ETM
ENGINEERING & TECHNOLOGY MANAGEMENT

RESCHEDULING STAFF SHIFTS IN X-RAY DEPARTMENT: PCC AIRFOILS

Course Title: Operations Research

Course Number: 540

Instructor: Dr. Timothy Anderson

Term: Winter

Year: 2017

Author(s): Anjana Penumarti, Alex Tacco Melendez, Catalina Reyes Herreno, Touraj Goudarznia

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Executive Summary

Employee schedule is an important concern for every business manager. A well-managed schedule keeps the organization moving and resolves many complex situations. In our paper, we're going to look into the best staff scheduling practices and come up with an optimal solution for rescheduling staff in an X-ray Department at PCC Airfoils - Deer Creek Facility in Portland, Oregon, based on the production plan. PCC X-Ray department is looking for a good staff shift schedule to find out how many outside contractors the department needs to use to meet the production requirements accordingly. So, based on that information we can decide regarding hiring more people, bringing in-house contractors, or sending parts for outside contractors. Through this paper we attempt the following:

1) To minimize the cost based on the production plan.
2) Create a resource allocation model to identify how to allocate the time to process the parts

1.0 Introduction

Managers schedule their staff days, weeks, or months in advance, depending on the job. Optimal staff scheduling and planning helps minimize cost, helps comply organizational and legal rules, and satisfies staff members and customers by avoiding excessive overtime hours[1].

PCC Airfoils has developed highly automated casting furnaces and investment casting processes for the manufacture of blades and vanes. PCC Airfoils principally manufactures Equiax Vane and Nozzle segments for the Industrial Gas Turbine (IGT) industry used in land-based turbine applications for power generation operations[2]. Producing flawless parts is crucial for gas turbine engine. Some methods could be used to satisfy this requirement. Super Alloys composed primarily of nickel and cobalt are used to cast the blades and vanes for gas turbine engines [2].Since super alloys are expensive and process of producing complicated gas turbine engine parts is costly, choosing a good method for testing parts is important. Moreover, gas turbine engines work in high temperature and pressure. Non destructive testing is a great option for testing without destroying the part. X-Ray is a non destructive testing (NDT) method. In this method, some shots will be prepared from different angles in order to have full coverage of whole part. Various X-Ray machines will be utilized for taking shots. Inspecting the shots is the next step of X-Ray operation. Inspection will be performed in a controlled ambient light and temperature booth in quiet environment. All employees have to participate in special classes which are held for X-Ray. Employees certified in taking shots are known as level I and employees certified in inspecting the shots are known as level II.

The X-Ray department functions every day from Monday to Sunday in three different shifts. The manager's task is to assign work schedules that will allow total coverage and that will minimize the cost employees. The department has to process 1365 parts with the sixteen employee capacity. Unlike other industries, the manufacturing industry works 365 days 24/7 with limited workforce[3]. The purpose of this paper is to describe a methodology for finding weekly schedules for each employee in the department. This means specifying the work days, their length, and the daily shift start times.

In the first part of the report, we reviewed the current situation and the major existing issues and problems. With a limitation of hiring external contractors, the department wishes to focus on efficient internal employee scheduling.

In the second part, a model is developed based on the mentioned current situation. A staff schedule model and a resource allocation model are analyzed using a linear program in Excel Solver.

2.0 Literature Review

Staff scheduling is a wide field where finding an exact model match is a challenge. For our project, we wanted to use a model that will satisfy all the constraints and find an optimal solution for the objective which is trying to re-schedule the staff shift in an X-Ray department. The objective of our background research is to study a model that satisfies the following requirements:

- Model that has previously been evaluated based on a real life event.
- The objective function is clear.
- The technique used is an LP model that satisfies all the constraints.
- Focuses on optimizing resource allocation.

Being a real life optimization problem, we want to look at models that have an advantage over our current situation.

Firstly, in 1986 Fred Glover and Claude Mcmlllant analyzed a general situation of employee scheduling. They went into further research by explaining the objective in the shift scheduling problem which generally is to approximate as closely as possible the desired number of employees on duty, either by minimizing the overage or minimizing the shortage/overage mix. [4] Further helped us to take into consideration the breaks that are required per shift.

Another research paper closer to our study is [3] where Jonathan F. Barda, Canan Binicia, Anura H. deSilvab developed a model to schedule staff in USPS. This paper presented a full-scale model of the tour scheduling problem and examined several scenarios aimed at reducing the size of the workforce. The problem is formulated as a pure integer linear program which is similar to our approach. Though this paper focuses on service industry it covers scheduling of full-time and part-time workers which in our case are the internal employees and the external contractors.

Furthermore in our background research, several ETM operations research report papers [5][6][7]have given us in depth knowledge on scheduling and optimization using linear programming and Excel Solver.

The challenge for our project is to develop the correct model which will include the most accurate variables and satisfy all the constraints. The above studies have been very helpful to apply leanings in operations research and optimizing resources for our study.

3.0 Current Situation

3.1 Current Situation

Currently, the X-Ray division is in charge of inspecting "industrial gas turbine" or IGT with X-Ray method. It has eight active stations where five stations are dedicated to X-Ray and three stations are dedicated to inspection. There are sixteen technicians that work in the department and they all need to cover a forty hour per week workload.

The X-Ray department functions every day from Monday to Sunday in three different shifts: Day Shift, Swing Shift and Graveyard Shift. Currently X-Ray department has two different types of shifts in each shift : 10 hours and the second one is : 8 hours, they both include a thirty-minute lunch break and two(or three if it's 10 hour shift) 15 minutes coffee break every two hour . Each employee is assigned to an 8 hour shift or a 10 hour shift depending on seniority in X-Ray department. The Swing shift has two types of schedules as well; the first one is from 14h30 to 22h30 (8 hours) and the second one is from 15h30 to 01h30 (10 hours), these shifts do not include a lunch break. Finally, the Grave shift only has one type of schedule: 22h30 to 06h00 (8 hours), there are only seven and a half working hours on this shift but it is considered as an 8 hour shift, it is a form of compensating a difficult schedule.

The manager's task is to assign work schedules that will allow total coverage and that will minimize the cost employees.

Table 1, gives us the technician position details within the department.

ID	NAME	JOBTITLE	SRVC DT
4578	Adam	Inspector	1/4/2000
5467	James	X-Ray	10/4/2003
5789	Anthony	Inspector	8/16/2006
6190	Robert	X-Ray	8/30/2008
6476	Timy	Inspector	3/28/2010
6565	Charles	X-Ray	1/30/2011
6624	Thomas	X-Ray	10/8/2011
6943	Mike	X-Ray	3/25/2012
7130	Chris	X-Ray	6/13/2013
7423	Daniel	X-Ray	7/28/2013
7490	Paul	X-Ray	11/14/2013
7576	Mark	X-Ray	4/17/2014
7648	Mary	Inspector	8/21/2014
7709	Donald	X-Ray	1/23/2015
7821	Richard	X-Ray	7/29/2015
7910	George	X-Ray	12/26/2015

Table 1 : Technician Details

Table 2, classifies a hypothetical schedule according to the current situation.

EE#	X-Ray		Mon	Tue	Wed	Thur	Fri	Sat	Sun
7910	George	Day - 5:00-1:30	8	8	8	8	8		
5467	James	Day - 5:00-1:30	8	8	8	8	8		
6190	Robert	Day - 5:00-1:30	8	8	8	8	8		
6565	Charles	Day - 5:00-3:30		10	10	10	10		
6624	Thomas	Day - 5:00-3:30	10	10	10	10			
6943	Mike	Day - 5:00-3:30	10				10	10	10
7130	Chris	Day - 5:00-3:30				10	10	10	10
7423	Daniel	Swing - 1:30-9:30	8	8	8	8	8		
7490	Paul	Swing - 1:30-9:30	8	8	8	8	8		
7576	Mark	Swing -3:30-1:30		10	10	10	10		
7709	Donald	Swing -3:30-1:30	10	10	10	10			
7821	Richard	Swing -3:30-1:30	10				10	10	10
	Inspector	Time	Mon	Tue	Wed	Thur	Fri	Sat	Sun
4578	Adam	Day - 6:00 - 2:30	8	8	8	8			8
5789	Anthony	Day - 6:00 - 2:30	8	8	8	8	8		
6476	Timy	Day - 6:00 - 2:30		8	8	8	8	8	
7648	Mary	Swing - 2:30-10:30		8	8	8	8	8	

Table 2 : Current Schedule

3.2 Issues and Problems

One person is assigned to work in each of the eight workplaces i.e. x-ray stations The department is in charge of inspecting 1356 parts every month. Furthermore, the department had to hire external contractors several times in order to meet the deadline. This means that there is a bottleneck effect in the process which we have to determine. The most appropriate action would be to use internal staff. However there is a time constraint with this option where it takes four to six months to adequately train a worker. In addition to this, constantly hiring external contractors is expensive for the company and denotes inefficiency in the department. The cost depends on the parts that are left to inspect until deadline.

3.2.1 Production plan

Production plan comes from sales plan. Sales plan means customer needs. There is a 12 month contract between company and customer which explain customer needs for each month. The numbers are not accurate and that is why flexible planning is very crucial in this company. Customers might change the plan at the beginning of each month which is valid throughout the month. There are some emergency order as well which could add to the main plan. This is the main reason that company needs instant need for emergency orders and normally uses outside contractors to meet emergency orders. Our model [A] validates and supports the analysis in the above mentioned production plan and the conclusions made in our paper.

4.0 Model

4.1 Staff Scheduling Model

We have developed and analyzed the below model as a tool to identify the best schedule planning which will minimize the costs[A]. In order to do that we have created the following variables:

For the 7 days a week:

i = {Monday=1, Tuesday=2, Wednesday=3, Thursday=4, Friday=5, Saturday=6, Sunday=7}

For the 24 employees:

From number 1 to 16: Those are numbers that refer to current employees

Numbers 17 and 18: Those numbers refer to new employees

From number 19 to 24: Those numbers refer to outside employees

j = {1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17, 18, 19, 20, 21, 22, 23, 24}

Decision Variables

This variable will show exactly the employee that will work each day.

X_{ij} = Binary variable

- 1 if employee j is working on day i
- 0 if employee j is not working on day i

Other Variables:

DC = Pay for one entire day to current employee = \$480

DN = Pay for one entire day to new employee = \$360

DO = Pay for one entire day to outside employee = \$800

$TC = \sum_{j=1}^{16} X_{ij} * DC$ → Total pay for the week for current employees

$TN = \sum_{j=17}^{18} X_{ij} * DN$ → Total pay for the week for new employees

$TO = \sum_{j=19}^{24} X_{ij} * DO$ → Total pay for the week for outside employees

Objective Function

For the objective function we want to minimize the cost by planning the schedule of the week for the 18 employees in the company and decide how many of the 6 outside employees they will need to hire for an specific day.

Min→ $TC + TN + TO$

Constraints

Minimum number of hours needed to be worked by the employees to complete the minimum amount number of parts required for the week

$$\sum_{i=1}^{7} \sum_{j=1}^{24} X_{ij} * 8 \geq 813$$

Minimum number of employees required from Monday to Friday. This number was chose because you need to cover at least one complete shift during the week.

$$\sum_{j=1}^{24} X_{ij} \geq 8 \qquad \forall\ i \in \{1, 2, 3, 4, 5\}$$

Minimum number of employees required on Saturday and Sunday

$$\sum_{j=1}^{24} X_{ij} \geq 3 \qquad \forall\ i \in \{6, 7\}$$

Maximum number of employees allowed from Monday to Sunday

$$\sum_{j=1}^{24} X_{ij} \leq 24 \qquad \forall\ i \in \{1, 2, 3, 4, 5, 6, 7\}$$

Current and new employees must work 5 days a week

$$\sum_{i=1}^{7} X_{ij} = 5 \qquad \forall\ j \in \{1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18\}$$

New employees cannot work on the weekend

$$\sum_{i=6}^{7} X_{ij} = 0 \qquad \forall\ j \in \{17, 18\}$$

4.2 Resource Allocation Model

Based on the total of hours work on the entire week (First constraint in first model). We found out that an optimal solution required by the employees to work during the week (Including weekends) for 816 hours in total[A]. Now, using a resource allocation model we are going to identify the best way to spend those 816 hours for the required views for the 28 parts.

For the 7 days a week:

i = {Monday=1, Tuesday=2, Wednesday=3, Thursday=4, Friday=5, Saturday=6, Sunday=7}

For the 28 parts that need to be review during the week:

k = {1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28}

Variable

$$T_k = \textit{Hours needed to produce part } k$$

Decision Variable

$$P_{ik} = \#\ \textit{of parts "}k\textit{" done in day } i$$

Objective Function

We want to identify the best way to allocate the time (816 hours) to do the views for all the parts during the week.

$$\sum_{i=1}^{7} \sum_{k=1}^{28} P_{ik} = 816$$

Constraints

$\sum_{k=1}^{28} P_{ik} * T_k \leq 160 \quad \forall \; i \in \{1,2,3\}$ → Maximum of available hours on day i to work on parts

$\sum_{k=1}^{28} P_{ik} * T_k \leq 136 \quad \forall \; i \in \{4,5\}$ → Maximum of available hours on day i to work on parts

$\sum_{k=1}^{28} P_{ik} * T_k \leq 32 \quad \forall \; i \in \{6,7\}$ → Maximum of available hours on day i to work on parts

$\sum_{i=1}^{7} P_{ik} \geq 18 \quad \forall \; k \in \{1\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 30 \quad \forall \; k \in \{2\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 5 \quad \forall \; k \in \{3\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 4 \quad \forall \; k \in \{4\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 16 \quad \forall \; k \in \{5\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 23 \quad \forall \; k \in \{6\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 30 \quad \forall \; k \in \{7\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 4 \quad \forall \; k \in \{8\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 20 \quad \forall \; k \in \{9\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 15 \quad \forall \; k \in \{10\}$ → Minimum quantity required of part k during the week

$\sum_{i=1}^{7} P_{ik} \geq 20 \quad \forall \; k \in \{11\}$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 7 \quad \forall \ k \in \{12\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 11 \quad \forall \ k \in \{13\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 6 \quad \forall \ k \in \{14\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 3 \quad \forall \ k \in \{15\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 5 \quad \forall \ k \in \{16\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 23 \quad \forall \ k \in \{17\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 15 \quad \forall \ k \in \{18\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 8 \quad \forall \ k \in \{19\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 8 \quad \forall \ k \in \{20\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 4 \quad \forall \ k \in \{21\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 10 \quad \forall \ k \in \{22\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 9 \quad \forall \ k \in \{23\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 10 \quad \forall \ k \in \{24\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 5 \quad \forall \ k \in \{25\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 6 \quad \forall \ k \in \{26\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 13 \quad \forall \ k \in \{27\}$$ → Minimum quantity required of part k during the week

$$\sum_{i=1}^{7} P_{ik} \geq 11 \quad \forall \ k \in \{28\}$$ → Minimum quantity required of part k during the week

5.0 Sensitivity Analysis

After running our optimization model with Solver, we were able to minimize cost by hiring new employees. However, in order to meet demand (813.75 hours) and comply with all of the constraints (i.e. only current or external employees can work on weekends), the model assigned external workers for the weekend as well. Taking all of this into account, we were still able to reduce total costs from $56.000 to $51.600.

Table 3, is the staff scheduling model we've obtained,

OPTIMIZATION MODEL							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Current	16	16	16	13	13	3	3
New	2	2	2	2	2	0	0
External	2	2	2	2	2	1	1
TOTAL COST						$51.600	

Table 3

After analyzing the results of our optimization model, we identified two factors that could even generate a greater cost reduction.

The data to determine week's demand was obtained through PCC's monthly production plan. The plan describes the information for the 28 parts that continuously need to be inspected by the X-Ray department. From this report, there were three key elements that helped us build our model: the number of parts that conformed a product, the number of *part views* and *part films* performed by X-ray and Inspection technicians, respectively; and the average time spent on views and films for each part. So, for example, product P40065 consisted of 20 parts; each part needed to have 2 *views* and 6 *films.* The average time spent on views was 10 minutes and 1.5 minutes on films. Therefore, we needed 29 minutes to process product P40065.

With the previous analysis, the production plan confirmed that we needed 813.75 hours to complete a week's demand. However, the available working hours of 16 current employees only came up to 640 hours, forcing the company to hire more employees.

We realized that by reducing the average time spent on *views* and *films* by 20% and 17%, respectively, the department could complete the tasks with its full staff and only needing to hire 3 new employees.

Table 4, shows the total cost reduced by 23%,

OPTIMIZATION MODEL (Task Time Reduction)							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Current	16	16	16	13	13	3	3
New	1	1	0	0	1	0	0
External	0	0	0	0	0	0	0
TOTAL COST					$39.480		

Table 4

The second factor that we analyzed for sensitivity was an increase in the number of current employees. In the current situation, PCC prefers to hire external employees instead of new ones to complete demand. This is because new employees take up to 6 months to be fully trained and become efficient and the company cannot afford to lose time or risk quality. New employees affect their trainers' efficiency as well since they need to be working with them at all times during their training period. We ran a model assuming that PCC counted with 18 current employees instead of having two new ones that they hardly used. This scenario increases the cost slightly but it is worth the investment.

Table 5, validates the information we obtained with the above considerations,

OPTIMIZATION MODEL (Training Program)							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Current	18	18	18	15	15	3	3
New	0	0	0	0	0	0	0
External	0	0	0	0	0	0	0
TOTAL COST					$43.200		

Table 5

6.0 Conclusions

We have developed an assignment model for staff scheduling according to week's demand. For the purpose of our investigation, we worked with a number of 814 hours per week, this number has represented an average for the last 12 months. However, demand is not a fixed number;

PCC’s workload depends on its customers’ needs for each week. This represents a limitation for our project; it is difficult to optimize the number of workers that should be assigned to a task when the workload changes from week to week.

PCC had 16 current, 2 new, and 6 external technicians. The 16 current technicians did not represent enough capacity to meet demand at 813.75. Therefore, they would have to decide to hire new or external employees. The company directors preferred to hire external employees since this guaranteed quality and saved time, this option was more expensive but had better results. New technicians were rarely used because they affected the department’s performance due to a deficient training program. It takes up to 6 months to completely train a new worker which undermines his trainer’s efficiency. A trainer has to dedicate too much time to ensure that the new worker achieves the optimal level. This is why PCC preferred to hire external workers, they thought this would be less expensive and more productive in the long run.

Based on the current situation, we created two decision-making models to improve PCC’s efficiency and minimize total cost. First, we implemented a staff scheduling model to assign workers to the week’s demand. We considered new employees in our model, assuming that their work would contribute to the department’s overall performance and minimize costs. Secondly, we implemented an allocation model to distribute work according to the average time spent on the product parts. Fortunately, the activities could be completed in fractional periods; this means that a product could be 74.6% processed at a certain time. This factor allowed the implementation of the allocation model to assign activities based on the best combination possible.

After running both models using a linear program in Solver, we were able to achieve our goal which was to minimize cost and enhance task distribution. However, we also pursued a sensitivity analysis by evaluating two factors that influenced performance significantly. First, we reduced the average time spent on *views* and *films.* We considered that this could be achievable by establishing a suitable training program that improves current and new employees’ performance. Second, we converted new employees into current employees. This means that the company would count with 18 fully trained and efficient employees. Under these circumstances, there would be no need to hire external workers since the new demand would only require 659 weekly hours instead of 813. The total cost dropped by 16% from our original model.

7.0 Recommendations

As for our recommendations, it is important for PCC to reach agreements with its customers to try to determine demand at average levels. This would facilitate staff scheduling and assure better results; making last minute adjustments due to uncertain demand causes delays and a tense working environment which affects results.

We consider that a suitable training program is a must; the program could be completed in one intensive month instead of six. This would improve efficiency and minimize costs by not having to contract external help.

Our last recommendation is to measure individual efficiency. PCC could assign tasks based on the worker's' skills. For instance, a worker might be better at processing certain types of parts than other workers, this would lead to significant time reduction and better working conditions. A technician would perform better when he works on tasks that he specializes on.

8.0 References

[1] What Is Staff Scheduling and Planning? https://www.clicksoftware.com/blog/what-is-staff-scheduling-and-planning/

[2] Pccairfoils.com, http://www.pccairfoils.com/home/

[3] Bard, Jonathan F., and Canan Binici. "Staff scheduling at the United States postal service." *Computers & Operations Research* 30.5 (2003): 745-771.

[4] Glover, Fred, and Claude McMillan. "The general employee scheduling problem. An integration of MS and AI." *Computers & operations research* 13.5 (1986): 563-573.

[5] Hashir, Naveen, Siva, Suresh, Turki. “Nurse Scheduling For Kaiser’s ICU, 2003-W-540-01-2, *ETM 540.*

[6] Stephen Noble Nadja Wolfangel Justus Arne Schwarz Tung Lung Li Ji Ting Yang. “Employee Utilization Model.” *ETM 540 Winter 2010.*

[7] Jorge Garcia, Kshiti Shah, Puniti Singla, Selen Yilmaz, Sowmini Sengupta, “Optimization of Staffing Schedule At SHARC (Shute Park Aquatic and Recreation Center).” *ETM 540 Winter 2013.*

[8] Optimization Modeling with Spreadsheets, Kenneth Baker, 2015, 3rd Edition, John Wiley & Sons, Inc.

Appendices

[A] Excel Workbook - Team7_ProjectModel.xlsx