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Analysis of Real World Personnel Scheduling Problem: An Experimental Study of Lp-Based Algorithm for Multi-Time Multi-Period Scheduling Problem for Hourly Employees

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Abstract: Scheduling service employees at any campus dining center is not an easy task for a manager because most positions at a campus dining center are hourly-paid positions, leading to a high employee turnover and many uncertainties. In such a circumstance, a manager has a hard time to organize and project employees' work schedules. The Johnson Commons (JC) dinning center at the University of Mississippi operated by Aramark also has similar difficulties in scheduling its hourly employees. After discussing with a manager and investigating the current scheduling system at the JC, it is found that the JC has one type of scheduling problem called the Multi-time Multi-Period Scheduling Problem. Therefore, the main purpose of this study is to find the optimal solution for the scheduling problem at the JC dining center. The result shows that with the optimal solution, the JC can save a total of $50,648.00 hourly employee labor expenses per year.

Key words: Linear problem, multi-time multi-period problem, scheduling problem

INTRODUCTION

Scheduling personnel has been a major issue for many organizations because it can significantly reduce costs related to the workforce, time and effort and increase effectiveness of work. In fact, personnel scheduling problems occur in a variety of service delivery settings, including the scheduling of airline and hotel reservation personnel, nurses in hospitals, coast guards, patrol officers and others. Therefore, personnel scheduling has been the subject of much research in literature over the past several decades[1-8]. The main goal of these problems in the literature was to determine appropriate workforce requirements, allocation and duty assignments for an organization in order to meet its internal and external requirements. This involves the allocation of human and non-human resources to timeslots and possible locations. However, this kind of scheduling problem is often extremely difficult to solve[9,10].

Scheduling the right persons at the right time at the right place is a critical problem for organizations without making them unsatisfied[10]. This study is a part of a consultancy project with the problem owner for the past nine months to find the best solution for the participating organization. The problem presented in the organization was defined as Multi-time Period Personnel Scheduling Problem because there are multiple timeslots and three time periods. Therefore, the main purpose of this study is to determine the optimal solution for the multi-time multi-period personnel scheduling problem.

Hourly employee scheduling problem

Johnson commons dining center: The Johnson Commons is the largest dining center at the University of Mississippi. Currently, there are 27 hourly employees covering six areas-Cashier/Front of House, Pan Geos/Grill, Bakery, Utility, Kitchen and Line. The main customers are students, faculty, visitors and staff on the campus. This campus dining center is based on the concept of all-you-care-to-eat[11]. This operation is designed to serve not only students having a meal plan, but also others paying with cash in a quick and friendly manner. Customers can choose from various menus, including fresh dough pizza, premium pasta with quality sauces, a full salad bar featuring more than thirty seasonal items, fresh hamburgers, Chinese cuisine, Mongolian grill and much more. It also offers monthly theme-oriented dinners to correspond with the time of year, such as Oktoberfest, traditional Thanksgiving dinner and Mardi Gras. Pan Geos is one of the trademark concepts that has made the dining program great. Pan Geos offers foods made fresh for customers in front of their eyes. All items are assembled and cooked for each customer while he/she watches and learns about the cuisine he/she is about to eat. Unlike other campus dining centers where customer service is not high, the JC always tries to provide better quality customer service.

It operates 7: 00 a.m to 7: 00 p.m Monday to Thursday, 7: 00 a.m to 4: 00 p.m on Friday, 10: 00 a.m to 2: 00 p.m on Saturday and 10: 00 a.m to 4: 00 p.m on Sunday. Fig. 1 shows the layout of the JC dining center. Because the dining center is small, each working area is closely located to the other working areas.

Problem of interest: Even though the management makes and updates all employees weekly schedules, each employee's schedule is the same every week unless there is a special event, for example a football game in the coming week. The current schedule system shows that the schedule of Monday to Thursday is the same for all employees, but the Friday, Saturday and Sunday schedule is different from one weekend to another because of the low demand of users. The management thinks that the current schedule system works without any major problems but is not sure whether or not the current scheduling system is the best for the JC in order to provide satisfactory customer service and save labor costs.

Therefore, the management wants to clearly know how many employees should be scheduled at each timeslot and period at the current cost level and how many employees should be hired, if necessary and where each employee should be located. The personnel scheduling model can help scheduling service workers at the JC. It can forecast the minimum number of service workers needed to be on duty at the different times and working areas of the day. As a result, this study defines the JC's problem as a typical Multi-time Multi-period Personnel Scheduling Problem because there are multiple timeslots in a day and multiple periods (Monday to Thursday, Friday, Saturday and Sunday) in a week.

Relevant data: After discussing with the management, important data for this study was collected. First, skill requirements for each area are different. However, most of employees are very familiar with all the skills because the JC is a small business unit on the campus. Skill requirements and pay-rate are described below:

Cashier: Should have general accounting skills and be familiar with cash transactions. Hourly pay rate is $6.50

Bakery: Should know how to bake and other knowledge about baking. Hourly pay rate is $8.00

Pan/Grill: Should know how to use grill equipment and should have customer service skills. Hourly pay rate is $6.25

Utility: Good knowledge of all areas. Hourly pay rate is $6.00

Line: Should have good customer skills and know about the every day menu. Hourly pay rate is $6.00.

Kitchen: Cooking skills and high maintenance. Hourly pay rate is $7.00

In addition, some policies considered for this study are identified:

- All employees in all areas are allowed to work a maximum of 40 hours per week.
- Each employee is allowed to work a maximum of eight hours per day. The overtime pay-rate is one and a half times the regular pay-rate.
- The busiest time period is 12:00 p.m. to 1:00 p.m. Monday to Friday and the slowest time period is 2:00 p.m. to 4:30 p.m. Monday to Friday.
- There is a 15 minute break for every four hour shift.
- There is a 30 minutes meal break for those employees having break time between 9:30 a.m. and 1:30 p.m.
- Employees should be familiar with the skills in all areas so each employee can be scheduled to work in any area, if necessary.

Required number of employees at each time period: Based on the past schedules, this study could project the number of minimum employees scheduled at each time period. Tables 1 to 4 show the minimum number of employees needed to be scheduled at each time period, given in the first column. There are six working areas and the bottom row shows the total number of employees for each area per day. The right hand column shows the total number of employee needed at each time period. Required numbers of employees at each time period should be satisfied without any exception.

Study approach: The problem in this study is a typical scheduling problem in Linear Programming (LP). However, this problem is one of the special types of personnel scheduling problems, called the Multi-time Multi-period Problem. This problem is *almost* decomposable into separate sub-problems. Each sub-problem in this case is concerned with optimizing the operation of the organization during one of the time periods. For this study, there are four different schedules; (a) Monday to Thursday schedule, (b) Friday schedule, (c) Saturday schedule and (d) Sunday schedule. Each schedule represents a sub-problem concerned with optimizing the schedule for the whole scheduling problem. To minimize any errors in solving the problem, first, a prototype problem was investigated in order to make sure that a solution approach for this problem is right. Then, the actual problem having more decision variables was examined. Two step approaches-initial and revised approach-are used. First, because all employees should learn skills required for all areas, any employee can be scheduled to work in any area regardless of their skills in the initial approach. Therefore, two assumptions are used in the initial approach:

Assumption 1: All employees have skills required for all work areas.
Assumption 2: Any employee can be scheduled in any area regardless of his/her level of skills.

Other constraints in this approach include:

- Each employee is only allowed to work a maximum of 8 hrs per day.
- Total number of employees being scheduled at each time period is equal to the number of employees required by a manager and
- Non-negativity constraint

However, even if this approach has the optimal solution for the problem, the solution may not be realistic simply because no employee possesses all skills required in six working areas. Employees can help each other because work areas are closely located as shown in Fig. 1. However, each employee can only be scheduled to work one area. Therefore, new constraints for the problem are examined, for instance, the available maximum number of employees in each area. In fact, only three employees are available to be scheduled in cashier/front of house area, one in bakery, six in pan/grill, seven in utility, four in line and six in kitchen. This data generates one more constraint, called proportion constraint (total number of hours required by managers over total number of available employees in each area). This proportion constraint is used to make fair schedules for each employee. Other constraints from in the initial approach are used. In the following section, LP formulation model for this problem is presented.

Formulation as a linear programming model:

$$\text{Min. } Z = \sum_{j=I}^{n}\sum_{i=I} c_{ij}\, x_{ij}$$

Subject to:

$$\sum_{i=I}^{n} x_{ij} = b \qquad i = 1,\dots n$$

$$\sum_{j=I}^{n} x_{ij} <= 8 \qquad j = 1,\dots n$$

$$\sum_{j=I}^{n} x_{ij} >= p_i$$

$$\left[\sum_{j=I}^{n} b_{jk} \div \sum_{j=I}^{m} x_{ijk}\right] \qquad I, j = 1,\dots n$$

and non-negativity.
Where

$\{x_{ij} =$ e_i who is scheduled to t_j
{1 – Scheduling employee
{0 – Not scheduling employee

- t_j = time period (task)
- e_i = employees (assignee)
- c_{ij} = cost per hour
- a_{ijk} = number of employees available at each time period in each area
- b_{jk} = number of employees required at each time period in each area by the JC management
- p_i = number of proportional hours for each employee (total number of employees required at each time period in each area by a management / total number of employees available at each time period in each area)

The objective function is to minimize total cost for each employee who is scheduled to work in each time period as mentioned earlier. Decision variables are binary and are represented by either '0' or '1.' '0' represents not-scheduling the employee at a time period and '1' represents scheduling the employee at a time period. Most of the constraints are implicitly represented by the decision variables. The first constraint is that the number of required employees in each time period must be the same as that required by management. The second constraint is that each employee must work less than or equal to eight hours a day. The third constraint is the proportional constraint. It is used for scheduling a fair amount of time for each employee. The last constraint is non-negativity.

RESULTS AND DISCUSSION

Using the optimal solution would bring several benefits for the JC. First, the direct labor cost savings are

Table 1: Monday to Thursday schedules

Time period	Working areas Cashier/Front	Bakery	Pan/Grill	Utility	Line	Kitchen	# of Emp. Needed
6:00a.m - 8:00a.m	3	1	3	2	3	3	15
8:00a.m - 9:00a.m	2	1	3	3	2	3	14
9:00a.m - 10:00a.m	2	1	4	3	2	3	15
10:00a.m - 11:00a.m	2	1	5	3	2	4	17
11:00a.m - 12:00p.m	2	1	6	4	3	5	21
12:00p.m - 01:00p.m	2	1	6	4	3	5	21
01:00p.m - 02:00p.m	2	1	5	4	2	5	19
02:00p.m - 03:00p.m	2	1	4	4	2	5	18
03:00p.m - 04:00p.m	1	0	2	3	2	3	11
04:00p.m - 05:00p.m	1	0	2	3	2	3	11
05:00p.m - 06:00p.m	1	0	2	3	2	2	10
06:00p.m - 07:00p.m	1	0	2	3	2	2	10
07:00p.m - 08:00p.m	1	0	0	3	1	2	7
Total # of Emp.	22	8	44	42	28	45	189

Table 2: Friday schedule

Time period	Working areas Cashier/Front	Bakery	Pan/Grill	Utility	Line	Kitchen	# of Emp. Needed
6:00a.m - 7:00a.m	1	1	2	2	2	3	11
7:00a.m - 8:00a.m	2	1	2	2	2	3	12
8:00a.m - 9:00a.m	2	1	3	3	2	4	15
9:00a.m - 10:00a.m	2	1	3	3	2	4	15
10:00a.m - 11:00a.m	2	1	4	3	2	4	16
11:00a.m - 12:00p.m	2	1	5	4	3	4	19
12:00p.m - 01:00p.m	2	1	5	4	3	4	19
01:00p.m - 02:00p.m	1	1	4	4	3	3	16
02:00p.m - 03:00p.m	1	0	2	2	2	3	10
03:00p.m - 04:00p.m	1	0	2	2	2	2	9
Total # of Emp.	16	8	32	29	23	34	138

Table 3: Saturday schedule

Time period	Working areas Cashier/Front	Bakery	Pan/Grill	Utility	Line	Kitchen	# of Emp. Needed
6:00a.m - 7:00a.m	0	0	0	0	0	1	1
7:00a.m - 8:00a.m	0	0	0	0	0	1	1
8:00a.m - 9:00a.m	0	0	0	4	0	1	5
9:00a.m - 10:00a.m	1	0	0	4	0	1	6
10:00a.m - 11:00a.m	1	0	0	4	0	1	6
11:00a.m - 12:00p.m	1	0	0	4	0	1	6
12:00p.m - 01:00p.m	1	0	0	3	0	1	5
01:00p.m - 02:00p.m	1	0	0	3	0	1	5
Total # of Emp.	5	0	0	22	0	8	35

Table 4: Sunday schedule

Time period	Working areas Cashier/Front	Bakery	Pan/Grill	Utility	Line	Kitchen	# of Emp. Needed
7:00a.m - 8:00a.m	0	0	0	0	0	2	2
8:00a.m - 9:00a.m	0	0	1	1	0	3	5
9:00a.m - 10:00a.m	1	0	2	1	0	3	7
10:00a.m - 11:00a.m	1	0	2	2	0	3	8
11:00a.m - 12:00p.m	1	0	2	2	0	3	8
12:00p.m - 01:00p.m	1	0	2	2	0	3	8
01:00p.m - 02:00p.m	1	0	2	2	0	3	8
02:00p.m - 03:00p.m	1	0	2	2	0	2	7
03:00p.m - 04:00p.m	1	0	2	2	0	2	7
Total # of Emp.	7	0	15	14	0	24	60

determined after calculating the actual cost of the current scheduling system. The hourly employee labor cost with the current scheduling system is $7,967.50 a week, including approximately four hours of overtime. However, total labor cost with the optimal solution is $6,384.75. The difference between these two costs is $1,582.75 per week, which is a large amount of savings for a small business unit like the JC Dining Center. The yearly savings would

Table 5: Comparison of weekly labor costs

	Mon.–Thurs.	Friday	Saturday	Sunday	Total
Costs with current scheduling system	$6,507.00	$847.38	$257.50	$355.63	$7,967.50
Costs with new scheduling system	$4,868.00	$911.00	$220.50	$385.25	$6,384.75
Differences	$1,639.00	$(63.62)	$37.00	$(29.62)	$1,582.75

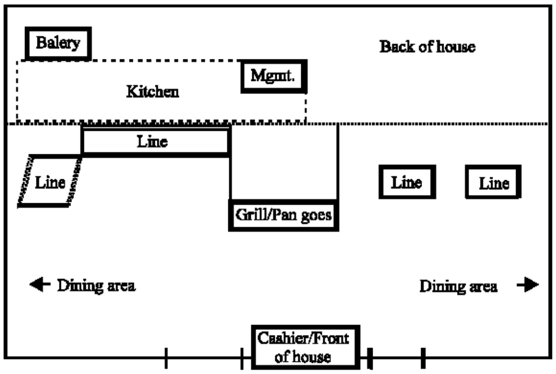

Fig. 1: JC dining center layout

be approximately $50,648.00 with the assumption that the JC stays open only eight months a year (it closes during summer break). Actual savings may be varied depending upon a number of events on campus. When there are more events, the management may need extra people to work. Table 5 represents the labor cost savings.

The indirect benefits from the optimal solution would be great because the management gains new insight into the hourly employee scheduling system while developing the optimal solution. The process may help the management to understand about LP. In addition, the optimal solution provides the management with more organized scheduling system so that in any situation, the management will know cost flows.

However, this study has some limitations. First, the study can look at other constraints applying to all decision variables. One constraint is called the linking constrain[12]. Linking constraints are not used in this study because of the limitation of the system this study used. Second, although the optimal solution makes each employee's schedule equal, not all employees have a continuous time schedule. In other words, some employees' schedules are choppy. Fig. 2 shows one example of non-consecutive eight hours shift.

This employee (W_1) is scheduled to work one hour in the morning. The employee then takes a three hour break and then works for two more hours in the morning. After another two hour break, he/she has a shift of five consecutive hours. In this case, W_1 may not be able to have another part-time job because of his/her irregular schedule. This situation may be prevented by using linking constraints. The third limitation of the study is that it used a consistent pay rate Monday through Sunday in order to simplify the labor cost calculation. However, there may be a different pay rate during weekend shifts and also for some employees who have worked for the dining center for a long time. Finally, the study uses the excel solver. Because there are too many decision variables, the excel solver is unable to solve everything at once. A higher power system should be used.

CONCLUSION

The personnel scheduling problem is not a simple problem in linear programming. Furthermore, scheduling hourly employees is much harder for many managers than that of full-time employees because of many uncertainties, such as high employee turnover. The management in the Johnson Commons dining center also spends a lot of time organizing its schedules for all employees and is not sure about its current scheduling system. The approach for multi-time multi-period scheduling problem can help the JC's current problem. The simple personnel scheduling model this study develops can help the JC in making its management's schedules more organized. It could also help the JC make its schedules faster. With this model, the JC can save labor costs and can organize its schedule in more efficient ways. In fact, the JC could save $1,582.75 per week and $50,648.00 a year with the optimal solution. This is a huge amount of savings for such a small business.

A manager at the JC can now spend less time in making hourly employee schedules with a pencil and paper. Using the optimal solution, the manager at the JC can spend less effort and time on creating personnel rosters, but at the same time present more elegant schedules to employees. Even in an emergency, for example, during the holidays or during an employee illness, the manager can make new personnel rosters in a short time.

In the following study of this scheduling problem, we can address some limitations that this study mentioned in the previous section. Also, the JC has another service, which is *catering* on the campus. Some of employees are scheduled to work not only at the dining center, but also for the catering service. We can extend this scheduling problem to the catering service scheduling. In this case, this scheduling problem will be considered a Multi-divisional Multi-time period problem.[12]. Dining service and catering service are considered to be two separate divisions. Each division can be considered to be Multi-time Multi-period problem.

Time period	06:00-07:00a.m	07:00-08:00a.m	08:00-09:00a.m	09:00-010:00a.m	010:00-011:00a.m	011:00-012:00p.m	012:00-01:00p.m	01:00-02:00p.m	02:00-03:00p.m	03:00-04:00p.m	04:00-05:00p.m	05:00-06:00p.m	06:00-07:00p.m
W1	1	0	0	0	1	1	0	0	1	1	1	1	1

Fig. 3: Non-consecutive time schedule

Therefore, the approach to find an optimal solution for the Multi-divisional Multi-time period problem should be examined in future research.

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