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Personnel Scheduling With Heuristic Search Approach

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Abstract

Personnel Scheduling or rostering problem is an assignment of shifts to employees. An efficient way of crew scheduling can save the scheduling cost for an organizations by means of using minimum manpower. And mostly cost incurred is due to employees assigned for performing a given task so this cost can be saved by optimizing the process of personnel scheduling. This paper describes a tabu search based heuristic algorithm which is applied on bus driver scheduling problem. Solution to this problem is an assignment of duties such that each employee should know when to work and also which task to perform while working. Finding the solution of this problem is minimization of the overall employees needed to cover all the shifts in the schedule and total service time and total scheduling cost while satisfying all the constraints.

Keywords: Duty, Heuristic search, Optimization, Personnel scheduling, Shift, Spell, Tabu Search, Workforce.

Introduction

Now days, every organization characterizes economy by their growth in service sector which is based on labor incurred in workforce. Human resources are most expensive resources for any sector hence it should be used very effectively and efficiently. Optimized staff scheduling can reduce this cost of human resource and also improves service and customer satisfaction. Personnel scheduling, staff scheduling and labor scheduling, is a difficult and time consuming problem that every company or institution that has employees working on shifts or on irregular working days must solve. It is a common problem that occurs in many practical instances. Most of the studies focus on assigning employees to shifts, determining working days and rest days or constructing flexible shifts and their starting times. The personnel or staff scheduling problem has a fairly broad definition. Different variations of the problem and sub problems are NP-hard and NP- complete [1] and thus it's extremely hard to solve. The first mathematical formulation of the problem based on a generalized set covering model was proposed by Dantzig [2]. instances. Most of the studies focus on assigning employees to shifts, determining working days and rest days or constructing flexible shifts and their starting times. The personnel or staff scheduling problem has a fairly broad definition. Different variations of the problem and sub problems are NP-hard and NP-complete [1] and thus it's extremely hard to solve. The first mathematical formulation of the problem based on a generalized set covering model was proposed by Dantzig [2].

Here, Tabu Search based heuristic search approach is used to solve the real life, bus driver scheduling problem. The proposed approach is combination of heuristic and mathematical programming with combinatorics and permutation. Real time problem instance is solved using this algorithm. The objective is to minimize the overall cost of personnel required to perform the given set of tasks.

In an operational day-to-day scenario, the personnel task scheduling problem is one of optimally allocating a specified set of tasks to the available/rostered personnel. The rosterer (or the shift supervisor) needs to allocate each individual task, with specified start and end times, to available staff that have the qualifications or skills to perform the task. Staff availability is indicated by personnel shifts (with specific start and end times, including overtime registrations). The problem of personnel scheduling in present, is very different from the one which was introduced by Dantzig [03] and Edie [04] in the 1950s. Along with scheduling, the relative importance of satisfying employee needs in staffing

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and scheduling decisions has also grown. Companies or organizations offer part-time contracts or flexible work hours and take into account employee preferences (e.g. working together with someone, preference for a specific shift type, specific days off or on and many more) when creating work schedules.

Good rosters have many benefits for an organization, such as lower costs, more effective utilization of resources and fairer workloads and distribution of shifts. Public transportation companies are faced with important challenges in the area of transportation planning due mainly to population growth, environmental policies, requirements for a service with quality, and the pressure from governments to a better use of their resources. Therefore, transportation planning systems in public transport have been gaining importance since a large amount of money can be saved if the available resources are employed efficiently, or wasted if not.

This paper is composed as follows. Section II briefly introduces the necessary terminology used. In section III, we review the literature on personnel scheduling. Section IV describes implementation details of proposed heuristic method. In section V we discuss about results and its analysis and section VI describes the conclusion with future work.

Terminology and driver scheduling process in detail

A. Personnel Scheduling:

Personnel scheduling is the problem of assigning staff members to shifts or duties over a scheduling period (typically a week or a month) so that certain constraints (legal, organizational, and personal) are satisfied. Broadly speaking, there are two classes of personnel scheduling problems: cyclical and noncyclical schedules.

1) Cyclical Scheduling: In cyclical scheduling, the same set of patterns is always used, but rotated amongst employees. Cyclical schedules have fallen out of fashion in recent years, because they are too restrictive and do not allow personal preferences to be included.

2) Non Cyclical Scheduling: The noncyclical scheduling process normally consists of three stages:

- The first stage involves determining how many staff must be employed in order to meet the service demand;
- The second stage involves allocating individual staff members to overall shifts patterns;
- And the final stage assigns actual duties to individuals for each shift.

Throughout the process, all industrial regulations associated with the relevant workplace agreements must be complied with.

Each employee has a total working time that he/she has to work during the planning horizon. Days are divided into *working days* (days-on) and *rest days* (days-off). Whole day time is considered as 24 hours pattern. A *shift* is a contiguous set of working hours and is defined by a day and a starting period on that day along with a *shift length* (the number of occupied timeslots) or *shift time*. Shifts are sometimes grouped into *shift types*, such as morning, day and night shifts. Each shift is composed of *tasks* and *breaks*. The sum of the length of a shift's tasks is called *working time*. A work schedule over the planning horizon for an employee is called a *roster*. A roster is a combination of shifts and days-off assignments that covers a fixed period of time.

B. Bus Driver Scheduling:

The driver scheduling problem is about finding the most efficient way of assigning drivers to the daily operations of a fleet of vehicles. Here, driver duties are made up of spells of work on one or more vehicles, and all the vehicle work must be covered by such duties.

In transportation system, driver scheduling problem is preceded by timetabling and vehicle scheduling problem, in which vehicles are allocated to the journeys to be operated (in advance the service is fixed, and will remain unchanged for usually months at a time). Figure 2.1 shows sub problems in real life transportation system.

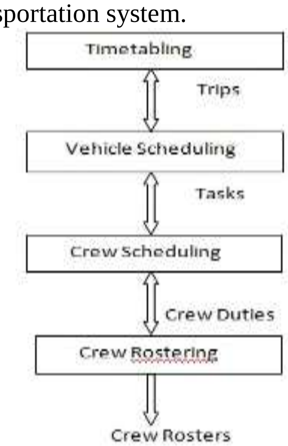

Figure 2.1: Transportation planning sub problems

Since both the vehicle scheduling problem and the driver scheduling problem are individually hard, the usual practice is to compile schedules separately for the vehicles and for the drivers.

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A *schedule* is defined as a solution that contains a set of shifts that cover all the required work, with the smallest number of drivers and the least costs. The driver scheduling problem can be formulated as the following set covering integer programming problem which ensures that all of the vehicle work is covered.

Objective Function:

$$Minimize \sum_{i=1}^{n} C_i X_i \qquad (1)$$

Subject to Condition:

$$\sum_{i=1}^{m} a_{ij} X_i > 1 , \qquad j \in \{1, \ldots \ldots, n\} \qquad (2)$$

$$X_i \in \{0,1\}, \qquad i \in \{1, \ldots \ldots, m\} \qquad (3)$$

Where,

$X_i = 1$ if used in a solution, otherwise 0.

$m = No. of\ potential\ shifts.$

$n = No. of\ work\ pieces\ to\ be\ covered.$

$C_i = Cost\ of\ shift\ (hours\ paid).$

$a_{ij} = 1\ if\ shift\ covers\ work\ piece\ j, otherwise\ 0.$

Equation (1) minimizes the total cost. Constraint (2) ensures that each piece of work is covered by at least one driver, and constraint (3) requires that whole shifts be considered.

The driver schedule must be legal according to the rules or policies of organization. It should use the minimum number of duties and/or have the lowest total cost.

As a consequence of challenges faced by public & private transportation system, there is an increasing need for computerized tools to aid planners in public and private companies. On everyday planning, organizations need fast methods to obtain several good scenarios in real time that can help the decision maker. Therefore, the objective of the paper is to develop a method to solve real crew scheduling problems that can be used in a transportation planning system, in a user-friendly environment.

Literature survey

Here we review the relevant literature in the work of personnel scheduling. The literature on personnel scheduling exhibits a wide range of research methodologies that combine a certain type of analysis with some solution or evaluation technique.

Since personnel scheduling problems are general NP-hard combinatorial problems (Garey and Johnson, 1979) which are unlikely to be solved optimally in polynomial time, various methods such as local search-based heuristics (Li and Kwan, 2005), knowledge based systems (Scott and Simpson, 1998) and hyper-heuristics (Burke, Kendall, and Soubeiga, 2003) have been studied. Over the last few years, metaheuristics have attracted the most attention. Genetic Algorithms (GAs) form an important class of meta-heuristics (Aickelin 2002), and have been extensively applied to personnel scheduling problems (Aickelin and Dowsland 2000 and 2003; Aickelin and White, 2004; Easton and Mansour, 1999 Li and Kwan, 2003; Wren and Wren, 1995) due to its ability of producing near optimal solution.

A number of attempts have also been made using other metaheuristics, such as tabu search [5] simulated annealing [6], memetic algorithms [7], Bayesian optimization [8], ant colony optimization [9], and variable neighborhood search.

The methods and techniques that have been used over the years to tackle personnel scheduling problems have tended to draw on problem-specific information and particular heuristics. Krishnamoorthy and Ernst [10] found one of the similar kinds of problem as the personnel task scheduling problem.

The literature on personnel scheduling exhibits a wide range of research methodologies that combine a certain type of analysis with some solution or evaluation technique. They are classified as:

- Mathematical Programming.
- Constructive Heuristic.
- Improved heuristic.
- Simulation.
- Constraint Programming.
- Optimization Algorithms.
- Queuing and others.

Mathematical programming approach groups most of the solution methods such as Integer programming, Linear programming, Dynamic programming, Goal programming, Mixed Integer programming, Column generation, Branch-and-price, Dynamic programming, Lagranges programming, etc.

Research by Kellogg and Walczak [11] indicates that it is crucial for a workforce management system to allow the employees to affect their own schedules. In general it improves employee satisfaction. This in turn reduces sick leaves and improves the efficiency of the employees, which means more profit for the employer.

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Implementation details

The implemented system is having basic steps as:

- Predetermined Timetabling.
- Service demand Estimation.
- Staff Allocation to defined task.

Figure 4.1 shows these steps in implementation

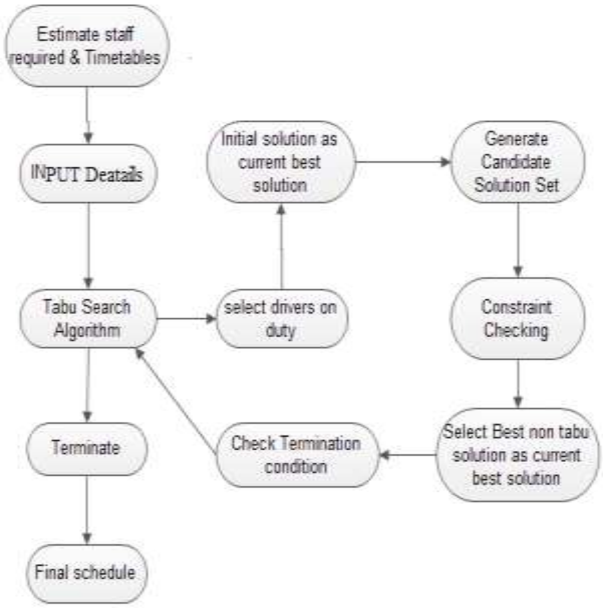

Figure 4.1: Bus Driver Scheduling System Steps

A. Tabu Search Algorithm:

Tabu Search (TS) is a class of meta-heuristics proposed by Glover [8], [9] for solving hard combinatorial optimization problems. TS can be roughly described as an iterative technique that moves from an initial solution through a neighbourhood of other solutions towards the global optimum. The basic idea is to avoid being trapped at local optima by allowing the acceptance of non improved solutions.

Figure 4.2 shows the basic steps in tabu search method. Tabu Search method is based on procedures designed to cross boundaries of feasibility or local optimality, instead of treating them as barriers. Recently, this metaheuristic has been gaining importance as a very good search strategy method to solve combinatorial optimization methods. Figure 4.3 describes actual flow of this proposed system.

A.1. Initial Solution:

The initial solution can be obtained by two methods:

- A random initial heuristic and
- A greedy heuristic.

The greedy heuristic builds a solution in a greedy fashion, at each step, a column is selected to enter the solution following some greedy function and the step is repeated until all lines have been covered. We have used a greedy heuristic method for generating an initial solution.

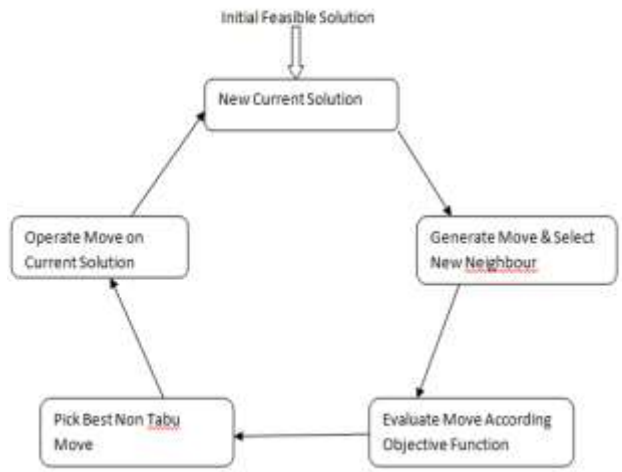

Figure 4.2: Basic Steps in Tabu Search

For generating initial solution, we must check that for '*n*' no. of duties, we must have 'm' *no. of drivers* available where, *m* >= *n*. So that service demand can be satisfied. For calculating cost of initial solution, we use the cost evaluation function as:

$$cost = C_i X_i$$

Where, $C_i = wages\ paid\ for\ employee\ i$

$$X_i = \begin{cases} 1, & if\ driver\ 'i'\ is\ assigned\ duty \\ 0, & if\ employee\ is\ not\ assigned \end{cases}$$

Further, next candidate's cost can be compared with initial solution cost and select best schedule with minimum cost.

A.2. Neighbourhood Generation :

To generate possible set of candidate solutions, generate and select approach is used. Operation of swapping drivers for allocating duties is used to form next neighbour. Figure 4.4 shows this swapping operation.

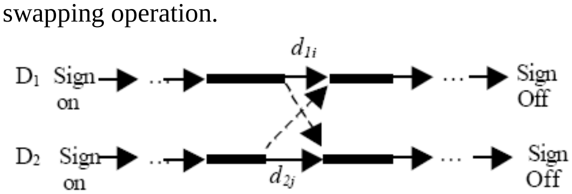

Figure 4.4: Method to generate Neighbour

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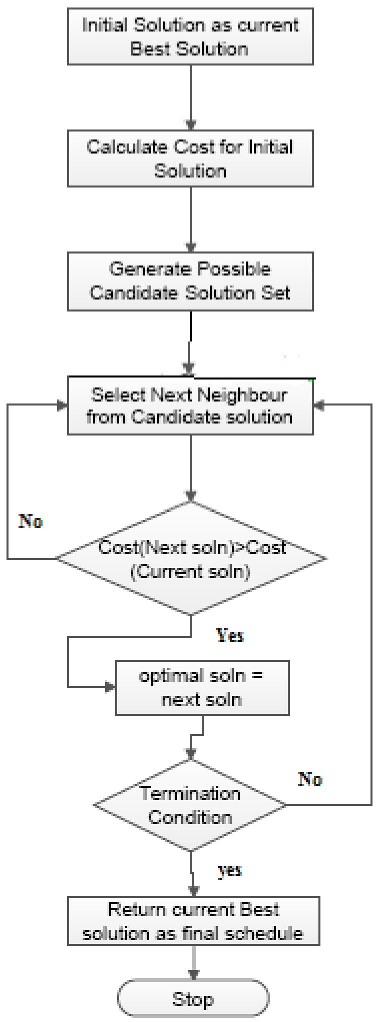

Figure 4.3: System Flow

A.3. Cost Evaluation and Selecting Best Non Tabu Solution from Candidate Solution Set:

The possible numbers of candidate solutions generated are totally depending upon total number of duties and drivers considerd as an input. For example, for 3 duties with 3 drivers it can have total 9 possible combinations among which some may not be feasible. So the evaluation function selects feasible solution and compares it with current best solution and returns the best solution with minimum cost among them. And the solution that does not satisfy the constraints are considered as tabu so that in next iteration they should not be revisited.

Descent method is used for selecting best non tabu neighbor as:

$$X^{next} \in N(X^{now})$$

Such that,

$$Cost(X^{next}) < Cost\big(N(X^{now})\big)$$

And terminate if no improving solution can be found until termination criteria is reached.

A.4. Termination Criteria:

A termination criterion or aspiration criteria is nothing but stopping condition for algorithm. There are two kinds of stopping conditions in the Tabu Search algorithm. The first one has to do with the Tabu Search as a whole (when the algorithm finishes) and the second one is a stopping condition over the search of "the best" among all solutions.

Some typical stopping conditions are as follows:

- Tabu list size exceeds,
- the maximum number of solutions to be explored is fixed,
- the number of iterations since the last improvement is larger than a specified number,
- the total number of iterations of the TS algorithm is fixed.

Here termination criteria considered is maximum number of solutions to be explored are searched for finding best solution. Here, bus driver scheduling is exercised on all possible solutions in iterations. So if total numbers of solutions are explored, stop the algorithm execution else repeat steps from initial solution to termination condition. After termination sort the all neighbour solutions and put the best solution as final result.

Results and discussion

This proposed algorithm is implemented using java platform on Intel(R) Core(TM)2 Duo processor with 2.00 GHZ processing speed.

The system is implemented to generate real time bus driver schedule for depot with real time problem instance of duty timetabling. It required very much less time for execution as compare to other system. As compared to manual process of scheduling, this gives much better results by saving scheduling time for organizer.

Table 5.1 shows the result overview for algorithm running time with resources needed for generating schedule. Table 5.2 shows number of crew allotted and reserved after generating schedule by this method which is much better as compared to manual scheduling process.

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Table 5.1. . Instance of Shifts Allocated for a week.

Total shifts Allocated	No. of Duties	No. of Driver s	CPU Time [sec]	Time Elapsed [sec]
35	5	8	10	5
126	18	21	15	5
140	20	24	30	5-10
175	25	30	90	10
229	27	32	120	10

Table 5.2: Allocation and reserved no. of drivers in a week

Duties / Days	27		26		25		20	
	Alloted	Reserved	Alloted	Reserved	Alloted	Reserved	Alloted	Reserved
SUN	27	0	26	1	25	0	20	0
MON	27	0	26	1	25	0	20	0
TUE	27	0	26	1	25	1	20	0
WED	27	0	26	1	25	1	20	0
THU	27	1	26	2	25	1	20	1
FRI	27	1	26	2	25	1	20	1
SAT	27	1	26	2	25	1	20	1
Total Reserved	3		10		5		3	

Conclusion

The proposed heuristic in above paper performs very well- both in terms of solution value as well as CPU time over problems. The proposed technique is innovative and there is still some room for further improvement. For example, by adding some more rules or constraints into the search, solution quality could be improved further. This would be interesting if we have more difficult instances to solve.

The most important challenges in scheduling can be considered as one of the constraints i.e. employee preferences for various scheduled characteristics and their impact on scheduling cost. One more challenge would be balance between schedule qualities with coverage. As the method is combination of heuristic search and mathematical programming, that can be embedded into other exact solution algorithms for solving other scheduling problem.

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