SIMULATION OF SCHEDULING AND COST EFFECTIVENESS OF NURSES USING DOMAIN TRANSFORMATION METHOD

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ABSTRACT

Nurse scheduling is a complex combinatorial optimization problem. With increasing healthcare costs, and a shortage of trained staff it is becoming increasingly important for hospital management to make good operational decisions. A major element of hospital expenditure is staff cost. In order to help Kajang Hospital to make decisions about staffing and work scheduling, a simulation model was created to analyse the impact of alternate work schedules and investigate the optimum balance between the staffing levels of the ward and the ability to achieve good quality schedules. In this paper, we extend our novel approach to solve the nurse scheduling problem by transforming it through Information Granulation. This approach satisfies the rules of a typical hospital environment based on a real data set benchmark problem from Kajang Hospital.

Generating good work schedules has a great influence on nurses` working condition which is strongly related to the level of a quality health care. Domain transformation is an approach to solving complex problems that relies on well-justified simplification of the original problem. Solution of such a simplified problem and subsequent refinement of this solution to compensate for the simplifications introduced in the first step. Compared to conventional methods, our approach involves judicious grouping (information granulation) of shifts types' that transforms the original problem into a smaller solution domain. Later these schedules from the smaller problem domain are converted back into the original problem domain by taking into account the constraints that could not be represented in the smaller domain. An Integer Programming (IP) is formulated to solve the transformed scheduling problem by expending the branch and bound algorithm. We have used the GNU Octave, open source mathematical modelling and simulation software for Windows to solve this problem. Results from simulations on real data problem sets for a typical hospital in Malaysia shows that this algorithm facilitated computation of feasible schedules in a short time with non-critical constraints being satisfied to a large degree. The resulting solutions facilitated cost benefit analysis of different staffing levels.

INTRODUCTION

Nurse scheduling problem, popularly known as (NSP), is the task of assigning an appropriate and efficient work regime for nurses in both private and government hospitals. Scheduling in an organization is very important to ensure the process of managing the company is effective and efficient. According to (Henderson V.A,1939) "The unique function of the nurse is to assist the individual, sick or well, in the performance of those activities contributing to the heath or its recovery that he would perform unaided if he had the necessary strength, will or knowledge". Therefore, in order for the nurses to perform their job well, they need to be organised and this resulted in the formation of nurse scheduling. Nurse scheduling is often done manually, takes too much time and seldom show best quality results (Bouarab et al, 2010).

This may seem like an easy task but in reality it's something that requires a lot of effort and is very time consuming. Several requirements must be taken into account such as a minimal allocation of a ward, legal regulations and personal needs of the nurse (Abdennadher & Schlenker, 1999). In NSP, there are two types of constraint. They are hard constraint and soft constraint. Hard constraint is a rule that need to be encountered at all times or else the schedule is counted to be infeasible and not accepted. Soft constraint is operated to estimate the quality of the solution. So, soft constraint is not necessary but is required to be fulfilled as much as possible. Nevertheless, to get a schedule that encounters all the hard constraints it is frequently required breaking some of the soft rules. A weight is allocated for each soft constraint to reflect its worth. The objective of nurse scheduling is to find a schedule that

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satisfies all hard constraints and minimises the degree to which the soft constraints are violated.

In this study, we present an alternative way of tackling a large, real world nurse scheduling problem by using integer programming (IP). With this approach, the hospital is supplied with detailed information about the schedule, which they can use to make the selection objectively. We use the domain transformation method introduced in [Baskaran et al. 2009, 2012,2013] as a practical illustration of the information granulation methodology [Bargiela et al. 2002, 2008] to generates multiple feasible low cost rosters, which are evaluated with simulation. Domain transformation is an approach to solving complex problems that relies on well-justified simplification of the original problem. We subdivided the problem into smaller subproblems in a systematic way and capable to reproduce the result. This approach is able to conquer solution easily by avoiding random search. Conversely, in other methods, some failed to reproduce results, and produce inconsistent performance, some works best on some datasets but failed to repeat the good characteristics on other datasets. The previous state-of-the-art never used Information Granulation (Domain Transformation Approach-DTA), thus dealing with a lot of cross referencing and checking of data. We have also approached the problem using the demand simulation to check the cost effective scheduling of nurses using the domain transformation method. In this paper, we discuss the process and results from these method.

NURSE SCHEDULING PROBLEM AT KAJANG HOSPITAL

The scheduling problem presented in this paper has been studied for three ward in a large Malaysian hospital. The problem is based on the situation of coronary care unit (CCU), medical ward and male ward in Kajang Hospital. We outline the following characteristics.

1. We have to adhere to Malaysia national laws, and the collective labor agreements enforced in Malaysian hospitals.

2. The requests of the personnel are very important, and should be met as much as possible; the soft constraints we use are those that, in our experience, represent the situation in Kajang hospital.

3. It is not necessary to consider qualifications, as all personnel are highly qualified. However, the specialized nurses are required to oversee all the tasks in each shift.

There are ten specialized nurses and eighteen normal nurses in Kajang Hospital. All the nurses are full time and have a contract of 40 hours per week. There are 28 scheduling problems involves assigning a certain number of different types of shifts as illustrated in Table 1 which satisfies the daily coverage requirements for these shift types.

Each of the shift types cover different number of hours including one hour of rest time. Early and Late shift covers 7 hours, day-shift covers 9 hours, and night shift covers 10 hours.The scheduling period practised in the hospital is 2 weeks. There are few types of rest days practised in this hospital. They are Sleep Day (SD), Day Off (DO), Public Holiday (PH), Annual Leave (AL), and Emergency Leave (EL).

Table 1: Shift Types and Demand during a week

Shift type	Start time	End Time	**Demands**						
			M	**T**	**W**	**T**	**F**	**S**	**S**
Early	07:00	14:00	6	6	6	6	6	6	6
Day	08:00	17:00	1	1	1	1	1	1	1
Late	14:00	21:00	6	6	6	6	6	6	6
Night	21:00	07:00	3	3	3	3	3	3	3

Early = E Day = D Late = L Night= N

Hard Constraints

The hard constraints listed below must be met in any conditions otherwise the schedule is considered to be infeasible and unacceptable.The hard constraints for NRP at Kajang Hospital are:

- HC1: Demands need to be fulfilled
- HC2:For each day, 1 nurse may start only one shift.
- HC3:One of the employee requires to perform only the Office Hour shift per day
- HC4:At least one skilled nurse must be scheduled to each shift.
- HC5:The number of consecutive shifts (night) is at most 3.
- HC6:The number of consecutive shifts (workdays) is at most 6.
- HC7:Following a series of 3 consecutive night shifts, a 48 hours rest is required.
- HC8:Following a series of 6 consecutive day shifts, a 24 hours rest is required.
- HC9:The maximum number of night shifts is 3 per period of 2 consecutive weeks.

Soft Constraints

Ideally these constraints should be satisfied as much as possible. However, in real world circumstances, it is usually necessary to violate some of these soft constraints. Depending on how strongly these soft constraints are desired (especially in comparison to other soft constraints), a weight is assigned to each of them. Soft constraints replicate the general preferences of the nurses and hospital’s requirements at Kajang Hospital. The weights of soft constraints in the Kajang Hospital are described in Table 2.

Table 2: Soft constraints and their weights

Soft Constraints		Weights
SC1	Avoid sequence of shifts with length of 1 for all nurses.	1000
SC2	The rest after a series of *morning* or *evening* shifts is at least 2 days.	100
SC3	The number of shifts is within the range [4, 6] per week	10
SC4	The length of a series of shifts should be within the range of [4, 6].	10
SC5	Day on/off request. Requests by nurses to work or not to work on specific days of the week should be respected, otherwise solution quality is compromised	10
SC6	Shift On/Off Request. Similar to the previous but now for the specific shifts on certain days.	10
SC7	For all nurses, the length of a series of *morning* shifts should be within the range [1, 4]. It could be within another series of shifts.	10
SC8	For all nurses the length of a series of *evening* shifts should be within the range of [1, 4]. It could be within another series of shifts.	10
SC9a	A *morning* shift after the office *hour* shift should be avoided.	5
SC9b	An *evening* shift after the *office hour* shift should be avoided.	5
SC10	An evening shift after the day off that follows by with night shift	1

Objective Function

The objective function aims to minimize the total penalty of the soft constraints violation. A penalty weight is given for each soft constraint based on the importance of that constraint. So, this penalty weighting is simply a number. The higher the weight, the more strongly desired the satisfaction of this constraint is. The penalty of a feasible schedule is the sum of the weights of all the violations of soft constraints in the schedule. One key concern regarding setting the weights of constraints in NSPs is that, there are no standard weights to be given for each soft constraint. This is based on the wide range of constraints that are diverse from one hospital to another. Table 2 presents the weight of each soft constraint. As a channel, the weights could be described as follows:

Weight 1000 : The constraint should not be violated unless absolutely necessary.
Weight 100 : The constraint is strongly desired.
Weight 10 : The constraint is preferred but not critical.
Weight 5: The constraint is favoured but not crutial.
Weight 1 : Try and obey this constraint if possible but it is not essential.

PROPOSED SOLUTION OF SIMPLIFIED PLAN FOR SIMULATION

The simulation model describes the functioning of the main processes in a nurse scheduling problem. In our (figure 1), we have not only performed an efficient scheduling simulation but also presented a cost effective schedule by excecuting the demand simulation.

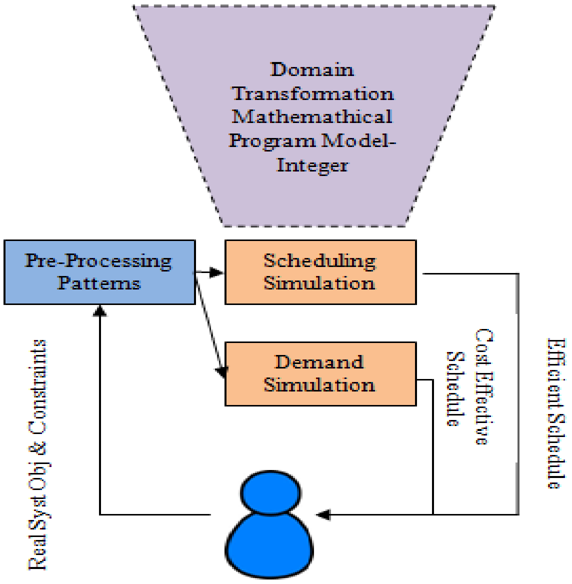


Figure 1: Design of the simulation model

Interactive scheduling is facilitated in our approach. The novelty in our research in contrary with other solutions. Our solution is focused on solving complex problems that relies on well-justified simplification of the original problem. We subdivided the problem into smaller subproblems in a systematic way and capable to reproduce the result. This identification of interactive scheduling is dynamic . It is thus fully independent user oriented and compatible with the new human centred computing paradigm. It is important to have easily understandable results in both domains. Another benefit in this simulation model is that the domain transformation can reduce computational complexity and therefore reduce the computational time. Besides, it also reduces the cross referencing over the detailed swapping of shifts for individual nurses. The goal of this scheduling simulation is to test how the different schedules perform when, for instance, the workload or capacity copes with uncertainty. In order to retrieve meaningful results, the simulation was tested intensively with a range of different parameters. This was then discussed with the real system materon to identify a number of service criteria in coordination with the hospital. If the first results indicate that the schedule do not meet the goals set in the simulation model, it can be necessary to adjust or add some of the constraints in the mathematical programming model. They can choose which schedule to implement, since they have been provided with all the information they need concerning the different steps. Through this simulation model, the schedule obtained will not make any difference in terms of the different order of processing. The schedule is the same when we change the order of individual patterns or nurses.

Balancing The Cost Of Soft Constraints And The Staff Cost

Nurse scheduling is inextricably linked with determining total number of nurses. Most of healthcare systems are under pressure to control costs while trying to provide high levels of service. This is a difficult balance to strike. Establishing nurse scheduling model is a delicate balance between enhancing patient safety and provider productivity while also optimizing organizational costs. With demands to improve patients' clinical outcomes and decrease the escalating costs of inpatient care, nurses are focusing on how nurses spend their time rather than just raising staffing levels to positively impact patient outcomes. Because nursing wages constitute a high proportion of a hospital's budget, understanding the costs of number of nurses required is critical to manage them. Having a small number of nurses may impact quality of care while employing a large number of nurses and not utilizing their contractual hours is clearly wasteful. In our approach, we are balancing these concerns by combining the cost for the underutilization of nurses with the costs of violation of soft constraints into a single performance index. This process is discussed in (Baskaran, G., 2013). Hence, based on this demand simulation, we have produced numerical simulation experiments for this current nurse scheduling problem. In this problem we assume that the following represents well the notional cost of underemployed staff:

$$CU = U * 0.2 \quad (1)$$

where:
CU = Cost of under- utilization

DOMAIN TRANSFORMATION USING INTEGER PROGRAMMING

The domain transformation approach introduced in [Baskaran et al. 2012, 2013] departs from the convention of direct exploration of the space of schedules, as described in the preface section. We observe that the three shifts (e, d, l) are subject to identical soft constraints. Consequently, the first overview of the scheduling problem is managed by considering the e-, d- and l-shifts as being of the same type. We denote this merged shift as M-shift and will refer to this transformation as transformation from the edlNR domain to the MNR domain.

In the MNR domain the requirement for staff cover during the corresponding shifts is summarised in Table 3. This in itself does not have any adverse effect on the computational complexity of the scheduling process. However, the important gain is that the reduction of the number of shifts from 5 to 3 makes the number of possible schedules in the MNR domain reduce to $\mathbf{28*3^{28}=6*10^{14}}$. This represents a reduction by a factor of 10^7. There is a potential for additional domain transformation and the associated computational gain even though traditional scheduling methods are more efficient in this reduced space.

Table 3: Shift Types and the required numbers of nurses on specific shifts in the MNR domain

Shift type	**Number of nurses on specific shifts**						
	M	T	W	T	F	S	S
M	13	13	13	13	13	13	13
N	3	3	3	3	3	3	3
R	Notional shift that last minimum of 2 days						

We introduce a granulated data structure referred here as "pattern". Pattern represent a feasible sequence of shifts that has a specific cost associated with it. So, as for this NSP problem, there are 36 zero- cost patterns. Figure 2 provides examples of such zero-cost patterns and Figure 3 provides examples of non-zero-cost patterns.

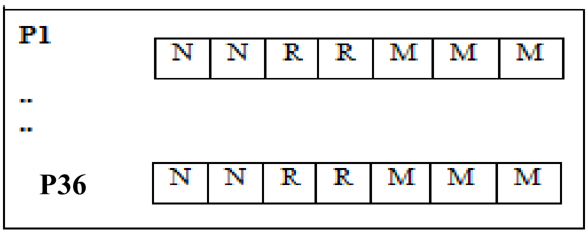


Figure2: No violation of Soft constraints (called as zero cost patterns)

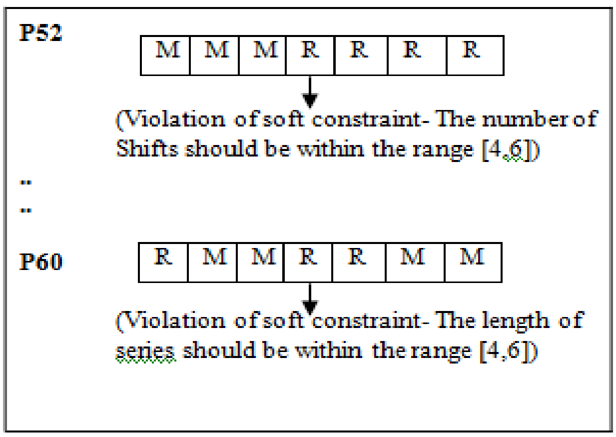


Figure3: Violation of Soft constraints with Cost 10 (called as non-zero cost patterns)

This solution of the scheduling problem in the domain of patterns needs to be converted back into the original edlNR domain. This involves small computational effort primarily concerned with the consideration of the specific requirements with regard to the preference of e-, d- and l-shifts as summarised in Table 4.

Table 4: Penalties of violation for the conversion of **M**NR domain to edlNR domain.

		Succeeding shifts			
		N	E	D	L
Preceding Shift	N	ok	n/f	n/f	n/f
	E	ok	ok	ok	ok
	D	nf	5	ok	5
	L	ok	ok	ok	ok

Early = E Day = D Late = L Night= N
Not Feasible = n/f

Our *domain transformation* approach can be summarised as a 3-stage process:

I) conversion of the problem from the original edlNR domain into a problem in the **M**NR domain;
II) solution of the problem in the **M**NR domain
III) conversion of the **M**NR solution into a solution in the original edlNR domain

Integer Programming

In this paper, we apply Integer Programming an extension of Linear Programming that solves problem requiring integer solutions. We have solved the IP by implementing branch and bound. The basic concept underlying the branch-and-bound technique is to *divide and conquer*. To specify the above problem, the objectives are to minimize the values of individual variables. We formulate the entire problem associated with a 2-week scheduling period as the following IP model, which can be altered to adapt to any other problems with different constraints.

Let's call this binary pattern matrix: **Pb** .
This matrix is replicated for each nurse so the combined pattern matrix "**Aeq**". The selection of patterns from the **Aeq** represents the schedule that satisfies the equality constraints such as the cover requirement. This can be expressed as:

$$\mathbf{Aeq' * x = c'} \qquad (2)$$

where **x** is the unknown binary vector, representing a solution to the scheduling problem and **c** is the staff cover requirement. The requirement that each nurse is assigned at most one pattern represents a constraint that can be written as

$$\mathbf{A' * x <= b'} \qquad (3)$$

where **A** is a matrix with the number of columns corresponding to the number of nurses (say 28) and and **b** is a vector of 1s corresponding to the number of nurses . The objective of the optimization of the scheduling might be defined as trying to satisfy the cover requirement with the minimum number of nurses. This is expressed simply as:

$$\mathbf{Min\ \ NP * x} \qquad (4)$$

where **NP** is a vector of 1s of size "number of nurses times the number of patterns". The mathemathical model described above prepared a weekly schedule for wards up to 28 nurses at a government hospital at Kajang, Malaysia. The objective function is considered as a cost function, where cost is interpreted as penalty and penalty is defined based on the desirability of a nurse to work at a shift type on a day. Therefore our attempt is to minimize the penalty to the given constraints.

SIMULATION RESULT

For our approach, the IP part is solved by the latest GNU Octave's GLPK (4.45). For this simulation, an Intel Pentium 1.64GHz PC with 448MB RAM under Windows 7 was used. The results obtained by solving the Branch-and-Bound Integer Programming (BBIP) is presented in the following table. Practically, the materon may have to modify some shifts related to these violations, but these modifications are much easier than making a work table from scratch by hand. Solving within practical time will be dependent on the performance of IP solver. However, in the case of a problem with many shift types, the window width should generally be small.

Experiments on Scheduling Simulation

There are three experiments done according to different types of weeks. This simulation experiments done according to the domain transformation method. In order to verify the simulation model, hospital records are compared with simulation results. Most of the time, hospital did not manage to fulfil the demand that needs to be covered. However, by using our domain transformation approach, we manage to fulfill the demand; not just satisfying the hospital scheduling period of two weeks but also we proposed the four weeks and five weeks scheduling. Below are results on the final outputs generated. Table 5 to table 7 are results on the final outputs generated. They are presented in the Appendix. To facilitate this improvements, Table 8 shows the cost summary for the scheduling period of 2,4,and 5. It also shows the computational time required. This clearly shows that, our approach has the ability to introduce changes. Besides, it also can reduce computational complexity and therefore reduce the computational time.

Table 8: Table with time execution and cost summary

Weeks	Days	Cost	Time(s)
2	14	44	21
4	28	77	47
5	35	100	52

Numerical Result on Demand Simulation

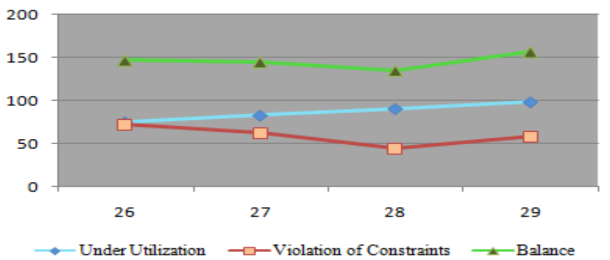
Numerical experiments described in this section provide a representative sample of the simulation studies conducted to balance the degree of satisfaction of soft constraints vs. the decisions on employing additional nursing staff. We have varied the required cover on individual shifts to simulate the decision support functionality. Based on the original problem, we have changed few sample runs of different number of nurses Table 9 presents the results of the best set of nurses which satisfies the demand of the original problem with a very reasonable cost for a month. While Table 10 and 11 represents the alternative demands with the number of nurses and this is concluded in Graph 1, Graph 2 and Graph 3 which shows clearly the representation of the various cost.

The results tables use the following notation:
TN = Total number of nurses
TC = Total number of contractual (in hours)
TW =Total Number of hours worked(in hours)
U(h/w) = Under Utilization of Nurses (hours/week)
CSC = Cost of violating Soft constraint
CU = Cost of under- utilization
T(s) = Time (in seconds) to execute the software

Case 1:

Table 9: The balance of violation of soft constraints and the underutilisation of nurses for the "13131313131313" D-shift and the "3333333" N-shift cover (TW=667h)

TN	TC	U (h/w)	CSC	CU	Ctot	T(s)
26	1040	193	67	38.6	105.6	18
27	1080	233	58	46.6	104.6	20
28	**1120**	**273**	**44**	**54.6**	**98.6**	21
29	1160	313	52	62.6	114.6	35

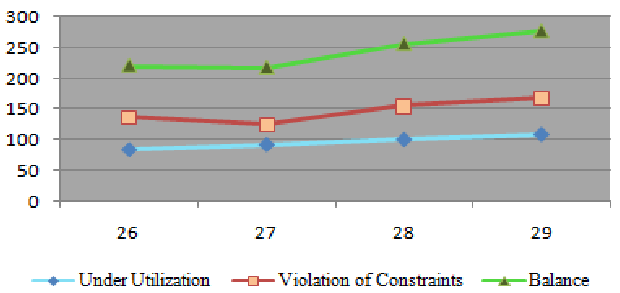


Graph 1: Balance between the constraint cost and the Under Utilization cost for the cover "13131313131313"

Case 2:

Table 10: The balance of violation of soft constraints and the underutilisation of nurses for the "12121212121212" D-shift and the "3333333" N-shift cover (TW=618h)

TN	TC	U (h/w)	CSC	CU	Ctot	T(s)
26	1040	422	136	84.4	220.4	45
27	**1080**	**462**	**125**	**92.4**	**217.4**	**55**
28	1120	502	155	100.4	255.4	57
29	1160	542	168	108.4	276.4	60

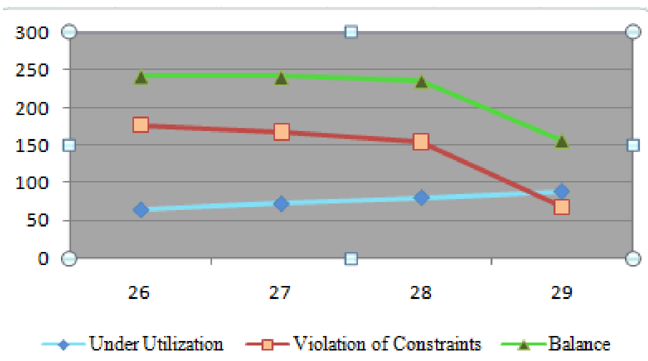


Graph 2: Balance between the constraint cost and the Under Utilization cost for the cover "12121212121212"

Case 3:

Table 12: The balance of violation of soft constraints and the underutilisation of nurses for the "14141414141414" D-shift and the "3333333" N-shift cover (TW=716h).

TN	TC	U (h/w)	CSC	CU	Ctot	T(s)
26	1040	324	177	64.8	241.8	64
27	1080	364	168	72.8	240.8	62
28	1120	404	155	80.8	235.8	56
29	**1160**	**444**	**68**	**88.8**	**156.8**	48



Graph 3: Balance between the constraint cost and the Under Utilization cost for the cover "14141414141414"

Discussion

This study illustrates the simulation modelling approach to nurse schedulling and the management decision support concerning the staffing levels. The scheduling simulation experiment provides the best schedules with different time horizons. Table 5,6, and 7 show snapshot of the schedules with the associated costs. Table 8 gives the summary of all the different time horizons and the associated costs. In reference to Table 8, we have suggested to the hospital management to have a 4 – 5 weeks scheduling as the cost is reduced with longer scheduling horizon. It is worth noting that manual scheduling by the hospital could not satisfy the required demand while our simulation result satisfies the demand and all other hard constraints.

Subsequently, the demand simulation experiments calculate how the constraints associated with the scheduling problem influence the cost-effectiveness of employing additional staff. We have shown this using a representative set of 3different scenarios with different number of nursing staff considered in each scenario. The result indicates that for the original problem demand of "13131313131313" D-shift, the exact balance is 28 nurses, as indicated in the graph 1. With fewer than 28 nurses we can't satisfy the clinical cover requirement and having larger numbers of nurses implies unnecessarily higher employment cost. The balance for the alternative clinical cover requirements (demands) of "12121212121212" is 27 nurses; and for the "14141414141414" the required number of nurses is 29.

CONCLUSION

As a conclusion, nurses performance in a hospital can be managed and coordinated with the aid of nurse scheduling. Nurse scheduling helps departments in the hospital to organise the number of nurses working in a day either in day shift or night shift. In a nutshell, with proper scheduling method of the nurses, a high quality roster can be produced. From the research that has been carried out, it has been quite clear that preparing a nurse schedule requires a huge amount of assessment on various criteria's such as organizational rules, personal data, legal regulations and many more. No single software can be used since each hospital has its own set of requirements and constraints but the same method can achieve a good solution. For proper results, the models and algorithms involved in generating the schedule should have a strong yet flexible structure in order to adapt to various unexpected situations that occur in a hospital. Modeling and simulating both process of scheduling and staffing , provide decision makers with a specific system that observe the impact of both interlinked process flow types. In the case of the documentation aid, it is important to take both process flow types into account. Framework and guidance for the modeler are essential in order to develop the quality of the developed model. Therefore, the method proposed is a valuable tool for the hospital modeler as it provides a raw model that can be adjusted to the requirements of the system under investigation.There are few main advantages that this simulated scheduling system offers such as it is cost effective, time efficient, repeatable and effective. This simulation model enables the visualization of the system over time. Besides, it is also versatile where model simulates real life and allows for a wide range of experiments with no impact on real objects. Domain transformation represents departure from a conventional one-shift-at-a-time scheduling approach. It offers an advantage of efficient and easily understandable solutions as well as offering deterministic reproducibility of the results. We note however that it does not guarantee the global optimum.

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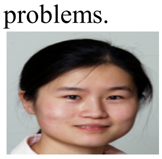
ANDRZEJ BARGIELA is Professor in the School of Computer Science at the University of Nottingham. He served as President of the European Council for Modelling and Simulation (ECMS) during 2002-2006 and 2010-2012. He is Associate Editor of the IEEE Transactions on Systems Man and Cybernetics and Associate Editor of the Information Sciences. His research involves investigation into Granular Computing, human-centred information processing as a methodological approach to solving large-scale data mining and system complexity problems.



DR RONG QU is a Lecturer in the School of Computer Science at the University of Nottingham. She gained her PhD in Computer Science from the University of Nottingham in 2002. Her main research areas include meta-heuristics, constraint programming, IP/ILP, case based reasoning methodologies and knowledge discovery techniques on scheduling, especially educational timetabling, healthcare personnel scheduling, network routing problems and graph colouring. In total she has more than 30 papers published or to appear at international journals and peer-reviewed international conferences. Dr Qu is also a guest editor for special issues at the journal of Memetic Computing and the Journal of Scheduling, and the program chair of several workshops and an IEEE symposium.

APPENDIX

Table 5: Two week in **edl**NR schedule with total cost 44

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Computed Schedule for 2 week(s)
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Days->   | MTWTFSS viol cost | MTWTFSS viol cost

Nurse 01(40, ):LLNNRRR   0    0|REEEERR   0    0|
Nurse 02(40, ):NNRRELE   0    0|EEERREE   0    0|
Nurse 03(40, ):RRRLNNN   0    0|RREEEER   0    1|
Nurse 04(40,o):DDDDRRR   0    0|RRRDDDD   0    0|
Nurse 05(40, ):RREEEER   0    0|LENNRRR   0    0|
Nurse 06(40, ):EEERRRL   0    0|EEEERRR   0    0|
Nurse 07(40, ):EERRRLE   0    0|NNRRREE   0    0|
Nurse 08(40, ):ERRRLLE   0    0|NNRRREE   0    0|
Nurse 09(40, ):RRRELEE   0    0|EERRREE   0    0|
Nurse 10(40, ):LLNNRRR   0    0|RDEEERR   0    5|
Nurse 11(40, ):NNRREEE   0    0|ERRRELE   0    0|
Nurse 12(40, ):REEEERR   0    0|RRDEELR   0    5|
Nurse 13(40, ):RREEEER   0    0|LLNNRRR   0    0|
Nurse 14(40, ):EEERRRD   0    0|ELLRRRL   0    5|
Nurse 15(40, ):RELEDRL   0    0|LLNNRRR   0    0|
Nurse 16(40, ):LLNNRRR   0    0|RLLLLRR   0    0|
Nurse 17(40, ):NNRRLEL   0    0|DRRRLLL   0    0|
Nurse 18(40, ):ERRRNNN   0    0|RRLLLRL   0   10|
Nurse 19(40,S):EEEERRR   0    0|RRRLNNN   0    1|
Nurse 20(40,S):RRLLEER   0    0|ELEEEER   0    0|
Nurse 21(40,S):LLLRRRE   0    0|LELRRRE   0    0|
Nurse 22(40,S):LLRRRLL   0    0|NNRRLLL   0    0|
Nurse 23(40,S):LLLRRRL   0    0|LLLRRRL   0    0|
Nurse 24(40,S):RRLLLLR   0    0|RRRLNNN   0    1|
Nurse 25(40,S):RRRRRRR   0   10|RRRRRRR   0   10|
Nurse 26(40,S):RRRLNNN   0    0|RRRLLLL   0    1|
Nurse 27(40,S):RRRLLDL   0    0|LRRRNNN   0    5|
Nurse 28(40,S):RRLLLLR   0    0|RRLLLLR   0    0|

Verifying total nurses available each day:
-------------------------------------------

Total E:  6666666 | 6666666

Total D:  1111111 | 1111111

Total L:  6666666 | 6666666

Total N:  3333333 | 3333333
```

Table 6: Suggested schedule 4 week in **edl**NR schedule
with total cost 77

```
Computed Schedule for 4 week(s)
-----------------------------------
Days->   | MTWTFSS viol cost | MTWTFSS viol cost | MTWTFSS viol cost | MTWTFSS viol c

Nurse 01(40, ):LLNNRRR   0     0|REEEERR   0     0|RRRLNNN   0     0|RREEEER   0     1|
Nurse 02(40, ):NNRRELE   0     0|EEERRLL   0     0|NNRRREL   0     0|EEEERRR   0     0|
Nurse 03(40, ):RRRLNNN   0     0|RREEEER   0     0|RREEEER   0     0|EEEERRR   0     1|
Nurse 04(40,O):DDDDRRR   0     0|RRRDDDD   0     0|RRDDDDR   0     0|RDDDDRR   0     0|
Nurse 05(40, ):RREEEER   0     0|LENNRRR   0     0|EEEERRR   0     0|RRRLNNN   0     1|
Nurse 06(40, ):EEERRRL   0     0|EEEERRR   0     0|LENNRRR   0     0|REEEERR   0     0|
Nurse 07(40, ):EERRRLE   0     0|NNRRRLE   0     0|EEEREEE   0     0|ERRRNNN   0     0|
Nurse 08(40, ):ERRRLLE   0     0|NNRRREL   0     0|EEEERRR   0     0|RRREEEE   0     0|
Nurse 09(40, ):RRRELEE   0     0|EERRRLL   0     0|NNRRREE   0     0|EERRREE   0     0|
Nurse 10(40, ):LLNNRRR   0     0|RDEEERR   0     0|RRLLNNN   0     0|RRRLEEE   0     5|
Nurse 11(40, ):NNRREEE   0     0|ERRREEE   0     0|ERRREEE   0     0|ERRREEE   0     0|
Nurse 12(40, ):REEEERR   0     0|RRDEEER   0     0|LENNRRR   0     0|RRELLDR   0     5|
Nurse 13(40, ):RREEEER   0     0|LLNNRRR   0     0|RRRLLLE   0     0|NNRRRLE   0     0|
Nurse 14(40, ):EEERRRD   0     0|ELLRRRE   0     0|EDERRRE   0     0|DELRRRD   0     5|
Nurse 15(40, ):RELEDRL   0     0|LLNNRRR   0     0|RLLEERR   0     0|LLNNRRL   0     0|
Nurse 16(40, ):LLNNRRR   0     0|RLLLLRR   0     0|RLLEERR   0     0|LLNNRRR   0     0|
Nurse 17(40, ):NNRRLEL   0     0|DRRRLEE   0     0|DRRRNNN   0     0|RRLLLRL   0    10|
Nurse 18(40, ):ERRRNNN   0     0|RRLLLRL   0    10|NNRRLLR   0    10|RLLRRLL   0    11|
Nurse 19(40,S):EEEERRR   0     0|RRRLNNN   0     0|RRREEEE   0     0|LRRREEL   0     1|
Nurse 20(40,S):RRLLEER   0     0|ELEEEER   0     0|LLNNRRR   0     0|RRLELLR   0     0|
Nurse 21(40,S):LLLRRRE   0     0|LELRRRE   0     0|EEERRLL   0     0|EEERRLL   0     0|
Nurse 22(40,S):LLRRRLL   0     0|NNRRLLE   0     0|LRRRLLL   0     0|NNRRLLL   0     0|
Nurse 23(40,S):LLLRRRL   0     0|LLLRRRL   0     0|LLLRRRL   0     0|LLNNRRR   0     0|
Nurse 24(40,S):RRLLLLR   0     0|RRRLNNN   0     0|RRRLLLL   0     0|RLLLLRR   0     1|
Nurse 25(40,S):RRRRRRR   0    10|RRRRRRR   0    10|RRRRRRR   0    10|RRRRRRR   0    10|
Nurse 26(40,S):RRRLNNN   0     0|RRRLLLL   0     0|LLRRRLL   0     0|NNRRLLE   0    11|
Nurse 27(40,S):RRRLLDL   0     0|LRRRNNN   0     0|RRLLLRD   0    10|LRRRNNN   0    15|
Nurse 28(40,S):RRLLLLR   0     0|RRLLLLR   0     0|RLLLLRR   0     0|LLLLRRR   0     0|

Verifying total nurses available each day:
------------------------------------------

Total E:  6666666 | 6666666 | 6666666 | 6666666

Total D:  1111111 | 1111111 | 1111111 | 1111111

Total L:  6666666 | 6666666 | 6666666 | 6666666

Total N:  3333333 | 3333333 | 3333333 | 3333333
```

Table 7: Suggested schedule 5 week in **edl**NR schedule
with total cost 100

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-----------------------------------
Computed Schedule for 5 week(s)
-----------------------------------
Days->   | MTWTFSS viol cost | MTWTFSS viol cost | MTWTFSS viol cost | MTWTFSS viol cost | MTWTFSS viol c

Nurse 01(40, ):LLNNRRR   0     0|REEEERR   0     0|RRRLNNN   0     0|RREEEER   0     0|LLNNRRR   0     1|
Nurse 02(40, ):NNRRELE   0     0|EEERRLL   0     0|NNRRREL   0     0|EEEERRR   0     0|LLNNRRR   0     0|
Nurse 03(40, ):RRRLNNN   0     0|RREEEER   0     0|RREEEER   0     0|EEEERRR   0     0|REEEERR   0     1|
Nurse 04(40,O):DDDDRRR   0     0|RRRDDDD   0     0|RRDDDDR   0     0|RDDDDRR   0     0|RDDDDRR   0     0|
Nurse 05(40, ):RREEEER   0     0|LENNRRR   0     0|EEEERRR   0     0|RRRLNNN   0     0|RRREEEE   0     1|
Nurse 06(40, ):EEERRRL   0     0|EEEERRR   0     0|LENNRRR   0     0|REEEERR   0     0|RRRLNNN   0     1|
Nurse 07(40, ):EERRRLE   0     0|NNRRRLE   0     0|EEEREEE   0     0|ERRRNNN   0     0|RREEEER   0    10|
Nurse 08(40, ):ERRRLLE   0     0|NNRRREL   0     0|EEEERRR   0     0|RRRLLLE   0     0|NNRRREE   0     0|
Nurse 09(40, ):RRRELEE   0     0|EERRRLL   0     0|NNRRREE   0     0|EERRRLE   0     0|EEERRRE   0     0|
Nurse 10(40, ):LLNNRRR   0     0|RDEEERR   0     0|RRLLNNN   0     0|RRRLEEE   0     0|ERRREEE   0     5|
Nurse 11(40, ):NNRREEE   0     0|ERRREEE   0     0|ERRREEE   0     0|ERRRELE   0     0|EEERRRE   0     0|
Nurse 12(40, ):REEEERR   0     0|RRDEEER   0     0|LENNRRR   0     0|RREEEER   0     0|RREEEER   0     5|
Nurse 13(40, ):RREEEER   0     0|LLNNRRR   0     0|RRRLLLE   0     0|NNRRRLE   0     0|EELERRR   0     0|
Nurse 14(40, ):EEERRRD   0     0|ELLRRRE   0     0|EDERRRE   0     0|DELRRRD   0     0|EELRNNN   0     5|
Nurse 15(40, ):RELEDRL   0     0|LLNNRRR   0     0|RLLEERR   0     0|LLNNRRL   0     0|DLLLRRR   0     5|
Nurse 16(40, ):LLNNRRR   0     0|RLLLLRR   0     0|RLLEERR   0     0|LLNNRRR   0     0|LLLLRRR   0     0|
Nurse 17(40, ):NNRRLEL   0     0|DRRRLEE   0     0|DRRRNNN   0     0|RRLLLRL   0    10|NNRRLDR   0    11|
Nurse 18(40, ):ERRRNNN   0     0|RRLLLRL   0    10|NNRRLLR   0    10|RLLRREL   0    10|RLLRLLR   0    11|
Nurse 19(40,S):EEEERRR   0     0|RRRLNNN   0     0|RRREEEE   0     0|LRRREEE   0     0|LRRREEE   0     1|
Nurse 20(40,S):RRLLEER   0     0|ELEEEER   0     0|LLNNRRR   0     0|RRLELER   0     0|RRRLLLL   0     0|
Nurse 21(40,S):LLLRRRE   0     0|LELRRRE   0     0|EEERRLL   0     0|EEERRLL   0     0|NNRRLLL   0     0|
Nurse 22(40,S):LLRRRLL   0     0|NNRRLLE   0     0|LRRRLLL   0     0|NNRRLDL   0     0|LRRRLLL   0     5|
Nurse 23(40,S):LLLRRRL   0     0|LLLRRRL   0     0|LLLRRRL   0     0|LLNNRRR   0     0|RRRLLLL   0     0|
Nurse 24(40,S):RRLLLLR   0     0|RRRLNNN   0     0|RRRLLLL   0     0|RLLLLRR   0     0|LLNNRRR   0     1|
Nurse 25(40,S):RRRRRRR   0    10|RRRRRRR   0    10|RRRRRRR   0    10|RRRRRRR   0    10|RRRRRRL   0    10|
Nurse 26(40,S):RRRLNNN   0     0|RRRLLLL   0     0|LLRRRLL   0     0|NNRRLLL   0     0|EEERRRL   0    11|
Nurse 27(40,S):RRRLLDL   0     0|LRRRNNN   0     0|RRLLLRD   0    10|LRRRNNN   0    10|RRLERLD   0    15|
Nurse 28(40,S):RRLLLLR   0     0|RRLLLLR   0     0|RLLLLRR   0     0|LLLLRRR   0     0|RRRLNNN   0     1|

Verifying total nurses available each day:
------------------------------------------

Total E:  6666666 | 6666666 | 6666666 | 6666666 | 6666666

Total D:  1111111 | 1111111 | 1111111 | 1111111 | 1111111

Total L:  6666666 | 6666666 | 6666666 | 6666666 | 6666666

Total N:  3333333 | 3333333 | 3333333 | 3333333 | 3333333
```