 (19.5–19.8)
Ward: 3	PAC: 3 Without rechecking patients from PAC at the ward	A&E: 2	Discharge preparation: 4	
100% of the conversations are replaced by telephone calls				18.6 (18.4–18.8)
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	
100% of the conversations are replaced by telephone calls				18.5 (18.3–18.7)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	
100% of the conversations are replaced by telephone calls				18.8 (18.6–18.9)
Ward: 3	PAC: 3 Without rechecking patients from PAC at the ward	A&E: 2	Discharge preparation: 4	
S_4 working schedule of PTs is changed				
Working times for MedRec 1 h later				36.9 (36.7–37.1)
Working times for MedRec 1 h earlier				36.3 (36.2–36.5)
Working times for MedRec 2 h earlier				30.4 (30.2–30.6)
S_5 combination of intervention S_2 and S_4				
Working times for MedRec 1 h earlier				22.6 (22.5–22.8)
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	
Working times for MedRec 2 h earlier				16.3 (16.1–16.5)
Ward: 3	PAC: 3	A&E: 2	Discharge preparation: 4	
Working times for MedRec 1 h earlier				22.4 (22.2–22.5)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	

Table 3 (continued)

				r_l (95% C.I.)
Working times for MedRec 2 h earlier				16.0 (15.8–16.2)
Ward: 4	PAC: 2	A&E: 2	Discharge preparation: 4	
S_6 post-hoc intervention				
Working times at the A&E department 2.5 h later				37.0 (36.9–37.2)

Ward: admission MedRec and finalising discharge MedRec

PAC: preanaesthesia evaluation clinic, admission MedRec

A&E: accident and emergency department, admission MedRec

PT: pharmacy technician

MedRec: medication reconciliation

r_l: proportion of the patients leaving the hospital without finalised MedRec

availability of staff and high workloads are still problems. Our mathematical technique provides insight into the process and possible interventions, although no publications are available to compare our conclusions.

Implications for practice and further research

Queueing theory enables the evaluation of the effect of strategic decisions on a process without interference with daily workflows, in contrast to measuring the effect of actually changing working methods in daily practice. Examples of possible trade-offs that may be analysed using this method are as follows. How can we balance admission and discharge MedRec? How will the omission of medication rechecking in the ward reduce the number of patients who leave the ward without finalised discharge MedRec? Such decisions often have medical implications that are determined by the logistical performance of the system. If data from not only the MedRec process but also other PT activities could be added to the model, the allocation of the PTs across different tasks could be made more accurately.

Furthermore, the impact of efficiency measures on the number of finalised discharge MedRec can be evaluated. For example, if there is less ambiguity in the medication list and the list is available earlier, PTs need less time for preparation. The quality of the information and the timeliness of its availability deserve continuous attention.

Conclusion

This study showed that queueing theory can be applied in computer experiments to test the impact of various interventions or combinations of interventions on the number of patients who leave the hospital without a finalised MedRec.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s11096-024-01722-0.

Acknowledgements The authors would like to thank the application managers of Hospital Group Twente for providing data of the MedRec process.

Funding No specific funding was received.

Conflicts of interest The authors have no conflicts of interest to declare.

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