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A multiple objective model to scheduling staff in fire station

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ABSTRACT

Staff- scheduling is one of the most important phenomena from the fire station management point of view. Here computer develops a Fire station staff - timetabling model. This staff-timetabling model is an alternative to the current manual-made schedules, which is an intricate and time-consuming phenomenon. Even then, it leaves the users (staff) in a dissatisfying state. The growing model is liable for fire station-targets and staff liking. The fire station targets include ensuring an uninterrupted service with appropriate staff skills. Staff proclivities include unbiased consideration, avoiding consecutive shifts. The paper presents a model of goal programming for staff – timetabling with multiple conflicting objectives of a study for one-week distribution. The results of study indicate that this model can be use in fire stations in today's competing decision environment.

***Keywords*: Staff scheduling, 0-1 goal programming, Fire station objectives, Appropriate staffing size, Allocation decisions**

1. INTRODUCTION

The present work is an attempt to develop a structured course of action to appoint staff to different working shifts and different workdays. Minimum staffing used to make certain a uninterrupted and relevant service of fire protection in such a way that specific work requirements are satisfied and by this way avoid wasted labour. Here some goals are also under consideration acting as worker requests versus the balance workload, work pattern, work stretch and personal requests for vacations. Fire Station staff timetabling is very strenuous and gradual task. To satisfy these given requirements by staff, the duty timetabling should determine every day shift engagements of each fire working staff for a specified time. The timetabling should also be under fair consideration for every staff member and fulfill various goals.

The structure also bargains on righteousness bases among staff and considers staff requests to maximize their contentment level.With the help of this approach, we can able to provide a proper quality of service. To developing the scheduling system, number of priority levels is under consideration.

An integrated time scheduling model this satisfies the interests of both higher authorities and staff. The model accommodates flexible workpatterns by incorporating hours-of-day and day of the week scheduling problems **[1].** In Society the health and safety services is the task of 24 hours in a day and It is the beginning of shifts in other related service areas such as transportation. Fire Station, Communication etc. As a demand of society, workers are needed to cover many variations of shift schedules throughout the day. Further Studies have shown that shift work also adversely affect on works health **[2-4].**

For betterment in the task of well-shuffled shift duties up to the mark of satisfaction level of the working staff, there is a linear goal-programming model to cover initial stage of shift assignments of rotation. This particular study reports the complete procedure of applying the shift assignments of system in rotation way **[5].**To implement a one full day shift program in the fire service system, this study examines health and safety effects. The purpose of this study is to find out regressive effects of continuous shift rotation in every day, to find out the situations and policies for better fulfillment and to identify potential areas for better changes in shifts **[6-7], [10].** The given approach directed towards to avoid strong assumptions for workforce timetabling that helps in service quality and give proper comparison between costs and service quality **[8-9].** With the help of Genetic Algorithm, the focuses to understand the timetabling problem and to provide the quality services, study reports are very useful. The present studies are also capable to explain the complex optimization problem for allocating staff to duty in Hospitals **[11-13].** The current study presents shift-timetabling problem in a twenty-four hours running Call centre. Here the study works under integer programming for scheduling problem **[14-15].**

2. MATHEMATICAL MODEL

First, current fire staff practices prevailing in the Fire Station investigated. A Fire Station has several departments to cover different type of practices on regular basis such as Quick Call response, Expert in area search to time management and fieldwork services etc. Most of the Fire Stations have specialized staff in each department and they work only in that department, while in some fire stations staff interchanged among the various departments. The staffs in three shifts cover each department (or unit). Every shift is of eight continuous hours. First, Second and Third shift starts at 7 A.M., 3 PM and 11 PM respectively and ends at 3 PM, 11 PM & 7 AM respectively. Herein, weekly schedules for a unit are considered and each staff is required to work at minimum 5 days a week (proportionality factor). It ensures each staff at least a day-off in each week. Discussion with the staff also demonstrates that generally the worker prefers that number of night shifts should be less than total number of day shifts (satisfaction factor). Further, no worker allowed working in consecutive shifts (healthiness factor). Requirement of workers in each shift and in each day is to be met (optimality and completeness factor).

Table-I: Requirement of Workers in Each Shift for a Week

	Number of Fire Workers	**$\forall$ i = 1, 2, 3,---- , 7**		
		P_i	**Q_i**	**R_i**
Subgroup 1 (A-D)	4	1	1	1
Subgroup 2 (E-I)	5	2	1	1
Total	9	3	2	2

Variables

The following variables used in the model:

mand **n** →m represents number of staff available and n shows number of days in a particular schedule.

i and **k** → represents index for days and workers respectively, where i has values 1 to n and k has values 1 to m.

Variable	**x_{ik}**	**y_{ik}**	**z_{ik}**
Value	If worker k is assigned first shi for day i then $x_{ik} = 1$ Otherwise $x_{ik} = 0$	If worker k is assigned Second shift for day i then $x_{ik} = 1$ Otherwise $x_{ik} = 0$	If worker k is assigned Third shift for day i then $x_{ik} = 1$ Otherwise $x_{ik} = 0$

The parameters used in the goal-programming model defined as:

P_i, $Q_i$and R_i represents the staff requirement for First, Second and Third shift of day i respectively.

Table-II: Results of First Subgroup after Sub Problem Execution

	1			2			3			4			5			6			7			Sum
	I	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**D + N =**
A	-	P	-	P	-	-	-	-	P	-	P	-	-	-	P	-	-	-	-	-	-	3+2 = 5
B	-	-	P	-	P	-	-	P	-	P	-	-	-	P	-	P	-	-	-	P	-	6+1=7
C	P	-	-	P	-	-	P	-	-	-	-	P	P	-	-	-	-	P	-	-	P	4+3=7
D	P	-	-	-	-	P	-	-	-	P	-	-	P	-	-	-	P	-	P	-	-	5+1=6
Total	2	1	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	1	1	1	1	**18+7=25**

Goals and Priorities

To assimilate the soft constraints in this timetabling model, some important goals will include, which are consistent with the above-explained constraints. There are three goals, which have important weights to each goal, and the importance of each goal with respect to other ones represents through weightage. To express these significant weights, use penalty level for contravening the particular goal.

Three penalty levels described as:

P_1 : to minimize the deviations between the maximum required working days and the sum of actual days on.

P_2 : to avoid allocating a worker to exertion of night shift and then first shift in continuation.

P_3 : keep number of more day-duties in comparison to night duties.

Table-III: Results of Second Subgroup after Sub Problem Execution

	1			2			3			4			5			6			7			Sum
	I	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**D + N =**
E	-	-	-	-	-	-	P	-	-	-	-	P	-	P	-	P	-	-	P	-	-	4+1=5
F	-	-	-	P	-	-	-	-	P	-	-	-	-	-	P	-	P	-	-	P	-	3+2=5
G	P	-	-	-	-	P	-	P	-	-	P	-	-	-	-	-	-	P	-	-	-	3+2=5
H	-	P	-	-	P	-	P	-	-	-	-	P	-	P	-	-	-	-	-	-	P	4+2=6
I	-	-	P	-	-	-	-	-	-	P	-	-	P	-	-	-	P	-	P	-	-	4+1=5
Total	1	1	1	1	1	1	2	1	1	1	1	2	1	2	1	1	2	1	2	1	1	**18+8=26**

Constraints

Hard Constraints:

1. Daily workers need for the three shifts was described through these constraints as:

$\sum_{k=1}^{m} X_{ik} \geq P_i$, i = 1, 2, 3 ……….n ------------------------------------(1)

$\sum_{k=1}^{m} Y_{ik} \geq Q_i$, i = 1, 2, 3 ……….n ------------------------------------(2)

$\sum_{k=1}^{m} Z_{ik} \geq R_i$, i = 1, 2, 3 ……….n ------------------------------------(3)

2. It has decided to assign at the most on shift per day.

$X_{ik} + Y_{ik} + Z_{ik} \leq 1$ for all i = 1 to n & k = 1 to m----------- (4)

Soft Constraints:

To assimilate the soft constraints in the schedule, following goals were identified which are consistent with the above hard constraints.

Goal 1: The following constraints represent maximum six working days per week schedule so that the fire - staff gets at least a day-off in a week.

$\sum_{k=1}^{m}(X_{ik} + Y_{ik} + Z_{ik}) + 6\ P_i$; k = 1,2,3 ------- m----------------- (5)

Goal 2 : This goal keep away from assigning a worker to duty a night shift of a day and the consecutive first shift of the coming day so that a worker does not get two consecutive shifts in a day.

$Z_{ik} + X_{(i+1)k} + (d^-_{2ik} - d^+_{2ik}) = 1$; i = 1, 2, ----- (n-1) & k = 1, 2, ------ m-------------(6)

Goal 3: This goal endeavor to schedule more day shifts (first and second shift are considered as day shifts) than night shifts (third shift is taken as night shift).

$\sum_{k=1}^{m}(X_{ik} + Y_{ik} - Z_{ik}) + (d^-_{3k} - d^+_{3k}) = 1; \quad k = 1,2,3,......., m$ ……….(7)

Objective Function:

Different weights have assigned to given goals, which reflect the relative presence of each goal in compare to other goals. It was determined based on discussion with fire-staff and described by priorities. The expression for the O.F. has given by

$$\text{Min } z = P_1\sum_{k=1}^{m} \mathbf{d}^+_{1k} + P_2\left(\sum_{k=1}^{n-1}\sum_{k=1}^{m} \mathbf{d}^+_{2ik}\right) + P_3\sum_{k=1}^{m} \mathbf{d}^+_{3k} \qquad \text{------------(8)}$$

Model- Implementation

This goal-programming model is made up of minimizing the objective function under hard constraints and soft constraints. This model consists a total (5mn + 2m) decision variables [3mn fixed variables and (2mn+2m) deviation variables]. The total number of model-constraints are 2mn + m + 3n [(mn + 3n) are hard constraints and m (n + 1) goal-constraints]. For the purpose of implementation of model, a unit (fire unit) of the fire station has selected. In this unit, there are in total nine fire workers. Table 1 shows the requirement of workers in each shift for a week. Head of workers prepares the schedule manually. It is a tedious and time-consuming job. It is the source of grievances by the duty-staff. The problem where nine workers have scheduled for a week consists of 333 decision variables and 156 constraints in total. The problem size in the current mathematical model is computationally large from the PC- point of view and some heuristic approach must used for a better solution on computer device.

Sub grouping:-

Huarng F. [5] proposes the idea to conduct the each subgroup in manageable size, consider the perspective of sub grouping by dividing workers and given workloads into desired sub-groups. These subgroups should select in such a way not to violate the hard constraints. The duration of single week for scheduling the workers have been chosen by this heuristic only. The appropriate approach of sub grouping is model-dependent. To use less the computational time (CPU time) and computer-storage always consider large number of subgroups but greater number of sub groups increase the deviation from optimality so always consider less sub groups as much require.

Case Study

There are nine workers in the unit in total for which the schedule is to be prepared. The problem solved using a computer-program in C^{++} language by linear goal programming technique. It decided to distribute the entire problem into two subgroups as for convenience to calculation. After careful considerations regarding the constraints and computer storage, the 4-5 size of subgroups finally decided. The reason is obvious, since size of subgroup up to five is more suitable in comparison to subgroups of sizes more than five. Therefore, the sub grouping 4-5 is most appropriate.

3. RESULTS AND DISCUSSION

The total staff of nine workers divided into two subgroups consisting of four and five workers respectively. The requirement of staff in the first, second and night shifts of each day was 3, 2 and 2 respectively as decided by the in charge. The requirement of workers in first shift as decided by the in charge was greater than second and night shifts, since first shift has additional activities like routine checkup of fire instruments and preparing schedule for the whole day. Therefore values of P_i, Q_i and R_i are taken as 3,2,2 $\forall i = 1,2,3,-----,7$. Since total workers were divided into two subgroups, so values of P_i, Q_i and R_i are also to be distributed into two subgroups. First, subgroup of four workers was considered and values of P_i, Q_i and R_i for this subgroup were taken as 1, 1, 1 respectively. This sub-problem consisted of 89 constraints and 84 variables. Sub problem executed and the results reported in table 2. Next subgroup of five workers was considered and values of P_i, Q_i and R_i are taken as 2,1,1respectively $\forall i = 1,2,3,-----,7$. This sub-problem consists of 136 constraints and 105 variables. This sub-problem also executed and results reported in table 3. Finally, both the results combined and final schedule exhibited in table 4. This table demonstrated certain notable features. First, requirement of fire workers in each shift is fulfilled (hard constraint 1) and each worker has at the most one duty per day (hard constraint 2). All the soft (goal) constraints are also satisfied and all the priorities have completely achieved. Each fire-worker gets at least a day-off (first goal). No worker assigned two consecutive shifts (second goal) and number of day shifts is always greater than number of night shifts for each worker. The computerized schedule has shown to the in charge and the individual fire-worker. It found satisfactory to all. In the next three weeks of the month, the components (fire-workers) in the subgroups may be changed and the schedule for each week is prepared. It will provide more unbiased attitude to the scheduling and finally monthly-schedule of the fire-workers may be prepared.

Table-IV: Combine Result of Final Schedule Execution

	1			**2**			**3**			**4**			**5**			**6**			**7**			**Sum**
	I	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**I**	**II**	**III**	**D + N =**
A	-	P	-	P	-	-	-	-	P	-	P	-	-	-	P	-	-	-	-	-	-	3+2 = 5
B	-	-	P	-	P	-	-	P	-	P	-	-	-	P	-	P	-	-	-	P	-	6+1=7
C	P	-	-	P	-	-	P	-	-	-	-	P	P	-	-	-	-	P	-	-	P	4+3=7
D	P	-	-	-	-	P	-	-	-	P	-	-	P	-	-	-	P	-	P	-	-	5+1=6
E	-	-	-	-	-	-	P	-	-	-	-	P	-	P	-	P	-	-	P	-	-	4+1=5
F	-	-	-	P	-	-	-	-	P	-	-	-	-	-	P	-	P	-	-	P	-	3+2=5
G	P	-	-	-	-	P	-	P	-	-	P	-	-	-	-	-	-	P	-	-	-	3+2=5
H	-	P	-	-	P	-	P	-	-	-	-	P	-	P	-	-	-	-	-	-	P	4+2=6
I	-	-	P	-	-	-	-	-	-	P	-	-	P	-	-	-	P	-	P	-	-	4+1=5
Total	1	1	1	1	1	1	2	1	1	1	1	2	1	2	1	1	2	1	2	1	1	**36+15=51**

4. CONCLUSION

In the present work, a goal-programming model has developed for fire staff - timetabling in a fire station. At present, the trial and error approach is in practice to prepare a manual schedule by the in-charge of staff. This prospective is not only tedious and time-consuming, but also inefficient and dissatisfying to various workers. Moreover, this tedious approach does not satisfy all-important criteria for efficient scheduling. This goal-programming model includes fire-worker preferences, balanced schedules and fairness considerations in addition to staffing needs. The upcoming model furnishes foremost developments besides this it proposes a perfect computerized tool. Satisfying all the criteria simultaneously is not possible, so constraints have distributed into two categories. First, one is hard constraints, which have to be satisfied compulsorily and second one is soft constraints, which must be satisfied according to their priorities.

For measuring a schedule quality, specify the following four factors:

- Entireness: It shows, degree by which the quantitative demands per shift have match.
- Optimality: represents the degree of optimalityby which fire-working proficiency distributed over the different shifts.
- Fitness: represents the degree in which, consider awareness of that the worker should not assigned consecutive duties and tried to assigned more day-duties than night duties.
- Proportionality: It shows the degree in which each fire-worker assigned same number of duties approximately.

This goal programming model accomplish entirely based on the above yardstick. The model has found not only to fulfil Fire station's targets, but also to large extent fire-workers grievances and avoids the biased factor often imposed on the in charge. The solution has obtained through sub grouping due to excessive computational time and computer storage. Subgroup sizes up to five are found most appropriate. For the next week schedules, the distribution of subgroups may change to give schedule more logical basis. Keeping in view of all these factors, monthly schedule of the fire-workers of different units of the Fire stations may be efficiently and computationally prepared.

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