Nurse Rostering Optimization

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1.0 Executive Summary

An important aspect of hospital operations in Singapore is the effective scheduling of nurses in various wards, which is vital for the hospitals' patients to receive timely care from the nurses with the necessary skill sets. The objective is to balance operational costs and safe patient care needs while maximizing the degree to which nurses' request are met.

However, the scheduling of the nurses' roster is very time-consuming and challenging due to the need to balance the intensive demands of healthcare and the well-being of nurses. In addition, due to the dynamic nature of the workload and unforeseen circumstances, rescheduling is also very common.

Our project focuses on taking the chore out of the painstaking process of scheduling with the objective of reducing the time taken to achieve the best possible schedule in a highly repeatable manner.

2.0 Business Value

Nurse rostering, especially via manual approaches, is a time-consuming and painstaking task to nursing managements due of its complexity. The laborious task can be broken down into several steps.

First is the prediction of service demands. It requires Nursing Management to analyze a long list of reports like ward occupancy pattern and nursing productivity calculation to determine the number of staff needed to deliver safe patient care at different time.

Next is the assignment of staff to shifts and locations based on a set of operational constraints such as staffs' specialties, work agreements, grades and preferences. Meeting these constraints while achieving a satisfying roster can be a tedious and painful process as it requires a lot of communication and coordination.

Final process involves the review of the planned roster to ensure operational costs is minimized while staff request is maximized.

Although there are clear guidelines given at the hospital level to regulate nurse rostering, the process can still be problematic, especially in today's increasingly complex healthcare landscape, with budgets frequently over-run, and staffing levels too often fail to match demands.

In view of these challenges and the market's potential, quite a number of companies design and implement commercial software packages to seize market opportunities. However, many hospitals are still reluctant or even resistant to replace their manual planning process with an automated system, because of high licence and maintenance costs.

In this project, our aim is to apply the knowledge acquired from the Reasoning Systems course to build automated nurse rostering prototypes to facilitate more efficient roster planning. Additionally, we also put some effort into evaluating the benefits and limitations of such systems to help business users to make more informed decisions and to make our project more meaningful.

3.0 Knowledge Specification

In this section, we specify how we collect and represent requirements.

3.1 Knowledge Acquisition

Our team used these approaches to gather requirements for system designs:

- Interviewed domain experts to better understand the screening processes;
- Analysed relevant academic researches and industrial reports to better study the nursing planning processes;

3.2 Knowledge Representation

Project requirements are defined in table formats for easier viewing and understanding.

Scopes Specification

Item	Description
Shift Type and Length	Day, Evening, Night or others (user definable)
Roster Days	The roster is constructed based on 24/7 working condition.
Roster Length	4 weeks calendar will be planned each time.
Skill Mix	Nurse officer, Staff nurse and others
Shift Requirements	Each staff will be given a rest day and a day off.
Employment Status	Full Time or Part-time

Hard Constraints

Hard constraints are a set of conditions that must be satisfied.

Item	Description
Working Hours	The working hours shall be regulated in accordance with the present practice on the basis of a maximum of 42 hours (excluding meal breaks) per week.
Leave Request	Staff on planned leave (annual leave, birthday leave, public holiday leave, family care leave, exam leave, maternity leave, long hospitalization leave) shall not be rostered with shifts.
Shift Requirements	One staff can only be rostered with one shift per day. The end

	time of previous shift shall be 10 hours away from the start time of next shift minimally.
Day Off and Rest Day	Every staff shall be entitled to 1 rest day and 1 day off per week.

Soft Constraints

Soft constraints are a set of conditions that should be satisfied whenever possible.

Staff Skill Mix Ratio

Shift/Ratio	Day Shift			Evening Shift			Night Shift		
	Nurse Officer	Staff Nurse	Others	Nurse Officer	Staff Nurse	Others	Nurse Officer	Staff Nurse	Others
Skill Ratio									

Staff Preference

Positive Soft Constraint	Negative Soft Constraint
Preferred Shift	Non-Preferred Shift
Preferred Day Off	Non-Preferred Day Off
Maximum consecutive working days	
Minimum consecutive working days	

Problem Modeling

Nurse rostering is a two-dimensional timetabling problem that deals with the assignment of nursing staff to shifts across a scheduling period subject to certain constraints.

Shift Planning	Day 1	Day 2	Day 3	...	Day N
Nurse 1	Day	Day	Day off	Rest Day	Night
Nurse 2	Evening	Day	Day	Day	Day
Nurse 3	Night	Night	Night	Day off	Rest Day
Nurse 4	Day	Day	Day	Night	Night
Nurse 5	Evening	Evening	Evening	Evening	Day off
Nurse 6	Night	Night	Rest Day	Night	Night
...	...	...	...	...	...
Nurse N	Day	Evening	Evening	Day off	Evening

4.0 Solution

4.1 Solution Research

The team has done intensive research for the design and architecture for the Nurse Rostering Optimization System. Particularly, the team evaluated:

1) Java Swing Based desktop application for Nurse Rostering, an example in Optaplanner 7.x;
2) Rotabuilder, based on Apache ISIS and Optaplanner 6.4.
3) Optaplanner web version, Optaplanner integrated with comprehensive UI.

Choice of Optaplanner

Optaplanner is chosen because it is an open source software with source codes readily available for learning and prototyping. Furthermore, it provides built-in rule engines to accommodate the ever-changing business rules and a score-based solver to assign staff to shifts.

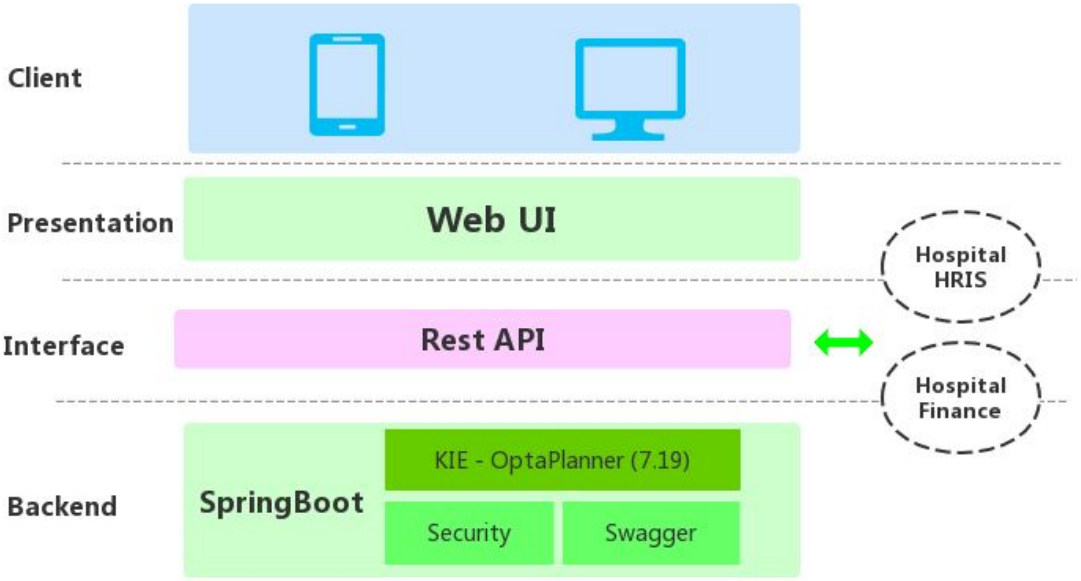
Choice of Spring Boot Framework

While these examples provide great education value on how Optaplanner works, they fall short in terms of enterprise-grade readiness, where factors like inter-system operability, security and scalability are highly valued. For example, in the financial services industry - a highly regulated industry like healthcare - large banks such as the Development Bank of Singapore (DBS) have been utilizing cloud native solutions and micro-service oriented architecture like Spring Boot to rapidly introduce features to the market and integrate with existing banking systems.

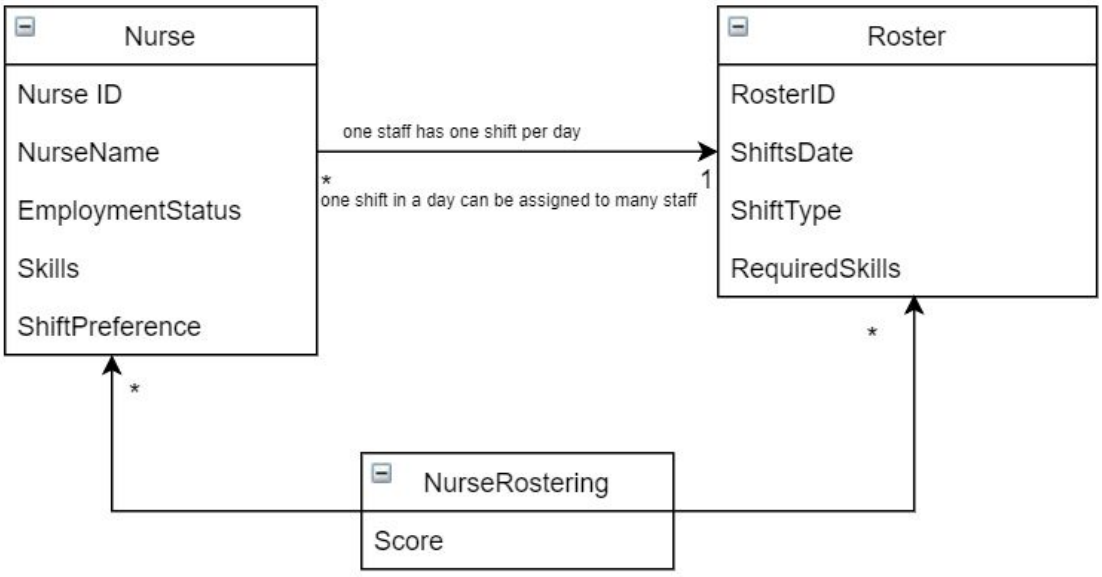
The team further researched and understood that RedHat Process Automation Manager (the superset of Optaplanner), from version 7.1 release, it supports the deployment of the process automation manager runtime as a “capability” within Spring Boot applications. Thus the team chose to adopt the micro-service oriented architecture to ensure easier and better integration in heavily regulated enterprise environments in hospital and healthcare industry in general.

4.2 System Architecture

The system architecture diagram shown below illustrates how the front-end web platform has been integrated with the back-end optimization system through REST API.



4.2 Solution Modeling



Rule and score Configurations

4.2 Tabu Search

4.5 Project Scope and Assumptions

To effectively demonstrate business value and functionalities of the product, the following scope and assumptions have been defined.

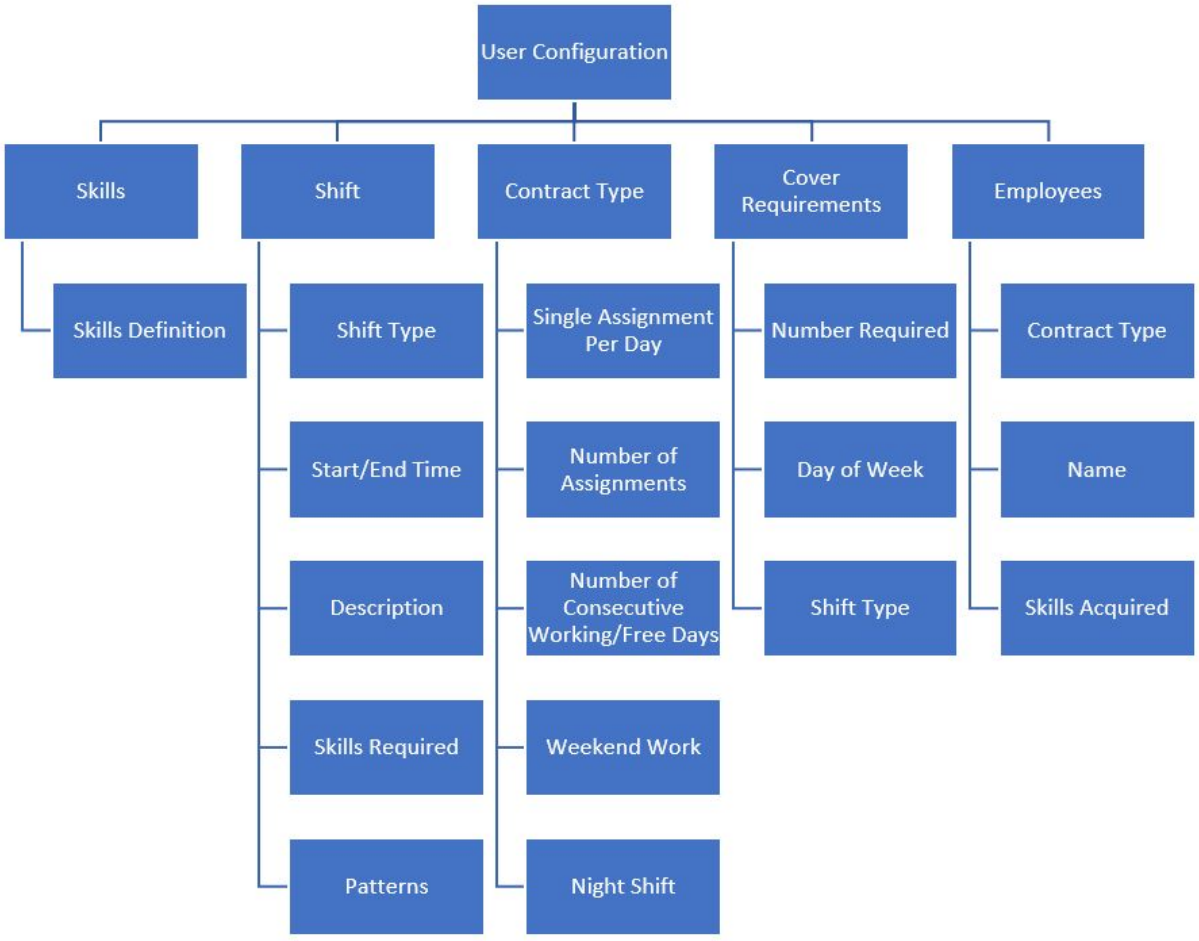
- Geographical context and scheduling constraints has been localized to Singapore
- For this project, only the rostering for nurses have been considered
- Planning duration has been defaulted to four calendar weeks (user configurable)

4.6 System Features

Despite many limitations, the team has leveraged on the pros and cons of different technologies to come up with the most optimized design, which can substantially add value to our users, mainly the banks.

4.6.1 System Intelligence - Constraints Configuration Variables

Most of our constraints variables are user configurable so that users can adjust them accordingly to meet their business needs. These variables will then be used by the constraints solver engine. The below chart shows the major configuration entities that users can change.



4.6.2 Ease of Access

The system front-end is a web platform. Running the front-end requires only one command line.

4.6.3 Security

After properly deployed, the front-end and back-end components works as blackbox. Although front user from internet can access to web platform but the planning and optimization service is completely blind to them. The RESTful API communication between front-end and back-end systems are secured by basic authentication.

4.6.4 Scalability

The system is developed as a micro-service that can be scaled to cater to high workloads in the future.

5.0 Limitations and Future Enhancements

5.1 Limitations

Given the limited time and resources, the team has decided to prioritize the project execution in the following order

1) **Understanding of Singapore specific nurse rostering challenges and requirements**
   We took time to understand the nurse rostering challenges from our Healthcare SME and defined the hard and soft constraints.

2) **Definition and design of a micro-services oriented system architecture**
   To ensure future enhancements can be added, we evaluated several Optaplanner sample implementations and decided on the Spring Boot framework that is based on the industry standard Micro-services oriented system architecture.

3) **Translation business and technical requirements into Optaplanner implementation**
   The team deep dived into sample Optaplanner implementations to understand its various components and implemented the aforementioned goals in Optaplanner.

4) **User Interface**
   User Interface is more of a prototype currently with a more developed version planned as future components. This section will be further addressed in later sections of the report.

5.2 Future Enhancements

As our system design is based on the micro-services oriented architecture that provides flexibility and scalability, the team is confident that future enhancements in the areas below can potentially be added

1) **Multi-tenancy to support other hospital departments**
   At the current state, the system supports on nurses and hospital wards. The system can be expanded to support other hospital departments such as clinics and & central kitchens, where similar requirements exist.

2) **Near real-time support**

In the future, near real-time planning can be implemented, where planning can be triggered automatically and roster updated with notifications to affected employees.

3) **Finance System Integration for Cost Optimization**
Integration with Finance systems can be done so that the optimization model can consider additional finance-related factors with the aim of achieving more operational savings.

4) **Hybrid Reasoning System with ML models for skills use & demand forecasting**
Machine Learning techniques can be employed to predict demands for number of nurses and their skills. This can then lead to a self-learning hybrid reasoning system where the optimization model can cater to changing demand and skill use trends.

5) **Enhanced User Interface**
Stub. **This section to be added for alternative implementation @Richard**

6.0 Conclusion

In this report, the team has demonstrated the business case of why effective nurse rostering is vital for hospital operations and how reasoning system implementations like optimization with Optaplanner helps to achieve business benefits and operational savings.

7.0 Bibliography

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7.0 Appendix A