

# Rescheduling nursing shifts: scoping the challenge and examining the potential of mathematical model based tools

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## Rescheduling nursing shifts: scoping the challenge and examining the potential of mathematical model based tools

**Aim** To review research in the literature on nursing shift scheduling / rescheduling, and to report key issues identified in a consultation exercise with managers in four English National Health Service trusts to inform the development of mathematical tools for rescheduling decision-making.

**Background** Shift rescheduling is unrecognised as an everyday time-consuming management task with different imperatives from scheduling. Poor rescheduling decisions can have quality, cost and morale implications.

**Evaluation** A systematic critical literature review identified rescheduling issues and existing mathematic modelling tools. A consultation exercise with nursing managers examined the complex challenges associated with rescheduling.

**Key issues** Minimal research exists on rescheduling compared with scheduling. Poor rescheduling can result in greater disruption to planned nursing shifts and may impact negatively on the quality and cost of patient care, and nurse morale and retention. Very little research examines management challenges or mathematical modelling for rescheduling.

**Conclusion** Shift rescheduling is a complex and frequent management activity that is more challenging than scheduling. Mathematical modelling may have potential as a tool to support managers to minimise rescheduling disruption.

**Implications for nursing management** The lack of specific methodological support for rescheduling that takes into account its complexity, increases the likelihood of harm for patients and stress for nursing staff and managers.

**Keywords:** nursing shifts, rostering, rescheduling, rostering, scheduling

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## Introduction and aims

A daily challenge for nurse managers working in hospital in-patient settings is rostering, or scheduling staff to ensure that safe and effective care can be provided. Staff allocation needs to balance service requirements with fairness and cost effectiveness. Effective schedules

not only provide the required levels and skill-mix of nursing and support staff to ensure optimum care 24 hours a day, but also ensure personnel are not unduly fatigued, perceive work–life balance is considered and contributes to overall staff morale. Irrespective of the quality of any planning, rescheduling frequently occurs due to staff illness, absenteeism,

unforeseen requests to change shifts, or changes to staffing requirements as a consequence of patient care needs. Nurse managers have to respond and this often requires replacement staff to be sought. The urgency can mean that some staff are moved from other duties, reallocated from other wards, or have their planned roster changed at short notice.

Staff fatigue and dissatisfaction are common complaints and both potentially can impact on the quality of care. Excessive alterations to planned rotas can disrupt sleep patterns and invade the personal lives of staff and their families and friends. Increased absenteeism is associated with the number of shift changes made at short notice, as is denial of leave or shift pattern requests (Silvestro & Silvestro 2008). The potential for a spiral of illness and absenteeism to become out of control is normally managed, nevertheless, if unchecked can result in extra costs if temporary staff need to be recruited. The management imperative is to minimise scheduling disruption with ideally no, or few, cost consequences. The net organisational impact of shift rescheduling is a daily, onerous time-consuming task for managers, yet one with the potential to cause harmful disruption if not well managed.

The aims of this paper are threefold: to present a review of the available research relating to in-patient hospital nursing and support staff rescheduling; to report the results of a limited, but nevertheless, illuminating consultation exercise of the real world rescheduling issues faced by nursing managers drawn from four English National Health Service (NHS) Trusts; and to examine the potential of mathematical-modelling tools to support decision-making.

The end objective of the exploratory work presented in this paper is to inform the development, validation and implementation of a mathematical-model based scheduling tool to support managers involved in the rescheduling of nurse shifts for use on a shift-by-shift basis in order to maximise patient care delivery within an unstable resource base.

In the context of this paper, the terms 'rostering' and 'scheduling' are used interchangeably as having identical meanings. The same also applies to the terms 'rerostering' and 'rescheduling'.

## Background

Rostering staff in any organisation is a balancing act between the requirements of the service, and the available staff resource. Shift work has the potential to impact negatively on the quality of life of staff, and ultimately on the productivity and quality of the

services provided. Organisations have different staffing needs and contexts that exert their individual limitations, so that distinct local scheduling approaches develop as a consequence (Ernst *et al.* 2004). For example, in the airline industry aircrew scheduling synchronises flight schedules, aircraft availability, and staff health and safety requirements, whereas call centre activity may be more predictable with identifiable peaks and troughs of activity that can be planned. Most hospital wards have to be staffed 24 hours a day, seven days a week, with a specified minimum number of staff often further complicated by specific requirements in terms of skill or grade mix and competencies.

Poor scheduling decisions carry risks, including adverse effects on the quality of care. Poorly constructed shift schedules can lead to fatigue, which can in turn lead to mistakes and poorer standards of patient care. Rogers *et al.* (2004) found that significant increases in mistakes have been associated with work patterns in which nurses undertake shifts of more than 12 hours, work more than 40 hours in a one week period, stay longer than their scheduled shift, or work scheduled overtime. The number of days a particular shift is worked before changing to another, the length of break between changing shift patterns, and the distribution of days off can impact on an individual's health and productivity at work (Kostreva *et al.* 2002). Over a decade ago the Royal College of Nursing (RCN) reported that nurses working a rotating pattern of day and night shifts were more likely to want to leave the NHS or seek employment in posts with regular working hours.

## Patient care

Poor patient care has been linked with inappropriate skill mix (Goldstein *et al.* 2000, McGillis Hall *et al.* 2004), too few nurses (Taylor *et al.* 1999, Aiken *et al.* 2002) and with shifts 12 or more hours long (Rogers *et al.* 2004). Rafferty *et al.* (2007) and Aiken *et al.* (2012) have demonstrated that these findings are transferable across health systems, and not unique to a particular country or organisation. However, a detailed review of 15 studies by Butler *et al.* (2011) found only very limited evidence that replacing registered nurses with unqualified nursing assistants impacted on patient outcomes. This contrasts with earlier findings by Needleman *et al.* (2002) who concluded that a higher proportion of care hours from registered nurses was associated with a better quality of patient care. Systematic reviews have demonstrated a significant association between nurse staffing levels

and the adjusted odds ratios for hospital-related mortality, failure to rescue, and other patient outcomes (Needleman *et al.* 2002, Kane *et al.* 2007).

### Nurse morale

A link between nurse scheduling policies and nurse morale has also been established (Hegney *et al.* 2006). Too few nurses on a ward (Taylor *et al.* 1999, Aiken *et al.* 2002), working long hours (Rogers *et al.* 2004) and/or working inequitable shifts (Wilson 2002, Dunn *et al.* 2005) all contribute to reduced nurse morale. Dunn *et al.* (2005) found that nurse scheduling ranked third highest out of ten factors that could improve nurse morale, after quality of patient care and relationships with other nursing staff. Offering some choice about the shifts that individual nurses work can improve the perception of fairness associated with shift allocation, which in turn impacts on morale and has an overall positive effect on staff well-being (Pryce *et al.* 2006).

### Cost of care

The over-staffing of wards (Newbold 2008) and the use of bank or agency staff (Silvestro & Silvestro 2008) directly increases costs. Increased indirect costs are incurred by longer patient stays as a consequence of poor patient care (Kane *et al.* 2007, Thungjaroenkul *et al.* 2007), high levels of staff turnover (Jones 2005, 2008, Hayes & Bonner 2010) and staff absenteeism (Silvestro & Silvestro 2008). Hospital costs are reduced when better patient care is delivered. Hence, there is a direct relationship between costs, length of patient stay, levels of complications (McCue *et al.* 2003, Rothberg *et al.* 2005) and appropriate ward staffing levels (Kane *et al.* 2007, Thungjaroenkul *et al.* 2007). When staff turnover is lowered (Jones 2005, 2008) and there is lower absenteeism (Silvestro & Silvestro 2008), reduced indirect costs ensue.

Figure 1 summarises the research evidence illustrating the links between poor scheduling, poor patient care, nurse morale, reduced patient satisfaction, cost effectiveness and ultimately poor hospital performance. The unique challenge exerted by rescheduling and its impact has received less attention and remains unsupported by a clear understanding of its nature, consequences and how to respond managerially.

### Evaluation of the literature

This review focuses specifically on rescheduling in the context of managing the nursing staff resource to

maintain effective care delivery in hospital in-patient settings. The review was undertaken in order to synthesise the existing understanding of the processes involved and outcomes of rescheduling on patient care, staff morale and cost, and to identify gaps for future research involving mathematical modelling tools.

### Method

A search for articles containing the terms 'nurse rostering', 'staff rostering', 'nurse rescheduling' and 'staff rescheduling' was carried out by the fourth author and reviewed by the first. The search used the CINAHL Plus and MEDLINE databases, multiple scientific databases via the SCIRUS search engine, 58 databases in the areas of health and social care accessed through the University of the West of England (UWE) library and finally across the Internet using Google Scholar.

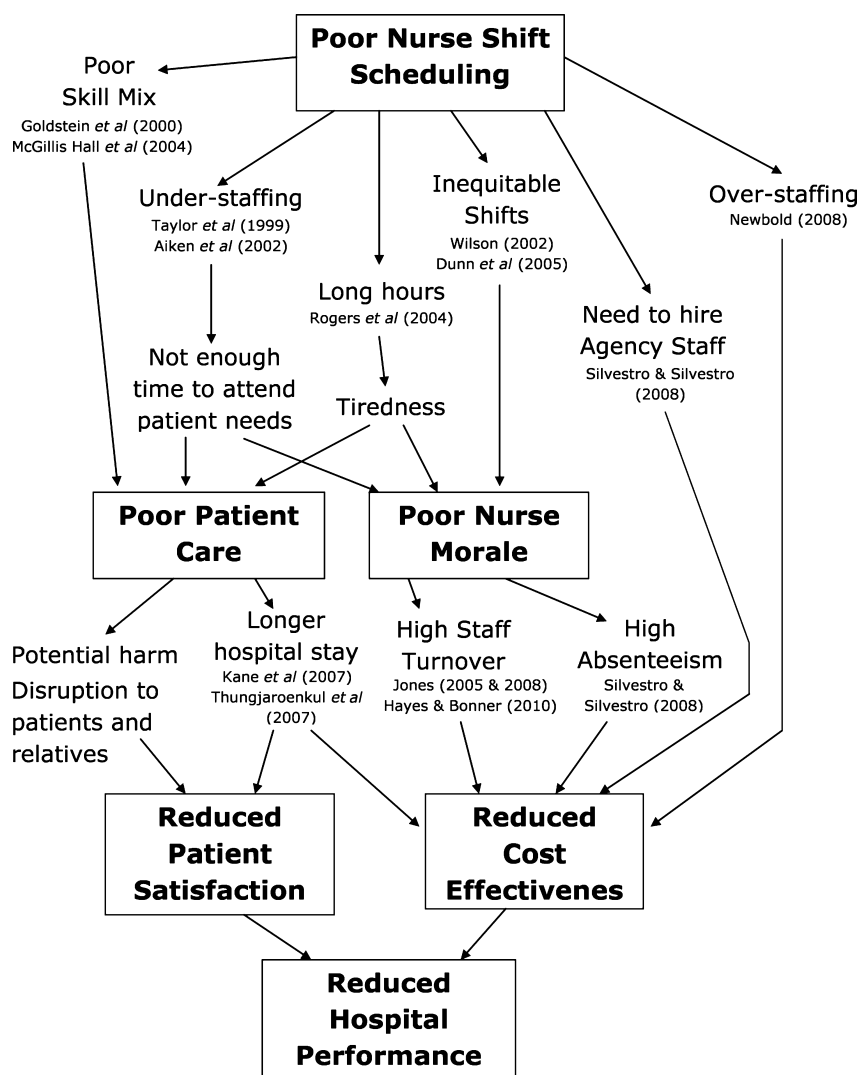
### Selection criteria

To be included in the review, articles had to relate to nurse scheduling or rescheduling, be published in peer-reviewed journals or conference abstracts, and be available in English. To ensure quality, only articles from peer-reviewed journals and conferences were accepted. Articles published before 1980 were not included. Articles thus accepted were then searched for citations to find further articles. All articles were manually screened to determine whether they met the inclusion criteria.

### Scheduling results and analysis

First of all, a similar search on scheduling was carried out using the phrases 'nurse rostering', 'staff rostering', 'nurse scheduling' and 'staff scheduling' in order to compare the number of rescheduling articles found with those on scheduling. An initial search produced 1348 articles with one of the four search phrases in the title, as shown in Table 1. By considering only those that discussed tools or models for nurse scheduling, this number was reduced to 299 articles. Further inspection and reading showed that just 61 of these articles directly considered nurse scheduling (as opposed to mentioning it in articles about other topics). This radical reduction relied heavily on the authors' past experience in this field.

Scheduling models and systems designed for health-care settings need to take account of the many



**Figure 1**  
The consequences of poor staff scheduling.

**Table 1**  
Initial search phases and sources with the number of articles found

Phrases in the title	Google scholar	CINAHL plus	MEDLINE	UWE library	SCIRUS	Total
Nurse scheduling	328	9	1	46	239	623
Staff scheduling	200	18	30	52	177	477
Nurse rostering	11	6	7	28	161	213
Staff rostering	0	2	3	6	24	35
Total	539	35	41	132	601	1348

constraints (Cheang *et al.* 2003) and local differences between wards (Malone *et al.* 1997), particular characteristics and needs of teams and individual staff members. To support this complex decision-making, a number of mathematical models have been developed, for example, Berrada *et al.* (1996) and Jaumard *et al.* (1998). Most authors agree that the complexity of scheduling makes mathematical precision difficult,

which has led to the use of hybrid mathematical and computer-science approaches (Aickelin & Dowsland 2000, 2004, Aickelin & White 2004, Brucker *et al.* 2005).

Fairness, the notion of equitable distribution and balance between individual requests and the allocation of popular and unpopular shifts has been linked with staff satisfaction and morale (Wilson 2002, Dunn

*et al.* 2005). Aickelin and Dowsland (2000, 2004) accommodated fairness using a schedule constructed from predefined shift patterns. Each pattern was assigned a preference rating for each individual nurse, calculated as a weighted sum of a number of factors and agreed in consultation with the ward manager. Bard and Purnomo (2005a,b) used mathematical models to identify acceptable levels of concession between managed and self-scheduling rostering approaches. Their model was developed with a limited number of 'candidate' shift schedules based on nurses' preferences or, if unavailable, a template based on the individual nurse's contract. The model quickly identified good quality schedules when tested on real and derived data with few preference violations (requests to change shifts) and a reduced dependency on temporary relief, bank or agency staff.

A review of research-based scheduling systems by Kellogg and Walczak (2007) found that less than 30% were implemented. Moreover little empirical evidence informed commercially available systems. They concluded that academic/commercial alliances would enhance nurse scheduling tools provided to hospitals. The range of mathematical and computational techniques used to model nurse scheduling is not the focus of this article and has been well reviewed elsewhere (Tein & Ramli 2010, Clark & Walker 2011). Rather the focus is the more complex problem of rescheduling. A key finding was that, irrespective of the effectiveness of the research-based or commercially

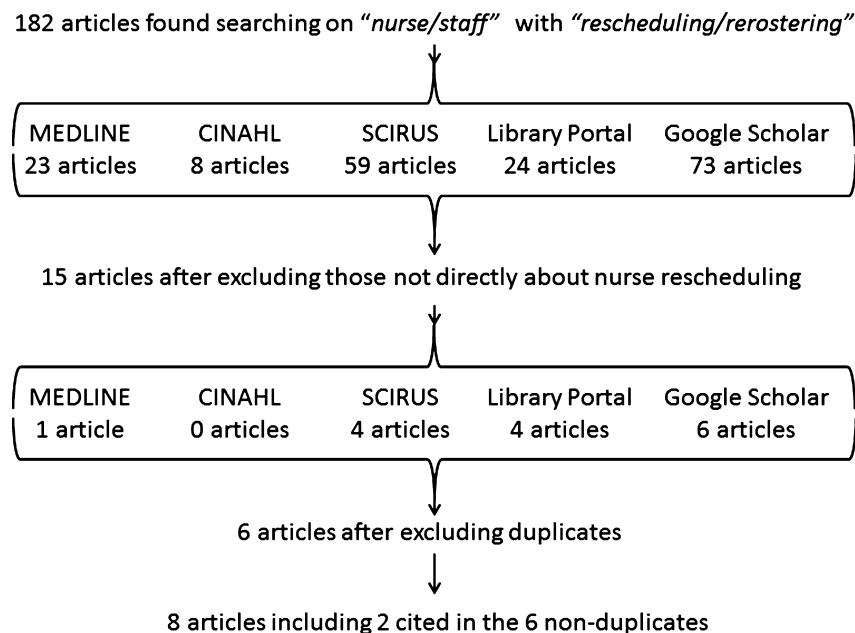
available rostering system, invariably management time and stress associated with rescheduling persisted, and these systems did little to reduce this burden (Bailyn *et al.* 2007).

## Rescheduling results and analysis

The search for research on nurse rescheduling initially yielded 182 articles. On the basis of number of published outputs alone, rescheduling appears to have received much less attention compared with scheduling.

Figure 2 illustrates the rescheduling search process and results. On analysis of the abstracts of the 182 articles identified, only 15 directly considered the problem of nurse rescheduling and these were included initially in this review. The excluded articles approached nurse rescheduling in relation to other activities (such as vaccination rates, the scheduling of non-nursing staff, the hospitalisation of children and post-discharge patient care) rather than the rescheduling of the nursing workforce shifts. After removal of duplicates only six articles remained, hand searching yielded a further two articles. All the remaining articles had been published between 2003 and 2011.

The eight articles relating to rescheduling are described in Tables 2 and 3. All eight papers present the algorithms used to solve rescheduling challenges and are aimed at a technical mathematical computing audience. Only the work by Bard and Purnomo (2006) has been used in hospitals in both the USA and



**Figure 2**  
Rescheduling search process and results.

**Table 2**

The eight rescheduling articles identified

<i>Authors</i>	<i>Title</i>	<i>Journal</i>
Moz and Pato (2003)	An integer multicommodity flow model applied to the rostering of nurse rosters	<i>Annals of Operations Research</i> <b>119</b> , 285–301
Moz and Pato (2004)	Solving the problem of rostering nurse rosters with hard constraints: new multicommodity flow models	<i>Annals of Operations Research</i> <b>128</b> , 179–197
Bard and Purnomo (2006)	Incremental changes in the workforce to accommodate changes in demand	<i>Health Care Management Science</i> <b>9</b> (1), 71–85
Moz and Pato (2007)	A genetic algorithm approach to a nurse rescheduling problem	<i>Computers and Operations Research</i> <b>34</b> (3), 667–691
Pato and Moz (2008)	Solving a bi-objective nurse rescheduling problem by using utopic Pareto genetic heuristics	<i>Journal of Heuristics</i> <b>14</b> (4), 359–374
Kitada <i>et al.</i> (2010)	A heuristic method in nurse rostering following a sudden absence of nurses	<i>Proceedings of the 11<sup>th</sup> Asia Pacific Industrial Engineering and Management Systems Conference</i> , Manila.
Maenhout and Vanhoucke (2011)	An evolutionary approach for the nurse rostering problem	<i>Computers and Operations Research</i> <b>38</b> , 1400–1411
Clark and Walker (2011)	Nurse rescheduling with shift preferences and minimal disruption	<i>Journal of Applied Operational Research</i> <b>3</b> (3), 148–162

**Table 3**

Rerostering article information

<i>Authors</i>	<i>Country</i>	<i>Technique</i>	<i>Technique tested using</i>	<i>Put into practice?</i>	<i>Usability considered?</i>	<i>Type of unit</i>
Moz and Pato (2003)	Portugal	Mathematical optimisation	Real data from a Lisbon hospital	No	No	N/A
Moz and Pato (2004)	Portugal	Mathematical optimisation	Real data from a Lisbon hospital	No	No	N/A
Bard and Purnomo (2006)	USA	Mathematical optimisation	Synthetic data	Yes	Yes	400-bed intensive care unit with 80 nurses
Moz and Pato (2007)	Portugal	Intelligent computerised search	Real data from a Lisbon hospital	No	No	N/A
Pato and Moz (2008)	Portugal	Intelligent computerised search	Real data from a Lisbon hospital	No	No	N/A
Kitada <i>et al.</i> (2010)	Japan	Intelligent computerised search	Real data from a Japanese hospital	No	No	N/A
Maenhout and Vanhoucke (2011)	Belgium	Intelligent computerised search	Synthetic data	No	No	N/A
Clark and Walker (2011)	UK	Mathematical optimisation	Synthetic data	No	No	N/A

UK, although no subsequent published evaluation has been found. This highlights the problem that research on rostering tends to be of a theoretical mathematical nature and has not yet produced any evidence that model-based tools can assist managers tasked with resolving staffing shortfalls.

The key principle underscoring rescheduling decision-making is to minimise any disruption caused to the previously published schedule, whilst maintaining quality nursing cover. This is the imperative considered by all eight articles in Tables 1 and 2.

Moz and Pato (2003, 2004, 2007) describe attempts to minimise change to the original schedule as far as possible. Their three papers are mathematics or computer-science focused and provide few details about the hospital in Lisbon, Portugal, that motivated their research. Their eventual aim was to supply nurse managers with rapid high quality rescheduling, but the papers do not provide any information on the practical implementation of the research.

Bard and Purnomo (2006) addressed a different rescheduling problem that they term ‘reactive scheduling’



whereby the 24-hour shift cycle is reviewed at a specific time. They began with a 6-week base schedule and then reviewed each shift a couple of hours prior to its start, and made amendments where necessary. Their method could reschedule up to 200 nurses and gave the nurse manager a set of options that included rescheduling and employing part-time or external staff. This was the only one of the eight articles described in Table 2 that reported the outcomes of implementation in a hospital setting. Unfortunately no follow-up report has been found describing the impact of the system on patient care outcomes or staff morale.

Kitada *et al.* (2010) and Maenhout and Vanhoucke (2011) developed and numerically tested intelligent computer search methods. The emphasis of both papers was on the algorithmic nature of the heuristic. Kitada *et al.* (2010) did not consider any operational aspects of how effective it might be in practice. This limitation is also the case for the Maenhout and Vanhoucke (2011) who emphasise their method's high-quality numerical results with benchmark datasets from the research literature, rather than testing it in a hospital.

Lastly Clark and Walker (2011) used mathematical programming models to produce rosters. They developed a disruption matrix that could be used to maintain some continuity with the original schedule, creating less disruption to nurse's preferences and planned individual rosters. Their emphasis was on models that can be solved with industry-standard commercial optimisation software that is fast enough for operational use; however, their models have yet to be validated in practice.

## Consultation exercise

Our search methods identified no research literature that provided insight into the perspective of managers involved in staff rescheduling. To overcome this omission we approached four different NHS trusts (a medium sized secondary and community care provider, a large inner city Teaching Hospital and a mental health organisation providing a range of in and out reach services to rural and urban populations) better to understand the managerial day-to-day burden presented by rescheduling at a ward, unit and organisational level. This exercise could best be described as fact finding with potential end users (nurse managers) and did not adopt formal research methods. It therefore fell outside the requirements for NHS research ethics and governance (National Patient Safety Agency 2009), however, every attempt to follow principles of good research practice were made. We spoke with executive nurses ( $n = 2$ ), managers involved in resolv-

ing staff shortages at unit or site level ( $n = 2$ ) and ward managers ( $n = 3$ ) across the four organisations. Our discussions focused on what they saw as the daily challenges associated with rostering and their solutions and these were captured in notes. No attempt was made to obtain a representative sample, as this exercise was intended to define the nature and scope of the problem prior to designing a more substantive research project and ultimately prototype. The following summarises the key issues raised by the seven managers who participated in those discussions.

- 1 Nurse scheduling was a recognisably strategic concern due to a perceived clear relationship between appropriate levels and skill-mix of staff, quality of patient care and cost implications of poor rescheduling decision-making.
- 2 Unfilled rostered shifts were seen as a risk with potential for negative consequences if emergency situations arose, contributing to the number of adverse events, failure to retrieve deteriorating patients, infection rates and staff morale.
- 3 Time spent preparing monthly scheduling was already a time consuming management role (e.g. a day a month), yet rescheduling activity was a daily organisational activity and could take up a significant amount of a ward and hospital manager's time.
- 4 Rostering required speedy and sometimes immediate decision-making.
- 5 If rescheduling was required, then a ladder of decision-making and accountability ensued as follows:
  - a Evaluate whether the ward/unit could manage with the shift unfilled.
  - b Fill vacant shifts with staff familiar with the environment:
    - i Invite existing staff to work additional hours (paid/time in lieu),
    - ii Approach off duty staff to change shifts,
    - iii Ask specific staff known to accommodate late requests to work.
  - c Ask the next tier of management to identify relief staff from elsewhere in the organisation.
  - d Approach a staff bank at additional cost, recognising that like-for-like replacements are unlikely to be available.
  - e As a last resort, bring in agency staff, an expensive option that most managers try to avoid. However, Snow (2012) suggests that use of agency staff is increasing as there is less 'slack' in the system to accommodate options (a) to (d).

The managers perceived that staff felt reasonable rescheduling was fair and inevitable. Urgent short-notice off-duty requests were often the most difficult to meet, and increasingly requests for preferred shifts were challenging. The difficulty of finding staff resources within the preferential nature of the rescheduling decision process was very different to that for one-off scheduling.

These insights, in common with the nurse rostering and scheduling literature, suggest that rerostering impacts on quality, costs and morale. In addition, the burden of rescheduling decision-making was characterised as both time consuming and demanding urgent attention. Ward managers who participated described typically spending approximately one day a month producing the schedule, with some senior managers then spending 10–20% of most working days rescheduling to cope with absenteeism and changes in the staff required.

The decision-making described in 5 (a)–(e) above reveals the uniqueness of rescheduling when compared with scheduling. It also illustrates the potential value for managers of effective methodological support that could accommodate the complexity required for staff rescheduling.

Our consultation exercise also revealed that automation of scheduling processes was variable across trusts. At one trust scheduling software was trialled but the staff did not perceive any advantage in using it and so the paper based system was retained. A second organisation had introduced nurse scheduling software, but due to the lack of training and support, its adoption has been poor, and most areas were still using a paper-based system. A third trust had trialled a system but could not find the financial resource to invest in a contract. Only one trust had introduced nurse scheduling software across all areas. These anecdotal accounts mirror the findings about uptake of automation described in the published literature (Bailyn *et al.* 2007, Kellogg & Walczak 2007). More pertinently to this paper, while some systems offer mathematical optimisation support for staff scheduling (Brucker *et al.* (2005), no automated systems were identified that specifically support the unique nature, and complexity of rescheduling decision-making processes for nursing staff.

## Key issues

The most important issues to emerge from the analysis are as follows:

- 1 Nurse scheduling carries risk and is a strategic issue with implications for the quality of care, staff morale and retention, and the cost of care.
- 2 Short-term rescheduling is a frequent, almost daily, activity.
- 3 To be effective, rescheduling needs to accommodate additional factors beyond those considered in the original schedule, namely to keep to a minimum the disruption from the shift patterns already rostered for individual staff. In rescheduling this often becomes a ward, unit and organisation imperative not merely confined to one staff team in isolation, unlike initial scheduling.
- 4 Ineffective rescheduling can impact on the quality of care, damage staff morale and increase the cost of care, compared with the original staff schedule.
- 5 There is currently little mathematical or computational support for rescheduling. In practice, it is an informal task although a skilled activity that can occupy a significant proportion of ward and senior managers' time.
- 6 Existing computer-aided systems for scheduling do not explicitly consider rescheduling.

The analysis has shown that, while staff scheduling is a strategic concern for managers, rescheduling is an even bigger issue due to the greater number of factors involved and its operational urgency. No methodological automated support is currently available. The research on rescheduling is exclusively mathematical or algorithmic, but none of the proposed methods has been operationally evaluated in practice. There is no research literature on the implementation, validation or managerial aspects of rescheduling methodologies; hence our consultation exercise with managers was a rich and valuable source of real world information.

## Discussion and implications for nursing management

This analysis identified serious implications for nursing managers. We have found that rescheduling is a strategic issue that impacts on the quality of care, its cost, staff morale and consumes significant managerial time. The lack of specific methodological support that takes into account the complexity of rescheduling increases the likelihood of harm to patients and stress for nursing staff and managers.

These considerations motivate the development of mathematical support to assist managers in rescheduling staff. Clark and Walker (2011) proposed a model for purpose, but it requires testing in hospital settings in order to evaluate its potential. The results of this review of the literature and consultation exercise



suggest that research is needed to answer a number of questions in order to inform an operable system. These include:

- 1 How can progress from paper-based or informal rescheduling to using mathematical support be best conducted in order to improve and speed up day-to-day rescheduling decision-making?
- 2 How automated should such support be? – as any new system should not add an unnecessary additional burden on users. Specifically, should any support be added to provide additional intelligence to already populated spreadsheets? – given that managers are familiar with this technology and the way of presenting information to inform decision-making. Or should it involve the use of specialist software that may require user support but offer greater specificity for problem-solving?
- 3 What are the human issues including risk management and error minimisation?
- 4 What end-user support and training would managers require?
- 5 How could a feasibility study be undertaken to identify possible (dis)benefits of mathematical support for rescheduling to improve manager and organisational productivity?

## Conclusions

The review of the literature showed that very little research has been conducted on nurse shift rescheduling. The limited research so far has been based on mathematical-modelling and computer-search approaches that have yet to be tested in operational practice. The scoping exercise with nursing managers clearly indicated that it is a regular and time consuming management activity which is more complex and challenging than one-off scheduling. Poor rescheduling decision-making is perceived to have serious implications for patient safety, cost minimisation and staff morale.

There is thus potential for a tool to support nursing managers to manage service disruption and to minimise its impact. Mathematical modelling could fill this gap by capturing some of the quantitative complexity and providing optimised decision advice for managers to use in conjunction with their own experience and judgement. The effectiveness of such a tool should be demonstrated using staffing data, before and after its introduction, to calculate metrics on ward skill mix, understaffing, overstaffing, hours worked and the frequency of hiring bank and agency staff. Before and

after staff surveys should be used to gauge the fairness of the rescheduling tool.

In summary, rescheduling, the activity that occurs when individual rostered staff unexpectedly become unavailable, is a frequent and difficult challenge in healthcare organisations despite good planning. A mathematical decision-support tool would help managers to make considered, operationally robust and speedier rescheduling decisions.

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