

# Complicating Factors in Healthcare Staff Scheduling Part 2: Case of Nurse Re-rostering

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**Abstract**—Nurse re-rostering is a highly constrained combinatorial problem characterized with several complicating features. This paper explores recent case studies on nurse re-rostering and identifies the common complicating factors in the nurse re-rostering problem. A taxonomic analysis of complicating factors is then presented. Further, an evaluation of the complicating factors and the solution methods applied, showing the shortfalls of the approaches. A more robust and appropriate approach is realized for the complex problem. Future approaches should be intelligent, interactive, making use of a combination of fuzzy theory, fuzzy logic, multi-criteria decision making, and expert systems techniques.

**Index Terms**—Healthcare staff scheduling, staff scheduling, nurse re-rostering, nurse scheduling, complicating factors

## I. INTRODUCTION

NURSES operate in a dynamic and fuzzy environment where unanticipated events may occur leading to complex schedule disruptions [1]. Due to unforeseen circumstances such as sickness absence, a nurse scheduled to work during a specific shift may report that she will not be available for the shift [1][2]. A statistical analysis of the occurrence of sickness absences among employees has been studied in [1]. The implication is that, decision makers will have to reconstruct the nurse roster, a process known as nurse re-rostering [1-7]. This involves re-assigning shifts to available nurses over the period that spans from the first day of reported absence to the end of the planning period. However, all the constraints associated with the original roster have to be considered. In addition, constraints related to the reported absences have to be factored into the new decision process.

The nurse rostering problem has been widely studied by several researchers and practitioners. Some of the major literature surveys are in [8-12]. However, though rostering has been considered widely, re-rostering has received very little attention. In the real world, it is difficult to accept the assumption that there is always a reserve pool of nurses to replace those reported absent. Further, it may be too costly to always have a reserve pool of nurses. Therefore, nurse re-

rostering is an important but complex problem for decision makers in hospital institutions. This will ensure that healthcare systems maintain quality rosters that enable them to contain labor costs without compromising staff satisfaction, patient satisfaction, patient safety, as well as organizational satisfaction.

Critical research questions in this study include the following:

1. Which real world case studies have considered nurse re-rostering as a decision problem?
2. What are the common complicating features in nurse re-rostering?
3. Which methods have been applied in those case studies?
4. Which are the most suitable approaches for nurse re-rostering?

The purpose of this paper is to explore the complicating factors in nurse re-rostering. The paper is the second in the series of five papers on complicating factors in healthcare staff scheduling.

The structure of the paper is as follows: Research methodology is described in Section II. Research findings are presented in Section III. Complicating factors in nurse rostering are described in Section IV. Solution approaches are outlined in Section V. Section VI concludes the paper.

## II. RESEARCH METHODOLOGY

The research methodology followed in this study is shown in Fig. 1. Literature search was surveyed from a wide range of sources, chiefly, from databases such as ScienceDirect, EBSCO Inspec, ISI Web of Science, and Ei Compendex. To eliminate irrelevant studies and to cut down on studies that did not major on nurse re-rostering, key words were used in the search process, including “nurse re-rostering,” “nurse re-scheduling,” “nurse scheduling,” and

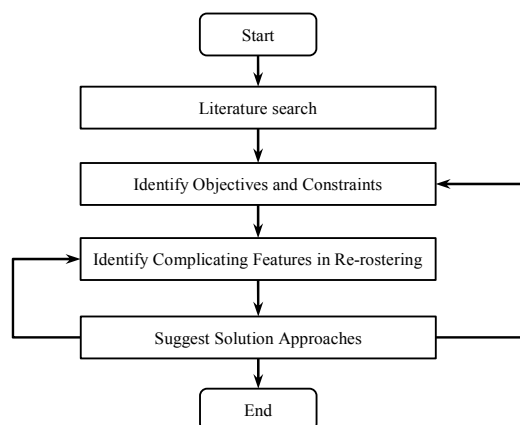


Fig. 1. Research Methodology

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“staff scheduling.” A few major case studies were retrieved. Complicating factors were identified, taking note of those that were addressed and those that were not. The associated solution approaches were also identified.

### III. LITERATURE SEARCH FINDINGS

A total of six real world case studies were realized, 2 journal articles were from Computers & Operations Research, 2 from Annals of Operations, 1 from Journal of heuristics. Only 1 thesis was from the Arizona State University Tempe.

The study in [2] emphasized that the primary nurse preference to be observed in rostering is to retain the original shift assignments as much as possible. An integer multi-commodity flow model was applied to solve the problem. In [3], multi-commodity flow models were presented. In [4], a genetic algorithm approach was used to model and solve a case study problem, based on real data from a hospital setting. In the same vein, an evolutionary metaheuristic approach was proposed for addressing a nurse rostering problem [5]. The authors generated problem sets with artificial complexity to test the algorithm efficiency and effectiveness. An optimal network-based approach to scheduling and re-rostering continuous heterogeneous workforces was presented in [6], with application to a number of re-rostering problems, including nurse rostering.

A real world nurse re-rostering problem was solved using a utopic Pareto genetic heuristic, from a bi-criteria perspective. However, studies based on fuzzy multiple criteria are rare. The next section presents the common re-rostering criteria derived from the case studies.

#### A. Common Decision Criteria

A study of the case examples in the literature revealed a number of common decision criteria, above and over those common to the original nurse rostering. These criteria are:

1. Maximize or maintain the quality of service as was intended in the original roster before disruptions,
2. Maintain or minimize schedule changes as much as possible,
3. Maintain or maximize or the satisfaction of individual nurse preferences,
4. Maintain or maximize schedule fairness,
5. Maintain or minimize schedule or labor cost, and,
6. Maintain or minimize workload variation.

The above criteria seek to ensure that the aspirations and expectations of the management, the nurse desires, and the patients are satisfied as much as possible. However, it is difficult to simultaneously satisfy all criteria. These criteria are usually conflicting. Moreover, the aspirations are often expressed in imprecise linguistic terms, which is difficult to quantify and model.

#### B. Common Constraints

From the literature search survey [2-7], the nurse rostering decisions are faced with two types of constraints, that is, the original roster constraints, and the roster disruption constraints. The original nurse roster constraints are summarized as follows:

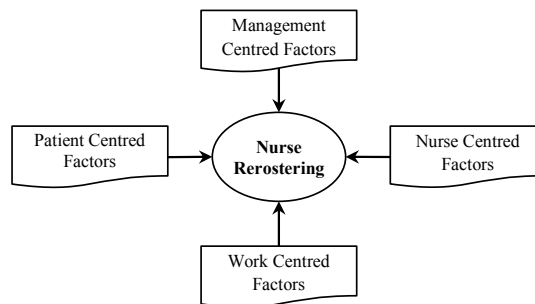


Fig. 2. A taxonomy of complicating features in nurse re-rostering

1. Shift sequence restrictions
2. Nurses holidays, vacations, and days off.
3. Nurse workload per period.
4. Nurses preferences or requirements.
5. Number of consecutive working days.
6. Number of consecutive shifts of the same type.
7. Shift coverage requirement, i.e., for each shift type.
8. Constraints among groups/types of nurses.
9. Nurse skill levels and categories.

Due to the reported inability to show up for the duty, some of the nurses must not be assigned any working shift on specific days. Therefore, in addition to the rostering constraints, disruption constraints state that:

1. Reported unplanned absences must not be assigned any shift.
2. Minimum satisfaction of the original roster criteria must be maintained.

Complicating factors in nurse re-rostering decisions are presented in the next section.

### IV. COMPLICATING FACTORS IN NURSE RE-ROSTERING

A meta-analysis of recent selected case studies [2-7] show that complicating factors in nurse re-rostering fall into four categories: (a) patient-centered factors, (b) management-centered factors, (c) nurse-related factors, and (d) work-centered factors. A taxonomy of the complicating factors is presented in Fig. 2.

A summary of the analysis of the selected case studies and their associated constraints is presented in Table I.

#### A. Patient-Centered Factors

Patient-centered factors are associated with patient acuity, patient care, patient expectations, which determine the required service level. A minimum satisfaction of the service level should be met according to the original roster.

##### 1) A1: Dynamic Healthcare Service Demand

Oftentimes, management cannot quantify the service level

TABLE I  
SELECTED RECENT CASE STUDIES IN NURSE RE-ROSTERING

Reference	Complicating Factors	Solution Approaches
[2]	A2, B3, B4, C2, D	Integer multi-commodity flow method
[3]	A2, B3, B4, C2, D	Multi-commodity flow method
[4]	A2, B3, B4, C2, D	Genetic algorithm, constructive heuristic
[5]	A2, B3, B4, C2, D	Evolutionary algorithms
[6]	B1, B3, B4, C2, D	Network programming
[7]	B1, B3, B4, C2, D	Pareto-based genetic heuristic

requirements in precise terms. Due to unforeseen emergencies and changes, the demand for healthcare service is dynamic and unpredictable. In addition, the unpredictable patient acuity and complexity further complicates the ever-changing demand for nursing care.

#### 2) A2: Patient Preferences

In spite of roster disruptions, patient satisfaction remains a priority. Thus, a minimum satisfaction level is set for the re-rostering problem, learning from the original roster. Consistency in patient-nurse assignment is expected as well; patients will still expect their preferred nursing staff to attend to them. Patient preferences over the expected quality of service, care service time, and other personalized choices, are supposed to be considered. These preferences and choices are expressed in fuzzy linguistic terms, which further complicate the problem.

### B. Management-Centered Factors

Management-centered factors are associated with decision makers who define the goals affecting the re-rostering decisions and the ultimate service offered. Management sets the minimum aspiration criteria according to the original roster solution.

#### 1) B1: Multiple Conflicting Goals

The nurse re-rostering problem faces numerous conflicting management goals. Because the goals are usually fuzzy and imprecise, the problem lends itself to fuzzy multi-criteria decision approaches. The re-roster must as satisfactory as possible.

#### 2) B2: Fuzzy Management Goals

Managers in modern healthcare institutions opt to accommodate nurse and patient preferences up to certain levels in order to improve schedule quality and the ensuing service quality [6]. Because management goals are often expressed linguistically, re-rostering decisions should be formulated based on fuzzy rather than crisp models.

#### 3) B3: Statutory Restrictions

Regulations from government bodies and labor unions impose hard constraints on the re-rostering problem [2-7]. As a result, the nurse re-rostering problem becomes even more complicated in the presence of a number of hard constraints.

#### 4) B4: A Myriad of Constraints

Modern healthcare institutions are faced with several constraints, as noted in the case studies [1-7]. With the additional disruptions constraints and the minimum aspirations criteria imposed by the original roster, it is difficult to meet the ever-rising need to simultaneously satisfy the patient, the nurse, the management and the hard constraints derived from labor laws. Consequently, the nurse re-rostering problem is increasingly becoming more difficult to solve.

### C. Nurse-Centered Factors

As the nurse shortage is gradually worsening across the world, nurse staffing, particularly re-rostering, is becoming more and more complex [1].

#### 1) C1: Fuzzy Nurse Preferences

With the introduction of new disruption constraints and the aspirations to meet the original roster solution criteria, meeting nurse preferences on shift types, shift times, days

off, work patterns, work mates, and workload, is non-trivial. Nevertheless, perceived fairness in shift allocation remains essential, lest low morale, absenteeism, poor performance, and high attrition are unavoidable.

#### 2) C2: Unplanned Absence

In the presence of reported unplanned absences and no shows, schedule disruptions, and labor shortages, decision makers have to devise robust multiple criteria methods that can effectively handle re-rostering. Without efficient methods, service quality is adversely compromised.

### D. Work-Centered Factors

Work-Centered factors relate to the aggregate demand for healthcare services over the planning horizon. The nature and quantity of the arising healthcare needs influence the labor requirement for each shift. Increasing uncertainties in the estimating labor requirements further complicate the re-rostering problem, especially given the reported unplanned absences.

## V. SOLUTION APPROACHES

As note in the selected case studies [2-7], solution approaches offered can be divided into manual methods, mathematical programming, constraint programming, and metaheuristics.

### A. Manual Methods

Manual methods, also know as naïve methods, basically utilize spreadsheets to manually re-construct shifts to nurses[1], which can be extremely time consuming, difficult, and prone to errors and poor quality. With unplanned absences and other unforeseen changes, and the preferences that must still be satisfied, reconstruction of the original roster is quite complex.

### B. Mathematical Programming Approaches

Mathematical programming-based methods have been applied to re-rostering problems [2-7]. Single-objective and multiple objective methods have been used [7]. However, modelling uncertainties and fuzzy features such as nurse preference, patient expectations, and conflicting management goals, is difficult [13].

### C. Constraint Programming

The aim of this technique is to find feasible solutions that satisfy several constraints, such as preference constraints, shift sequence constraints, and original roster constraint aspirations. However, optimal solutions are rare when using this method. Also, it is difficult to capture fuzzy goals, preferences, and decision maker's expert opinion into the models [13].

### D. Metaheuristic Methods

Metaheuristic methods, including genetic algorithms [4] [15], particle swarm optimization [16], tabu search, and other evolutionary algorithms have been studied in the literature [2-7]. To provide more satisfactory solutions, fuzzy models [15][17] and techniques must be infused into these methods so that fuzzy imprecise features are addressed adequately.

## VI. RECOMMENDATIONS AND FURTHER RESEARCH

Real world nurse re-rostering is a hard decision problem inundated with several fuzzy complicating features. This study analyzed the nurse re-rostering case studies, identifying common complicating factors associated with the problem. A taxonomic analysis of complicating factors and solution approaches was carried out. By considering the identified factors and the solution approaches used, shortfalls of the approaches were realized.

Approaches in the case studies scarcely address the following features:

1. The fuzzy and imprecise patient expectations, nurse preferences, and management goals aspirations,
2. The uncertainties due to reported unplanned absences leading to schedule disruptions
3. The dynamic nature of patient acuity, expectations, and complexities
4. The need for interactive decision methods that can handle fuzzy decision choices and intuitions

It is anticipated that more intelligent and robust solution approaches will be used to solve real world re-rostering problems. These methods are expected to make use of methods such expert systems [14], fuzzy theory [13-15], fuzzy logic [17], intelligence [16], and multi-criteria decision techniques [15]. Expert knowledge and intuitions can conveniently be incorporated into the decision models. Such methods have a potential to address fuzziness and imprecision inherent in most practical nurse re-rostering problems.

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