# Complicating Factors in Healthcare Staff Scheduling Part 1: Case of Nurse Rostering

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***Abstract*—Nurse rostering is a hard problem inundated with inherent complicating features. This paper explores case studies on nurse rostering in order identify complicating factors common in the nurse rostering problem. A taxonomy of complicating factors is then derived. Furthermore, a closer look at the complicating factors and the solution methods applied is performed. Inadequacies of the approaches are identified, and suitable approaches derived. The study recommends future methods that are more intelligent, interactive, making use of techniques such fuzzy theory, fuzzy logic, multi-criteria decision making, and expert systems.**

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

## I. Introduction

THE nurse rostering problem is concerned with the construction of work schedules for nursing staff in a hospital setting, so that organizational and healthcare service objectives are satisfied to an acceptable level [1]. Satisfying these objectives is complex due to a combination of several factors relating to the patient, the nursing staff, and the healthcare organization. In the first place, labor laws and union laws restrict the way the nurse work schedules are constructed and assigned [1] [2] These laws control the utilization of nursing staff in healthcare organizations. In addition, every healthcare organization has its own requirements that need to be satisfied.

Nurses are the largest healthcare professional group in every health organization [2][4]. As such, their involvement in rostering decisions is essential. Healthcare systems have no option except to consider their wishes and preferences in regards to workloads, shift construction and shift assignment [10]. This will help to avoid job dissatisfaction, absenteeism, attrition, and poor healthcare service. However, the desires and preferences of nurses may change over time due to changes in their work environment, as well as acuity and complexity of patients.

The patient is the most crucial entity in every healthcare system [3-10]. Satisfying the patients, together with the concerned family members, and the society at large will ensure business survivability in the long run. However, as the expectations of the patients and the society continue to increase, coupled with the unpredictability of the demand for healthcare services, staffing and scheduling continues to be a major cause for concern in most healthcare organizations all over the globe.

In view of the issues outlined above, it is essential for healthcare systems to make appropriate staffing scheduling decisions that will enable them to contain labor costs, howbeit, without compromising patient safety, patient satisfaction, staff satisfaction, and organizational satisfaction. Questions arising in this study include:

1. What are the common complicating factors in nurse rostering?
2. How may the complicating features be factored in when constructing nurse work schedules?
3. Which are the most suitable approaches for nurse rostering?

The purpose of this paper is to explore and deliberate on the complicating factors in nurse rostering. The paper is the first in the series of five papers on the complicating factors in healthcare staff scheduling. The paper is structured thus: Section II presents the research methodology. Section III outlines the nurse rostering problem. Complicating factors in nurse rostering are presented in Section IV. Common solution approaches are outlined in Section V. Section VI concludes the paper.

## II. Research Methodology

A wide range of literature sources were used to compile case studies in nurse rostering. Largely, databases such as ScienceDirect, EBSCO Inspec, ISI Web of Science, Ei

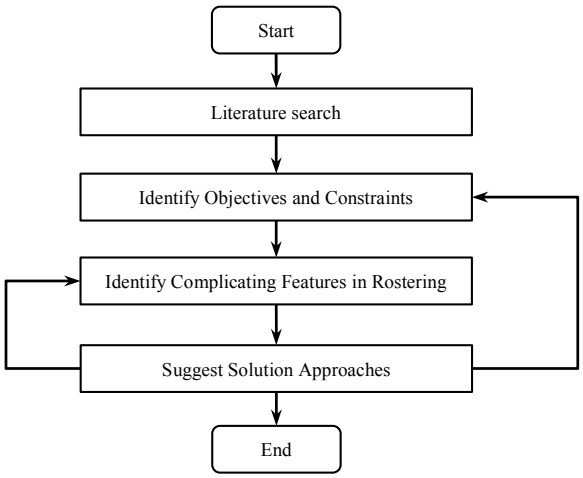


Fig. 1. Research Methodology

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Compendex, were used. Key words used in the search process include "nurse rostering," "nurse scheduling," "personnel scheduling", "staff scheduling" and "patient assignment". This streamlined irrelevant studies and eliminated studies which did not major on nurse rostering/scheduling. Major case studies were selected, and complicating factors were identified, distinguishing between those that were addressed and those that were not. The ensuing solution approaches were also identified. Fig. 1 outlines the research methodology followed in this study.

## III. Nurse Rostering Problem Situation

Nurse rostering involves construction and allocation of shift schedules to nurses in a fair and equitable manner, in order to satisfy several criteria or objectives [1][2]. However, the decision process is subject to several constraints.

### A. Common Objectives

A study of the case studies in the literature show that common objectives considered in nurse rostering decisions are as follows:

1. Minimize schedule cost
2. Minimize labor cost
3. Minimize workload variation
4. Maximize satisfaction of nurse preferences
5. Maximize patient satisfaction

Objectives 1 and 2 pertain to management goals, 3 and 4 relate to worker satisfaction, while 5 relates to patient satisfaction. However, it is difficult to satisfy all criteria since, more often than not, they are not expressed in precise terms and are conflicting.

### B. Common Constraints

From the literature search conducted in this study, common constraints in nurse rostering decisions are as follows [6-12]:

1. Shift sequence restrictions, e.g., preceding shift assignment, shifts assigned in the previous period.
2. Nurses holidays, vacations, and days off between certain working shifts.
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 in the scheduling period.
7. Shift coverage requirement - required number of nurses of different types for each shift type.
8. Constraints among groups/types of nurses, e.g., nurses who must or must not work together.
9. Nurse skill levels and categories.

Constraints can be divided into three categories; sequence constraints (1 to 2), schedule constraints (3 to 6), and roster constraints (7 to 9). Complicating factors in nurse rostering decisions are presented in the next sections.

## IV. Complicating Factors In Nurse Rostering

Deriving from the recent selected case studies [6-12], a number of complicating factors in nurse rostering are identified and classified into four categories: (a) patient-centered factors, (b) management-centered factors, (c) nurse-related factors, and (d) work-centered factors. Fig. 2 presents a taxonomy of the complicating factors in nurse rostering decision making. Selected case studies and their associated complicating features are presented in Table I.

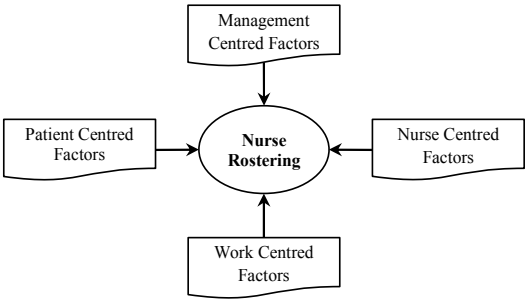


Fig. 2. A taxonomy of complicating factors in nurse rostering

### A. Patient-Centered Factors

Patient-centered factors relate to patient acuity, patient care, patient expectations, which guide the determination of the required service level and how it may be achieved.

#### 1) Dynamic Healthcare Service Demand

Demand for healthcare service is dynamic, that is, it changes over time, due to unforeseen emergencies. Patient acuity and complexity is unpredictable, leading to ever-changing demand for nursing care in the course of day. Quantifying the service requirements in precise terms is a non-trivial task.

#### 2) Patient Preferences

With modern calls for patient satisfaction, consistency in patient-nurse assignment is a key performance measure. Patients may prefer to be taken care of by specific nurses. Further, patients may also show their preferences regarding expected quality of service, the time of care service, and other personalized choices. However, most of these choices, being human, tend to be imprecise in nature.

### B. Management-Centered Factors

Management-centered factors relate to the concerns of decision makers who define the goals that affect the rostering decisions and the ultimate service offered. These factors add to the complexity of the rostering process.

#### 1) B1: Multiple Conflicting Goals

Nurse rostering problem situations usually faces

TABLE I
Selected Recent Case Studies

| Reference | Complicating Factors | Solution Approaches |
|---|---|---|
| [6] | B1, B2, B3, B4, C1, D | Fuzzy mathematical programming |
| [7] | A1, B1, B3, B4, C2, D | Rule-based heuristics, Mathematical programming |
| [8] | A1, B2, B3, B4, D | Metaheuristic – Ant Colony Algorithm |
| [9] | A1, B1, B3, B4, C2, D | Mathematica programming - Mixed Integer Programming |
| [10] | B1, B3, C1,C2, D | Integer programming and heuristics. |
| [11] | B1, B3, B4, C1, D | Genetic Algorithms, Mathematica Programming |
| [12] | B1, B3, B4, D | Indirect Genetic Algorithm, Constructive Heuristics |

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numerous conflicting goals, which makes them well suited for multi-criteria optimization in order to find schedules that are 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, rostering decisions should be formulated based on fuzzy rather than crisp models.

*3) B3: Statutory Restrictions*

Regulations from government regulatory bodies and labor unions restrict the working conditions in healthcare institutions [1-4]. These lead to hard constraints on the nurse rostering problems.

*4) B4: A Myriad of Constraints*

In modern healthcare institutions, nurse rostering is characterized by several constraints, as noted in Section III [14-18]. With the ever-rising need to simultaneously satisfy the patient, the nurse, the management and the labor laws, nurse rostering is increasingly becoming more complex.

### C. Nurse-Centered Factors

Nurses are usually the largest category of staff in hospitals. Nurse shortage is gradually worsening across over the globe; the scarcity of nurses further complicates nurse staffing and rostering process [19].

*1) C1: Fuzzy Nurse Preferences*

Oftentimes, individual nurses are allowed to express their preferences on shift types, shift times, days off, work patterns, work mates, and total workload. Perceived fairness in shift allocation is an essential consideration. If nurses feel ignored, low morale, absenteeism, poor performance, and high attrition are unavoidable. However, preferences are often expressed in linguistic terms which are difficult to model in precise terms.

*2) C2: Unplanned Absence*

Reported unplanned absences and no shows lead to schedule disruptions and labor shortages. Consequently, service quality is adversely affected. In the presence of these unforeseen events, it is difficult to make effective rostering decisions.

### D. Work-Centered Factors

These factors relate to the overall behavior of the aggregate demand for healthcare service over the planning horizon. The nature of healthcare needs determines the rate at which work can be performed, and the labor requirement for each shift. Due to increasing uncertainties in the nature of work and its anticipated magnitude, estimating labor requirements becomes more complex. The estimated labor requirements are to be compared with the nursing staff expected to be available over the planning period.

## V. Solution Approaches

As realized in the selected case studies in the literature, several solution approaches have been applied on different rostering problems. These approaches can be divided into manual methods, mathematical programming, constraint programming, and artificial intelligence.

### A. Manual Methods

Manual or naïve methods usually utilize spreadsheets to manually allocate shifts to nurses [1]. Clearly, this is not only extremely time consuming, but is also prone to errors and poor nurse rosters. In case of unplanned absences, no shows, nurse preferences, and other unforeseen changes in the roster, adjusting the original roster is complex.

### B. Mathematical Programming Approaches

Mathematical programming has been applied to several rostering problems [1-4] [6-12]. Single-objective and multiple objective methods have been used, with appreciable success. However, modelling uncertainties and fuzziness inherent in fuzzy features such as nurse preference, patient expectations, and conflicting management goals, is difficult with such methods.

### C. Constraint Programming

Constraint programming seeks to find feasible solutions that satisfy several constraints, such as preference constraints, shift sequence constraints, and roster constraints which come in various forms. However, with this method, good solutions are rare, especially where optimal or near optimal solutions are required out of a huge solution space. In addition, it is highly difficult to capture fuzzy goals, preferences, and decision maker's choices into the models.

### D. Metaheuristic Methods

Metaheuristic methods, including genetic algorithms, particle swarm optimization, tabu search, simulated evolution and simulated metamorphosis have been applied to rostering problems [14-17]. To provide more satisfactory solutions, fuzzy models and techniques must be infused into these methods so that fuzzy imprecise features are addressed adequately.

### E. Intelligent Fuzzy Multi-Criteria Approaches

It can be seen from the study of the common approaches in the literature that most methods scarcely address the following:

1. The fuzzy and imprecise factors such as patient expectations, nurse preferences, management goals,
2. The dynamic nature of patient acuity, expectations, and complexities
3. The need for interactive decision methods that can allow decision maker's input choices and suggestions.

Intelligent approaches are expected to make use of methods such fuzzy theory [18], fuzzy logic and expert systems. Expert knowledge and intuitions are conveniently incorporated into the decision models. An important potential of such methods is the ability to address fuzziness and imprecision inherent in the nurse rostering problems.

## VI. Conclusions and Further Research

In practice, nurse rostering is a hard decision problem inundated with several fuzzy complicating features. This study presented a meta-analysis of nurse rostering case studies in order identify complicating factors common in nurse rostering. A taxonomy of complicating factors was derived. In addition, a classification of solution approaches

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was developed. A closer look at the identified complicating factors and the solution approaches revealed the shortcomings of the approaches. It is hoped that future methods will be more intelligent, interactive, making use of techniques such fuzzy theory, fuzzy logic, multi-criteria decision making, and expert systems.

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