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BAMS 508 Group Project: Dental Clinic Scheduling & Revenue Optimization

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Executive Summary

In this group project, we proposed dental scheduling and revenue optimization for a clinic called PacificWest Dental Group. We provided optimized solutions to maximize the revenue in a regular week based on the clinic's availability and demands. The report includes two optimization solutions: one is to minimize the doctors' weekly salary pay to minimize the labor cost. Based on that, another optimal solution is to maximize the weekly revenue by generating a schedule of the provided treatment by each doctor on each working day.

The report consists of five parts:
- Background information about the clinic, detailed staff data, and optimized problems.
- Process of model construction for two main problems, including choosing variables, setting hard and soft constraints, and building the mathematical objective formulas.
- Optimization results generation using Gurobi and explanation of the results.
- Discussion and Recommendations to the clinic based on the results.
- Summary and future plan for improvement.

1. Background Information

1.1 Introduction

PacificWest Dental Group (PWDG) is one of the best orthodontic clinics in Greater Vancouver. It has two locations in Vancouver Mainland and Surrey and provides a variety of orthodontic treatments, including initial consultation, braces, Invisalign, and lingual braces. With the increasing demand for orthodontic treatment, the clinic is facing a shortage of staffing and having a hard time scheduling them to achieve maximum efficiency.

To minimize the labor cost of the office and maximize the revenue produced, the doctors would like to automate the scheduling process for all the doctors in the Vancouver office, as well as which treatment/service should be seen on each day based on doctors' schedules.

1.2 Scheduling & Staffing Details

The Vancouver office in PWDG opens every Monday to Friday from 9:00 a.m. to 5:00 p.m. Currently, there are four doctors in the office, one head doctor, one senior doctor, one junior doctor, and an internship. Their hourly pay is different according to their experience, as well as each doctor has their own daily and weekly working hour limit **(Table 1.1).**

Table 1.1 Hourly Pay and Working Limit

	Head doctor - W	Senior doctor - X	Junior doctor - Y	Internship - Z
Hourly Pay ($/hr)	210	180	150	120
Daily working limit (hrs)	6	4	6	3
Weekly working limit (hrs)	15	8	8	6

Besides each doctor's working limitation, there are minimal weekly hours limits for each day based on the clinic's operation system and the number of patients from the past experience **(Table 1.2)**. For instance, Monday and Thursday have the least patients coming to the clinic whereas Tuesday and Wednesday have the most patients.

Table 1.2 Minimal Working Hours per Day

	Monday	Tuesday	Wednesday	Thursday	Friday
Minimal working hours (hrs)	6	12	12	6	8

If the above hard constraints cannot be met due to the weekly working hour limit of each doctor, overtime might apply to them, which costs 1.5 times of their normal hourly salary. PWDG also would like to minimize the total cost of overtime.

The time needed for each treatment and each price is shown in Table 1.3 below. And the treatments that each doctor can provide are shown in Table 1.4.

Table 1.3 Time and Price of Each Treatment

	Treatment Length (hrs)	Price/Hours ($/hr)
Braces - A	3	300
Initial Consultation - B	3	270
Lingual - C	2	360
Invisalign - D	4	300

Table 1.4 Treatments Each Doctor can Provide

Treatment/Doctor	W	X	Y	Z
A			✓	
B		✓	✓	
C	✓			✓
D	✓	✓		✓

2. Model Formulations

2.1 Model 1 - Doctor Scheduling:

Problem Description:
In a time period of one week, PWDG would like to find out how to allocate each doctor's working schedule to minimize the labor cost while meeting all the working time restrictions the clinic has and minimize all the doctor's over working hours.

Variables:

Let D_i be the number of hours that doctor D works on weekday i, where, $D \in \{W, X, Y, Z\}$, $i \in \{m(Monday), t(Tuesday), w(Wednesday), th(Thursday), f(Friday)\}$

e.g. Variable W_m means the number of hours that doctor W works on Monday.

Variable Z_f means the number of hours that doctor Z works on Friday.

Table 2.1 Variables *Di* of the Model

	Monday(m)	Tuesday(t)	Wednesday(w)	Thursday(th)	Friday(f)
Doctor(W)	W_m	W_t	W_w	W_{th}	W_f
Doctor(X)	X_m	X_t	X_w	X_{th}	X_f
Doctor(Y)	Y_m	Y_t	Y_w	Y_{th}	Y_f
Doctor(Z)	Z_m	Z_t	Z_w	Z_{th}	Z_f

Let O_D be the possible weekly overtime hours per doctor, where $D \in \{W, X, Y, Z\}$, but with an upper bond of 5, which means each doctor can at most exceed their weekly working hour limit by 5 hours.

e.g. Variable O_W means the possible overtime hours of doctor W on a weekly basis

Table 2.2 Variables *OD* of the Model

	Doctor(W)	Doctor(X)	Doctor(Y)	Doctor(Z)
Possible Weekly Overtime Hours (hrs)	O_W	O_X	O_Y	O_Z

Objective Function:

The objective for this question is to minimize the total labor cost.

$$Minimize \qquad \sum_{D}\sum_{i} C_D D_i \ + \ 1.5 * \sum_{D} C_D O_D \qquad D \in \{W, X, Y, Z\}$$

$$i \in \{m, t, w, th, f\}$$

$C_D = labor\ cost\ for\ doctor\ D\ (labor\ cost\ for\ overtime\ hours\ is\ 1.5\ times\ of\ the\ normal\ cost)$ (refers to Table1)

$D_i = \#\ of\ hours\ that\ each\ doctor\ D\ works\ on\ each\ weekday\ i$

$O_D = \#\ of\ the\ possible\ weekly\ overtime\ hours\ for\ doctor\ D\ on\ a\ weekly\ basis$

$Min(210 * (W_m + W_t + W_w + W_{th} + W_f) + 180 * (X_m + X_t + X_w + X_{th} + X_f) +$
$150 * (Y_m + Y_t + Y_w + Y_{th} + Y_f) + 120 * (Z_m + Z_t + Z_w + Z_{th} + Z_f) + O_W + O_X + O_Y + O_Z)$

Constraints:

- **<u>Hard Constraints:</u>**

1. Each doctor has their own daily working hour limit.

$$D_i \ \le \ DL_D \qquad D \in \{W, X, Y, Z\},\ i \in \{m, t, w, th, f\}$$

$DL_D = \ daily\ working\ hour\ limit\ for\ doctor\ D\ (Table\ 1.1)$

- $W_m \le 6,\ W_t \le 6,\ W_w \le 6,\ W_{th} \le 6,\ W_f \le 6$
  (Doctor W can only work up to 6 hours per day)
- $X_m \le 4,\ X_t \le 4,\ X_w \le 4,\ X_{th} \le 4,\ X_f \le 4$
- $Y_m \le 6,\ Y_t \le 6,\ Y_w \le 6,\ Y_{th} \le 6,\ Y_f \le 6$
- $Z_m \le 3,\ Z_t \le 3,\ Z_w \le 3,\ Z_{th} \le 3,\ Z_f \le 3$

2. The clinic has requirements for each working day's minimum available slots.

$$\sum_{D} D_i \ge MW_i \qquad D \in \{W, X, Y, Z\}, i \in \{m, t, w, th, f\}$$

$MW_i \ = \ minimal\ working\ hours\ per\ day\ (Table\ 1.2)$

- $W_m + X_m + Y_m + Z_m \ge 6$
  (Sum of All Doctors' working hours on Monday has to be more than 6 hours)
- $W_t + X_t + Y_t + Z_t \ge 12$
- $W_w + X_w + Y_w + Z_w \ge 12$
- $W_{th} + X_{th} + Y_{th} + Z_{th} \ge 6$
- $W_f + X_f + Y_f + Z_f \ge 8$

3. Doctors' overtime working hours have an upper limit of 5 hours per week.

$$0 \leq O_D \leq 5 \qquad D \in \{W, X, Y, Z\}$$

- $0 \leq O_W \leq 5$
- $0 \leq O_X \leq 5$
- $0 \leq O_Y \leq 5$
- $0 \leq O_Z \leq 5$

- **Soft Constraints:**

4. Each doctor has their own weekly working hour limit, if a doctor's weekly working hour exceeds the weekly working hour limit, he/she will be paid 1.5 times the usual salary for overtime work.

$$\sum_i D_i - O_D \leq WL_D \qquad D \in \{W, X, Y, Z\}, i \in \{m, t, w, th, f\}$$

$WL_D = $ $weekly\ working\ hour\ limit\ for\ doctor\ D$ ($Table$ 1.1)

- $W_m + W_t + W_w + W_{th} + W_f - O_W \leq 15$
  (Doctor W can work maximum 15 hours per week, but can work at most 5 more extra hours)
- $X_m + X_t + X_w + X_{th} + X_f - O_X \leq 8$
- $Y_m + Y_t + Y_w + Y_{th} + Y_f - O_Y \leq 8$
- $Z_m + Z_t + Z_w + Z_{th} + Z_f - O_Z \leq 6$

2.2 Model 2 - Treatments schedule based on Model 1

Problem Description:

After determining the optimal working schedule, PWDG now would like to find out a way to arrange different treatments provided on each working day to maximize the revenue and also meet all the constraints the clinic faced.

Variables:

Let D_{j_i} be the binary indicator of whether the doctor D will provide treatment j on weekday i, where ,$D \in \{W, X, Y, Z\}$, $j \in \{A, B, C, D\}$, $i \in \{m, t, w, th, f\}$.

$$D_{j\_i} = 1,\ if\ \ doctor\ D\ will\ provide\ treatment\ i\ on\ weekday\ i$$

$$= 0,\ otherwise$$

e.g. $Y_{A\_M} = 1$ means that doctor Y will provide treatment A on Monday.

Table 2.3 Variables D_{i_j} of the Model

	Variables D_{j_i} for each Doctor
Doctor(W)	W_{C_m}, W_{D_m}, W_{C_t}, W_{D_t}, W_{C_w}, W_{D_w}
Doctor(X)	W_{B_w}, W_{D_w}, W_{B_th}, W_{D_th}, W_{B_f}, W_{D_f}
Doctor(Y)	Y_{A_t}, Y_{B_t}, Y_{A_w}, Y_{Bw}, Y_{A_f}, Y_{B_f}
Doctor(Z)	Z_{C_m}, Z_{D_m}, Z_{C_w}, Z_{D_w}, Z_{C_th}, Z_{D_th}, Z_{C_f}, Z_{D_f}

Objective Function:

The objective for this question is to maximize the total revenue per week.

$$Max \quad \sum_D \sum_j \sum_i P_{D\_j} D_{j\_i}$$

$where, D \in \{W, X, Y, Z\}, i \in \{m, t, w, th, f\}, j \in \{A, B, C, D\}, P_{D\_j}$ is the estimated revenue for each doctor for each treatment

$P_{D\_j} = (Treatment\ Price\ per\ Hour - Doctor\ salary\ per\ Hour\ (C_D)) \times Treatment\ Length$ required (Refer to Table 1.1 and 1.3)

$Max\ (300W_{C\_m} + 360W_{D\_m} + 480Z_{C\_m} + 720Z_{D\_m} + 300W_{C\_t} + 360W_{D\_t} + 450Y_{A\_t} + 360Y_{B\_t} + 300W_{C\_w} + 360W_{D\_w} + 270X_{B\_w} + 480X_{D\_w} + 450Y_{A\_w} + 360Y_{B\_w} + 480Z_{c\_w} + 720Z_{D\_w} + 720X_{B\_th} + 480X_{D\_th} + 480Z_{C\_th} + 720Z_{D\_th} + 270X_{B\_f} + 480X_{D\_f} + 450Y_{A\_}f + 360Y_{B\_f} + 480Z_{C\_f} + 720Z_{D\_f})$

Constraints:

1. One kind of treatment can only be treated by one doctor.

$$\sum_D D_{j\_i} \leq 1, \quad D \in \{W, X, Y, Z\},\ i \in \{m, t, w, th, f\},\ j \in \{A, B, C, D\}$$

$W_{C\_m} + Z_{C\_m} \leq 1, \quad W_{D\_m} + Z_{D\_m} \leq 1, \quad W_{C\_w} + Z_{C\_w} \leq 1, \quad W_{D\_w} + X_{D\_w} + Z_{D\_w} \leq 1,$
$X_{B\_w} + Y_{B\_w} \leq 1, \quad X_{D\_th} + Z_{D\_th} \leq 1, \quad X_{B\_f} + Y_{B\_f} \leq 1, \quad X_{D\_f} + Z_{D\_f} \leq 1$

2. The kinds of treatments provided each day should be equal to or less than three.

$$\sum_i D_{j\_i} \leq 3, \quad D \in \{W, X, Y, Z\},\ i \in \{m, t, w, th, f\},\ j \in \{A, B, C, D\}$$

- $W_{C\_m} + W_{D\_m} + Z_{C\_m} + Z_{D\_m} \leq 3,$
- $W_{C\_t} + W_{D\_t} + Y_{A\_t} + Y_{B\_t} \leq 3,$

  $W_{C\_w} + W_{D\_w} + X_{B\_w} + X_{D\_w} + Y_{A\_w} + Y_{B\_w} + Z_{C\_m} + Z_{D\_m} \leq 3,$
- $X_{B\_th} + X_{D\_th} + Z_{C\_th} + Z_{D\_th} \leq 3,$
- $X_{B\_f} + X_{D\_f} + Y_{A\_f} + Y_{B\_f} + Z_{C\_f} + Z_{D\_f} \leq 3$

3. Each day, the total time of each treatment should be less than the available time of the doctor who provides this treatment from question 1.

$$\sum_j T_j D_{j\_i} \leq AT_{D\_i}$$

T_j is the the time needed by each treatment as shown in Table 1.3

AT_{D_i} is each doctor's available slots per day from Model 1's optimal result as shown in Table 3.1.

- $2W_{C\_m} + 4W_{D\_m} <= 4$
- $2Z_{C\_m} + 4Z_{D\_m} <= 2$
- $2W_{C\_t} + 4W_{D\_t} <= 6$
- $3Y_{A\_t} + 3Y_{B\_t} <= 6$
- $2W_{C\_w} + 4W_{D\_w} <= 5$
- $3X_{B\_w} + 4X_{D\_w} <= 1$
- $3Y_{A\_w} + 3Y_{B\_w} <= 3$
- $2Z_{c\_w} + 4Z_{D\_w} <= 3$
- $3X_{B\_th} + 4X_{D\_th} <= 3$
- $2Z_{C\_th} + 4Z_{D\_th} <= 3$
- $3X_{B\_f} + 4X_{D\_f} <= 4$
- $3Y_{A\_} f + 3Y_{B\_f} <= 1$
- $2Z_{C\_f} + 4Z_{D\_f} <= 3$

3. Model Results

3.1 Model 1 - Doctor Scheduling:

According to figure 3.1**,** the minimal labor cost per week is $8,760, and the optimal doctor schedule is shown in table 3.1. In order to fulfill the minimum working hours per day for the clinic, the junior doctor needs to work 2 hours of overtime and the internship doctor needs to work 5 hours of overtime.

```
# print optimal objective value
m.objVal
```

```
8760.0
```

```
# print optimal decisions (if not listed, that means their optimal value = 0)
m.printAttr('X')
```

```
    Variable            X
-------------------------
          Yt            6
          Yw            3
          Yf            1
          Xw            1
         Xth            3
          Xf            4
          Wm            4
          Wt            6
          Ww            5
          Zm            2
          Zw            3
         Zth            3
          Zf            3
          OY            2
          OZ            5
```

Figure 3.1 The Optimal Solution for Model 1

Table 3.1 Minimal Working Hours per Day

	Mon	**Tue**	**Wed**	**Thu**	**Fri**	**Total & Max hours limit per doctor**
Head doctor - W	4	6	5			**15** (15)
Senior doctor - X			1	3	4	**8** (8)
Junior doctor - Y		6	3		1	**10** (8)
Internship - Z	2		3	3	3	**11** (6)
Total & Min hours per day	**6** (6)	**12** (12)	**12** (12)	**6** (6)	**8** (8)	

3.2 Model 2 - Treatments schedule based on Model 1

According to figure 3.2, the maximum revenue per week for this clinic is $5010. The treatment schedule is shown in the table 3.2.

```
# print optimal objective value
m.objVal
```

```
5010.0
```

```
# print optimal decisions (if not listed, that means their optimal value = 0)
m.printAttr('X')
```

```
    Variable            X
-------------------------
       W_D_M            1
       Z_C_M            1
       W_D_T            1
       Y_A_T            1
       Y_B_T            1
       W_D_W            1
       Y_A_W            1
       Z_C_W            1
      X_B_Th            1
      Z_C_Th            1
       X_D_F            1
       Z_C_F            1
```

Figure 3.2 The Optimal Solution for Model 2

Table 3.2 Treatment Schedule based on Model 1

Treatment	Mon	Tue	Wed	Thu	Fri
Head doctor - W	D	D	D		
Senior doctor - X				B	D
Junior doctor - Y		A & B	A		
Internship - Z	C		C	C	C

4. Discussion & Recommendations

Based on the results above, we have some strategic advice for PWDG in the future, and some aspects we think PWDG can improve on.

Reduce Labor Cost: While the cost for different levels of Doctors is different and the revenue of different types of treatment is volatile, though we have optimized the schedule plan for the current level, we think it would be better to hire more intern Doctors. Compared with other levels of Doctors, Intern doctors have the lowest cost, but their revenue is still relatively high. The clinic can also choose to train the interns to become junior doctors who have more weekly working hours.

Monitor quality of treatments: When trying to control the labor cost, the clinic should also be careful to not reduce the quality of treatment. We recommend the clinic keep monitoring the performance of Junior Doctors and Intern Doctors to ensure that patients can receive quality-assured treatments if they decide to hire more Intern Doctors.

Increase Slots availability: Currently, with the restriction of doctors' working hours, PWDG has very limited opening slots for the clients, thus largely affecting the weekly revenue. Combined with hiring more intern doctors above, PWDG can open more treating slots and to further maximize the revenue.

Build a Booking system: While currently the treatment periods are designed based on the optimized doctor availability schedule, PWDG can consider launching a booking system in the future. With that, PWDG can estimate the demand for different treatments based on the booking record and then optimize the doctors' working schedules based on the real demand.

Employee Training: Treatments provided by each doctor are limited currently, thus largely reducing the treatment efficiency. In the future, PWDG can open a training session where each doctor can learn from each other about different types of treatments so that more treatment slots will be available.

Connection with Medical School: It is very beneficial for PWDG to build up a long-term connection with local medical schools to provide internship opportunities for orthodontic students. Moreover, PWDG can also keep up with the most advanced technology and treatments, and consider providing more services to the clients.

5. Conclusion

In this report, we developed two mathematical models to address the dental scheduling problem for PacificWest Dental Group. The first model is formulated using the integer programming method with the objective of minimizing the weekly salary payments of the doctors, thereby generating weekly available slots for doctors in regard to the working hour limitations from the clinic and the doctors. The minimized weekly cost for hiring doctors is $8760. Then, based on the schedule table, the second model is formulated with binary indicators of the types of treatments provided by each doctor on each working day. In relation to the treatment price and the treatment length, we optimized the weekly revenue to be $5010.