The nurse rerostering problem: An explorative study

M. Mutingi[1,2] , C. Mbohwa[2]
[1]Faculty of Engineering
Namibia University of Science & Technology
Windhoek, Namibia

[2]Faculty of Engineering and the Built Environment,
University of Johannesburg, Johannesburg, South Africa
mmutingi@nust.na, cmbohwa@uj.ac.za

Abstract

Oftentimes, hospitals encounter disruptions of nurse schedule due to unforeseen absence of nurses from their scheduled shifts. Known as the nurse rerostering problem, this problem is commonplace in most hospitals all over the world. In such uncertain environments, decision analysis need to reconstruct the roster, ensuring minimal changes on the original roster, subject to reported disruptions. Service quality, staffing requirements, management goals, as well as nurse preferences have to be satisfied as much as possible. The rerostering decisions taken have implications on staff morale, service quality, and costs incurred. Thus, the problem is of critical importance to the healthcare sector. This paper presents a chronological review of literature on nurse rerostering (rescheduling literature) from the year 2000 to 2016. The review critically analyses the nurse rerostering research activities over the years, the range of modelling approach used, the challenges and future research implications. The paper stimulates insightful thinking and research foci on topical issues in nurse rerostering which could be very helpful in developing appropriate decision support systems and strategies for nurse rescheduling.

Keywords
Nurse rerostering, nurse rerostering problem, nurse rescheduling, explorative study

1. Introduction

Healthcare systems provide round-the-clock medical and paramedical services to the society. Oftentimes, these systems operate under dynamic and fuzzy environments in which unanticipated events may take place, leading to disruptions of planned operations. This is commonplace in hospital wards where limited nurses are scheduled 24 hours a day 7 days a week (Moz and Pato, 2003, 2004, 2007; Pato and Moz, 2008; Kitada et al., 2011; Bard and Purnomo, 2005, 2006; Maenhout and Vanhoucke, 2011, 2013a, 2013b; Kitada and Morizawa, 2013). For example, a nurse who is scheduled to work in a specific shift may be unavailable for the shift due to unforeseen absences or staff turnover (Maenhout and Vanhoucke, 2011, 2013a, 2013b). Apart from legal and cost constraints, patient care has become a crucial consideration in nurse scheduling. Patient care may be compromised, and patients' lives may be at risk if schedules are disruptions are not rectified on time. On the other hand, patient care may be compromised if nurses are scheduled to work undesirable shifts, leading to low worker morale. In other words, if nurse preferences are not satisfied, their performance is likely to be affected negatively, which ultimately impacts on the quality of service (Moz and Pato, 2003, Bard and Purnomo, 2005, Mutingi and Mbohwa). In as much as nurse preferences need to be satisfied, rerostering of nurses is essential due to unforeseen disruptions.

A significant percentage of total labor resources are often lost due to unplanned schedule disruptions (Moz and Pato, 2003, 2004, 2007). Since such occurrences are unavoidable due to uncertainties, decision makers need to put in place decision support systems to effectively reconstruct the nurse schedules, in reaction to unanticipated events. Unfortunately, the schedules have to be reconstructed subject to nursing resources and nurse preferences, otherwise,

extra labor expenses are incurred when nurses are hired from external interim nurses or reserve pool. Most hospitals are often confronted with such rescheduling (or rerostering) problems.

In practice, whenever unplanned schedule disruptions occur, schedules have to be reconstructed, howbeit, with minimum changes. The schedule quality has to be maintained or even improved. This implies that the schedule is still expected to meet the management goals, the staffing requirements, the individual nurse constraints, and the nurse preferences. Thus, the objective is to re-assign shifts to the available nurses, starting from the first day of reported absence, subject to the reported absences, while ensuring that (i) staffing requirements are met, (ii) schedule changes are minimized, (iii) management goals and aspirations are satisfied as much as possible, and (iv) nurse preferences are satisfied as much as possible. It is important to note that, typically, nurse preferences, management goals and aspirations are not expressed in precise terms. Moreover, the goals, aspirations and constraints are conflicting, leading to a complex fuzzy multi-criteria decision problem (Mutingi and Mbohwa, 2015b). To provide high quality service consistently, healthcare systems need to put in place robust decision systems that can generate effective reactive plans efficiently. However, the major research challenges in this context are as follows:

1. In the presence of disruptions, how do we address fuzzy management goals and aspirations?
2. Given that schedule changes are imminent, and may not be acceptable to nurses, how do we maintain or improve satisfaction of their imprecise wishes and preferences?
3. Given that schedule changes are inevitable, how do we balance the conflicting fuzzy optimization criteria, while ensuring that staffing requirements are met?

Though the rerostering problem has received some attention (Clark and Walker, 2011; Maenhout and Vanhoucke, 2013a, 2013b), little has been touched on the case where management goals and aspirations, and nurse preferences are fuzzy and conflicting This paper reviews the rerostering challenges and stimulates research on topical issues in nurse rerostering.

The rest of the paper is structured as follows: The next section provides and overview of the nurse scheduling problem. This is followed by a description of the research methodology in Section 3. Section 4 presents the literature search results and analysis. Further discussions and research implications are presented in Section 5. Section 6 concludes the paper.

2. Nurse Rerostering: An Overview

The nurse rerostering problem is concerned with reconstructing nurse schedules by making minimal changes to the original schedule, subject to reported absences, so that staffing requirements are achieved as much as possible. Altering schedules leads to changes in the original individual nurse schedules, which may cause unforeseen frustrations among the nurses due to personal inconveniences caused on almost all of them (Mutingi and Mbohwa, 2016; Bäumelt et al., 2016; Kitada and Morizawa, 2013; Clark and Walker, 2011). Above all, since patient care is of paramount importance, decision makers should ensure that service quality and service delivery are not compromised.

2.1 Patient Care and Quality of Service

Poor service quality and service delivery in healthcare systems is associated with factors such as inadequate or nurses due to poor roster planning or unforeseen nurse absences, and long shifts (e.g., 12 hours or more) (Moz and Pato, 2003, 2005). Poor rostering decisions lead to adverse effects on the overall quality of service and nurse morale (Bard and Purnomo, 2006). In this respect, it is crucial to put in place decision support systems for effective nurse rerostering.

2.2 Nurse Preferences

Apart from working long hours, nurses expect equitable shifts. In addition, nurses also expect their individual preferences to be taken into account when constructing rosters. When their personal preferences are considered, this sends a message of fairness among nurses, which in turn, improves worker morale and positive attitude towards service quality (Mutingi and Mbohwa, 2016). On the contrary, disregarding individual choices leads to job dissatisfaction and poor patient care.

2.3 Management Goals

When reconstructing nurse rosters, management have their aspirations over rostering decision criteria such as service quality, nurse job satisfaction, direct costs cost due to overstaffing, high staff turnover, and nurse absenteeism, as well as indirect costs caused by poor patient care. These decision criteria are often interrelated. For satisfactory rostering decisions, the decision maker needs to assign an aspiration level or a weight on each decision criteria.

3. Research Methodology

Our research methodology was carried out in three phases. First, an initial literature search survey was conducted, exploring the nurse rerostering literature in several online databases, library resources, Google Scholar and Research Gate. To limit the range of articles, key words containing special terms "nurse rerostering", and "nurse rescheduling", and "reconstruction" were used in the search process. Second, we streamlined the literature to ensure that selected articles strictly relate to nurse rerostering/rescheduling and are published in peer-reviewed journals and conference proceedings. Only articles from the year 2000 onwards were considered. Third, selected articles were analysed focusing on the main aim of the study, the modelling approaches used, the place of study, and the progression of the research activities over time.

4. Results and Discussions

Our results analysis and discussions were based on the exploration of published works on nurse rerostering. Literature search findings and the realized challenges and implications are presented.

4.1 Literature Search Findings

Initially, literature search yielded a total of 229 articles from various sources. By analysing the titles, abstracts and keywords of the articles, we found out that only 14 of them strictly focused on nurse rerostering (or rescheduling). Table 1 lists the 14 articles, describing the research title, the place of study, the modelling approach used in each research work, and the respective authors. All the articles were published in within the period 2003 to 2016. It was realized that almost all researchers in the field were concerned about reconstruction of the nurse rosters so that deviation from the original roster is minimized, and quality of services is not compromised.

Table 1: Research articles in nurse rerostering

No.	Research Title	Country	Modelling Approach	Authors
1	An integer multi-commodity flow model applied to the rerostering of nurse rosters	Portugal	Integer programming	Moz and Pato (2003)
2	Solving the problem of rerostering nurse rosters with hard constraints: new multi-commodity flow models	Portugal	Integer programming	Moz and Pato (2004)
3	Hospital-wide reactive scheduling of nurses with preference considerations	USA	Integer programming	Bard and Purnomo (2005)
4	Incremental changes in the workforce to accommodate changes in demand	USA	Integer programming	Bard and Purnomo (2006)
5	A genetic algorithm approach to a nurse rescheduling problem.	Portugal	Genetic algorithm	Moz and Pato (2007)
6	Solving a bi-objective nurse rescheduling problem by using utopic Pareto genetic heuristics	Portugal	Pareto genetic-based algorithm	Pato and Moz (2008)
7	A heuristic method in nurse rerostering following a sudden absence of nurses	Japan	Recursive tree search algorithm	Kitada et al. (2010)
8	A Heuristic method for nurse rerostering problem with a sudden absence for several consecutive days	Japan	Recursive tree search algorithm	Kitada and Morizawa (2013)
9	An evolutionary approach for the nurse rerostering problem.	Belgium	Evolutionary metaheuristic algorithm	Maenhout and Vanhouke (2011)
10	Nurse rescheduling with shift preferences and minimal disruption	UK	Integer programming	Clark and Walker (2011)
11	An artificial immune system based approach for solving the nurse re-rostering problem	Belgium	Artificial Immune System	Maenhout and Vanhoucke (2013a)
12	Reconstructing nurse schedules: Computational insights in the problem size parameters	Belgium	Evolutionary metaheuristic algorithms	Maenhout and Vanhoucke (2013b)
13	Fuzzy simulated evolution algorithms for nurse rerostering	South Africa	Fuzzy simulated evolution algorithm	Mutingi and Mbohwa (2016)
14	A novel approach for nurse rerostering based on a parallel algorithm	Czech Republic	Parallel algorithms	Bäumelt et al. (2016)

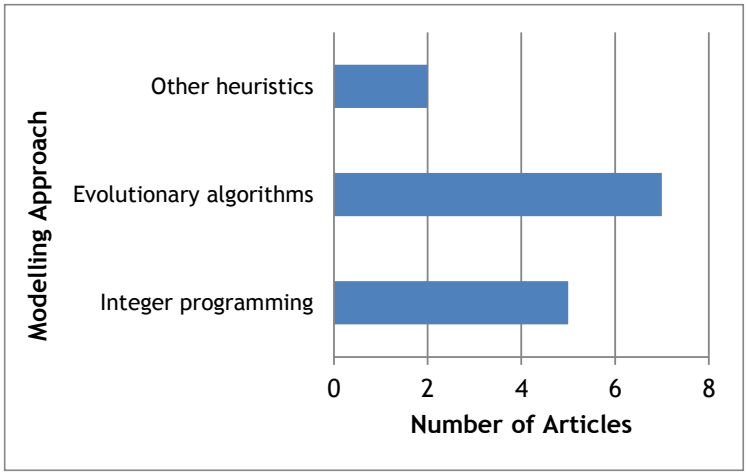

Figure 1. Frequency of modelling approaches applied in articles

Three major modelling approaches used in solving the rerostering problems were classified into integer programming, evolutionary algorithms, and other heuristics. Among the three, evolutionary algorithms were the most preferred, followed by integer programming. Figure 1 shows the frequency of modelling approaches applied in articles.

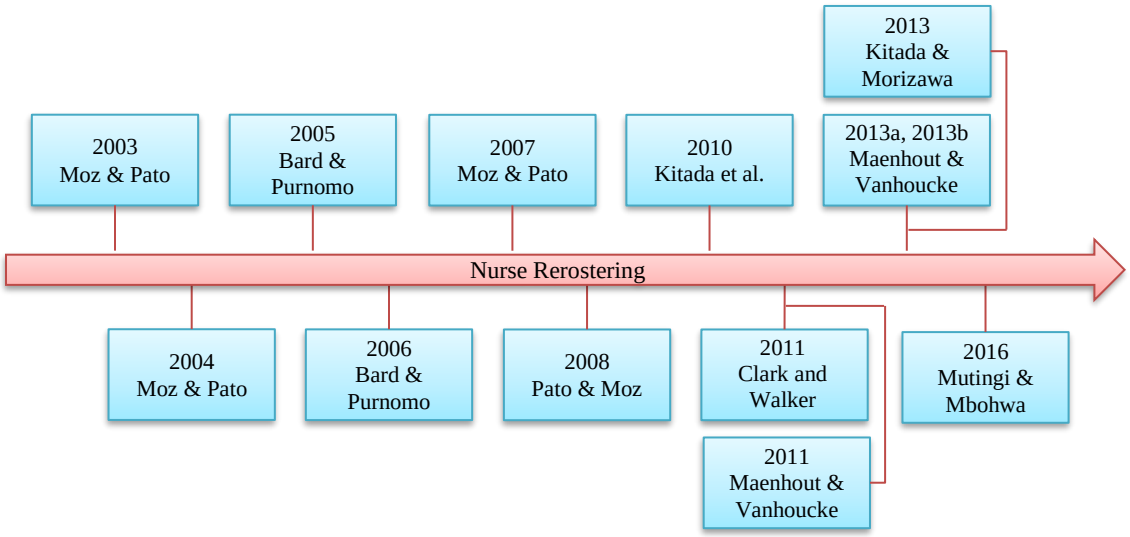

Figure 2. A timeline of the nurse rerostering articles

Figure 2 presents a timeline of the nurse rerostering problem over the period 2003 to 2016. The rerostering problem first appeared in 2003 in Moz and Pato (2003) where the problem was formulated as an integer multi-commodity flow model, with the objective of minimizing deviations from the original roster. Similar further studies were carried out in 2004 in (Moz and Pato (2004), taking into account the issue of overstaffing. Further research appeared in 2005, where Bard and Purnomo (2005) modelled the rerostering problem as a "reactive scheduling" problem in which a 24-hour period was reviewed at time. The same authors further developed their work in 2006, based on incremental changes in workforce to accommodate changes in demand (Bard and Purnomo, 2006). Moz and Pato (2007) hybridized their multi-commodity model with genetic algorithm and a constructive heuristics, deriving from their earlier research (Moz and Pato, 2005). In 2008, the same authors improved their work by adding another objective aimed at minimizing overtime (Pato and Moz, 2008).

In 2010, a recursive heuristic method incorporating tree search was used to model the nurse rerostering problem (Kitada et al., 2011). The following year 2011, an evolutionary metaheuristic approach that combines principles from various meta-heuristics was proposed (Maenhout and Vanhoucke, 2011). In the same year, Clark and Walker (2011) proposed models that seek to satisfy nurse preferences and minimize the number of disruptions, providing notable suggestions such as the use of explicit fairness constraints and human judgement in modelling the nurse rerostering problem.

In 2013, a heuristic method was proposed for nurse rerostering problem with a sudden absence for several consecutive days (Kitada and Morizawa, 2013). In the same year, artificial immune system and evolutionary based approaches were presented (Maenhout and Vanhoucke, 2013a, 2013b), providing computational insights in the problem size parameters. Recently, in Mutingi and Mbohwa (2016), the researchers presented a unique approach based on fuzzy simulated algorithm by applying fuzzy evaluation techniques to model several objectives centered on minimizing schedule changes, maintaining or improving quality of service, maximizing satisfaction of nurse preferences, and maximizing schedule fairness. A novel approach for nurse rerostering based on a parallel algorithm was proposed by Bäumelt et al. (2016).

4.2 Major challenges and research implications

From our study, several lessons were derived, and the most important of these are outlined as follows:

1. Nurse rerostering has a strong direct impact on the quality and efficiency of healthcare service, job satisfaction for nurses, and the satisfaction of management goals;
2. Once the original nurse schedule is established, any reschedules usually face unexpected reactions and resistance;
3. Nurse rerostering is of common occurrence in most hospitals, as indicated by the several empirical studies;
4. Nurse rerostering is associated with several uncertainties due to patient expectations on the quality of service, nurse preferences, and management aspirations. These are usually imprecise and difficult to model using conventional approaches;
5. To date, decision support systems that can handle nurse rerostering are rare, more so for nurse rerostering in uncertain environments; and,
6. Nurse rerostering is often more complex than original nurse scheduling due to extra considerations: the need to minimize the number of schedule changes, and to at least maintain the quality of healthcare service, schedule fairness, and nurse satisfaction.

In light of the challenges identified above, it can be seen that rerostering brings along managerial implications that require more attention than the normal schedules. While the normal nurse scheduling problem is known to be uncertain, the nurse rerostering problem brings even more uncertainties with it. That implies that researchers need to seriously consider developing interactive and flexible decision support systems that can handle nurse rerostering problems in uncertain environments.

5. Conclusions

The exploratory study revealed that research on the nurse rerostering problem is quite a limited. It was found out that nurse rerostering is often associated with complex challenges, which include the need to satisfy multiple conflicting decision criteria: (i) patient expectations on service quality and service delivery, (ii) cost of healthcare service, (iii) staff preferences over shift sequences and workload assignments, and (iv) management aspirations and goals. The aim is to manage these challenges effectively. Not much attention has been given to the development of strategies or decision support systems to help managers in this regard. Effective systems will assist decision makers to avoid low quality of service, poor service delivery, low employee morale, and high costs of healthcare. Decision support tools and strategies for the nurse rerostering problem should be able to model and address the following:

1. Mathematical complexities of the problem, arising from the presence of multiple decision criteria, and multiple constraints;
2. Vagueness, imprecision, or fuzziness associated with human expectations due to patients, nurses; and management;
3. The need to incorporate decision maker's intuition, experience, and choices in the solution process;
4. The need for high quality rosters with fairness and equality among the nurses.
5. The need for a faster decision making process in a busy healthcare system.

By considering the above findings, it is hoped that future research will develop appropriate and decision support tools and strategies for effective nurse rerostering.

References

Moz, M., Pato, M.. An integer multicommodity flow model applied to the rerostering of nurse schedules. *Annals of Operations Research*, vol. 119, pp. 285–301, 2003

Moz, M. and Pato, M.. Solving the problem of rerostering nurse schedules with hard constraints: new multicommodity flow models. *Annals of Operations Research*, vol.128, no.(1), pp. 179–197, 2004

Bard, J.F., Purnomo, H.. Hospital-wide reactive scheduling of nurses with preference considerations. *IIE Transactions*, 37, pp. 589–608, 2005

Bard J.F., Purnomo, H.. Incremental changes in the workforce to accommodate changes in demand. *Health Care Management Science*, 9 (1), pp. 71-85, 2006

Moz, M. and Pato, M.. A genetic algorithm approach to a nurse rerostering problem. *Computers & Operations Research*, 34, 667–91, 2007

Pato, M., Moz, M.. Solving a bi-objective nurse rerostering problem by using a utopic Pareto genetic heuristic. *Journal of Heuristics*, 14, pp. 359–74, 2008

Kitada M., Morizawa, K., Nagasawa, H.. A heuristic method in nurse rerostering following a sudden absence of nurses. *Proceedings of the 11th Asia Pacific Industrial Engineering and Management Systems Conference*, Manila, 2011.

Clark, A.R., Walker, H.. Nurse rescheduling with shift preferences and minimal disruption. *Journal of Applied Operational Research*, 3 (3), pp. 148-162, 2011

Maenhout, B., Vanhoucke, M.. An evolutionary approach for the nurse rerostering problem. *Computers and & Operations Research*, pp. 1400-1411, 2011

Maenhout, B., Vanhoucke, M. An artificial immune system based approach for solving the nurse re-rostering problem, *Lecture Notes in Computer Science*, 7832, pp. 97-108, 2013a.

Maenhout, B., Vanhoucke, M.. Reconstructing nurse schedules: Computational insights in the problem size parameters. *Omega*, 41 (5), pp. 903-918, 2013b

Kitada M., Morizawa K.. A heuristic method for nurse rerostering problem with a sudden absence for several consecutive days. International Journal of Emerging Technology and Advanced Engineering, 3 (11), pp. 353-361, 2013

Mutingi, M., and Mbohwa, C. Fuzzy simulated evolution algorithm for nurse rerostering. In M. Mutingi, C. Mbohwa (Eds.), Healthcare Staff Scheduling: Emerging Fuzzy Optimization Approaches. CRC Press, Taylor and Francis, New York, USA, pp. 83-100, 2016.

Bäumelt Z., Dvořáka J., Šůchaa P. Hanzáleka Z. A novel approach for nurse rerostering based on a parallel algorithm. *European Journal of Operational Research*, 251 (2), pp. 624–639, 2016.

Acknowledgements

The authors would like to appreciate the reviewers for their invaluable comments on this paper.

Biography

Michael Mutingi is a Senior Lecturer in Industrial Engineering at the Namibia University of Science and Technology, Namibia. He is also a Senior Visiting Research Associate at the University of Johannesburg, South Africa. He obtained his PhD in Engineering Management from the University of Johannesburg, South Africa. He also holds a MEng and a BEng in Industrial Engineering from the National University of Science and Technology, Zimbabwe, where he served as a Research Fellow and a Lecturer in Industrial Engineering. Michael Mutingi also served as a Research Associate at the National University of Singapore, Singapore, and a Lecturer at the University of Botswana, Botswana. His research interests include operations management, quality management, multi-criteria decision making, and operational excellence in healthcare. He has published two books and more than 90 articles in international journals and conference proceedings.

Charles Mbohwa is a Professor at the University of Johannesburg. He has been a senior lecturer in mechanical engineering at the University of Zimbabwe and a mechanical engineer at the National Railways of Zimbabwe. He has a Doctor of Engineering from Tokyo Metropolitan Institute of Technology, masters in operations management and manufacturing systems from the University of Nottingham and a BSc (honours) in mechanical engineering from the University of Zimbabwe. He has been a British Council Scholar, Japan Foundation Fellow, a Heiwa Nakajima Fellow, a Kubota Foundation Fellow and a Fulbright Fellow. His research interests are in operations management, engineering management, energy systems and sustainability assessment. He has published two books, several book chapters and more than 130 academic papers..