A REVENUE MANAGEMENT FRAMEWORK FOR APPOINTMENT ALLOCATION IN REHABILITATION OUTPATIENT CLINICS

A Thesis by

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ABSTRACT

Rehabilitation outpatient clinics help patients overcome physical disabilities through various rehabilitation services. Appointment scheduling and accepting new patients are very important processes in rehabilitation outpatient clinics. In this thesis, several mathematical models for generating optimal appointment schedules with an objective to maximize the profit when demand is deterministic are developed. In these models, the possibility of treating more than one patient simultaneously is also considered. In this case, grouping patients results in the minimal use of part time therapists. When the demand is stochastic, a revenue management framework to allocate appointments is proposed. Using the proposed revenue management framework, the revenue and overall profit generated is maximized. To test the effectiveness of this framework, extensive simulation study is performed. Analysis of mathematical and simulation models reveal that the proposed methodologies result in an increased revenue and profit when the capacity is tight and demand is high. The revenue management framework also increases the number of new customers accepted for treatment in an outpatient clinic significantly.

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BACKGROUND

1.1 Overview

Healthcare is defined as "the prevention, treatment, and management of illness and the preservation of mental and physical well-being through the services offered by the medical and allied health professions" [31]. Healthcare industry provides various services such as acute care, long term care, and rehabilitation (rehab). While acute care hospitals and long term care hospitals cater to the requirements of the customers that have serious health conditions and require continued care respectively, rehab hospitals help the patients overcome physical and mental disabilities. One common challenge for all these fields in healthcare is scheduling the patients in such a way that patients' waiting time and doctors' idle time is at a minimum. Extensive study has been conducted on these issues but not many concentrate on maximizing the profit to the health care organization.

This research facilitates the scheduling of patients in a rehab outpatient clinic in such a way that the profit is maximized while giving quality treatments to patients. In this thesis, several mathematical programming and simulation models are proposed. A comprehensive experimentation is performed to test the efficacy of the models.

This chapter is organized as follows: In section 1.2, a detailed overview of the rehab outpatient clinics is presented. Section 1.3 discusses the problem statement and the motivation for this study. The organization of this thesis is presented in the final section of this chapter.

1.2 Rehabilitation Outpatient Clinics

Rehab hospitals help patients overcome physical and mental disabilities through various rehabilitation programs. The scope of rehabilitation programs varies according to the individuals' requirement and patients' diagnosis. There are many types of rehabilitation programs such as physical, occupational, speech, respiratory, neurological, and industrial rehabilitation. These rehabilitation programs may be performed in a variety of settings: Outpatient clinics, physicians' office, acute care and sub acute care hospitals, fitness clubs, and nursing homes. Of all types of rehabilitation programs, physical rehabilitation is an area that the majority of outpatient facilities concentrate on. We are interested in outpatient clinics where patients having musculoskeletal conditions such as orthopedic, sports injuries, rheumatologic conditions such as arthritis are treated.

Physical rehabilitation is usually comprised of the following therapies [32]:

- Physical Therapy (PT): Treatment of musculoskeletal and neurological injuries and conditions to promote a return to function and independent living. PT entails the use of physical exercise and functional training.
- Occupational Therapy (OT): OT aims at helping people regain the movement and skill necessary for functioning independently. OT is concerned with treatment of neurological and neuromuscular injuries and conditions such as stroke, spinal cord injury, brain injury and multiple sclerosis.
- Aquatic Therapy: Aquatic Therapy can be used as a supplement to PT and OT.
- Speech Therapy

Customers visiting the rehabilitation outpatient clinics first undergo new patient evaluation, wherein their problem is diagnosed and a rehabilitation plan is recommended. As a result, customers may end up visiting the rehab facility several times for follow-ups.

1.3 Problem Statement

The patients requiring any of these rehabilitation services need to visit the rehab facility regularly. Hence, there is a high probability that any customer who visits a rehab facility for the first time would return to the same facility for further care. One of the performance metrics that an outpatient clinic might use is how soon a customer can have a new patient evaluation. Generally, patients would like to have an appointment as soon as possible. If the patients are asked to wait for a long duration for an appointment, especially for the very first visit where the therapist comes up with the rehabilitation plan, patients might move to a different facility. In other words, outpatient clinics might lose a customer to one of the competitors. From the management perspective, rehabilitation outpatient clinics cannot afford to lose a potential customer to its competitors for not having an effective appointment system.

Outpatient clinics operate differently from inpatient hospitals. Unlike inpatient service wherein the service is sold in the form of beds, outpatient clinics operate by selling fixed period appointments for different treatments, which usually last from 15 minutes to hours. The challenge being faced by any outpatient clinic including rehab hospitals is to maximize profit by allocating appointments optimally.

The operation of an appointment system depends on the effectiveness of appointment allocation. Appointment systems can be designed to suit the needs of individuals. Traditional appointment systems in healthcare aim at improving the resource utilization and reducing patient waiting times [13]. Doctors, therapists, time, and equipment can be considered as resources in healthcare. No doubt, resource utilization and waiting times are very important for any organization and so is the profit. Traditional appointment systems fail to take this into account.

Like any other healthcare service, rehabilitation service is also covered by a majority of insurance sources, which implies that patients usually do not pay for the service directly. Instead, a third party insurer will pay for the treatments that patients receive. In some cases patients may have to pay a portion of the price as co-payment. The third party insurers could be private commercial insurers or their government equivalents like Medicare or Medicaid.

The insurance coverage depends on the contract between the hospital and private insurers or the rate set by the government in the case of Medicare and Medicaid.

In rehab outpatient clinics, it is possible for a therapist to give certain treatments to more than one patient simultaneously without affecting the quality of treatment to each individual patient. In such situations, patients that are scheduled for the same appointment slot with the same therapist are said to undergo a group therapy (GT). If a therapist is treating only one patient at a time, the patient receives an individual therapy (IT). Certain insurance sources do not pay the full amount if the patient is given group attention. Each payment source has its own regulations and definition of individual and group attention. It is possible with some insurance that the patient is scheduled for group therapy and still be charged individual therapy fare.

Only a trained therapist can treat the patients and it is unlikely that a therapist is trained in all rehab services. It is therefore essential for any rehab hospital to have a pool of therapists with varied expertise. A therapist could either be a qualified registered therapist or a certified assistant. Certain treatments require the supervision of the registered therapist and cannot be handled by assistants. In other words there is a variation in the skill level of therapists. Usually new patients are initially treated by the qualified therapist and are scheduled with an assistant therapist for subsequent appointments. It is also natural for outpatient clinics to employ both full-time and part-time staff as part of their staffing policy.

1.4 Research Objective

Rehabilitation service is growing in demand because of the increase in aging population, accidents, and injuries in the workplace. Every rehab facility wishes to serve as much demand as possible. While scheduling patients to group therapy helps in coping with the growing demand, individual therapy restricts the number of patients to the number of appointment slots available. There is a need for an efficient and robust decision support system that could address the following issues with an objective to maximize the profit.

1. What is the optimal mix of full time and part time staff of different skill level for fulfilling the demand?
2. Given the demand, payment source and treatment of patients, what form of attention (group or individual) should they be scheduled for?
3. When the demand is uncertain and customer arrival is stochastic, how should the resources be allocated to different customer classes (customers with different payment sources)?
4. How can the new customer fill rate, i.e., the number of new customers accommodated in the system, be improved?
5. How can the waiting time of new customers for an appointment be reduced?

1.5 Organization of the Thesis

This thesis is organized as follows. In chapter 2, a detailed literature survey outlining the revenue management philosophy, and scheduling is explained. Chapter 3 focusses on the optimization approach for the problem discussed above and explains two different deterministic models for scheduling appointments and therapists. In chapter 4, a revenue management framework for appointment allocation is proposed. Chapter 3 assumes that the demand is deterministic while chapter 4 addresses the issue of stochastic arrivals of customer request. The research is concluded with chapter 5, which along with providing feasible suggestions, also brings out some of the potential areas for future research. Appendices A and B present the results of deterministic models and the abbreviations used in the thesis respectively.

1.6 Summary

An overview of rehab hospitals is presented in this chapter. Appointment allocation in rehab outpatient clinics is identified as the potential area for improvement. This chapter discusses various functions of an appointment system such as maximizing profit, improving new customer fill rate, and reducing waiting time.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

The operation of an appointment system depends on the effectiveness of appointment allocation. Appointment systems can be designed to suit the needs of individuals. Traditional appointment systems in healthcare aim at improving the resource utilization and reducing patient waiting times [13]. No doubt, maximizing resource utilization and minimizing waiting time of patients are very important for any organization and so is the profit. Traditional appointment systems fail to take this into account.

The problem discussed in this thesis encompasses different areas, such as appointment and therapist scheduling and timetabling, and revenue management. This chapter discusses each of these areas in separate sections.

2.2 Scheduling and Timetabling

The problem of appointment allocation deals with scheduling resources to satisfy the demand at the right time and right place. Resources could be in the form of machines, staff, space, time or equipment and the demand obviously is the customer order. In healthcare, we can consider doctors (therapists in case of rehabilitation hospitals) and time as the key resources and the patients as the demand. The prime factors that affect operations of appointment systems are staff scheduling and appointment scheduling.

Most real life scheduling problems are NP-hard. For even moderate sized problems, algorithms will find them difficult to solve, due to the exponential size of the solution space [3]. Staff scheduling finds its application in many different industries. Examples include employee scheduling at a fast food chain, airline crew scheduling, nursing application, scheduling a rotating workforce, military manpower planning, scheduling bus drivers, casino security officers [3].

Naidu et al. [22] identify the importance of resource scheduling in healthcare. Naidu et al. [22] give an outline on the various approaches such as linear programming, expert based system and heuristic approaches for achieving an optimal staffing plan that would meet the requirement at the lowest possible cost.

Traditional staff scheduling models focus only on minimizing the overall staffing cost. Cai and Li [12] argue that this single criterion approach is not feasible as it does not account for variation in demand. Furthermore, these models assume that the skill level of the staff is homogeneous, while in reality the skill level of the staff vary a lot. Recognizing these drawbacks in the traditional models, Cai and Li [12] propose a multi criteria model with three objectives of importance. Apart from minimizing the staffing cost, the model aims at maximizing the surplus staff and minimizing the variation of surplus staff. The model also considers the possibility of employees possessing multiple skills.

In outpatient clinics there are pre-registered patients and patients who just walk in. The main problem associated with appointment scheduling is setting the appointment times that would balance the patients' waiting time and doctors' idle time [9, 24, 25]. In this thesis, it is assumed that every appointment is pre-registered. Bosch and Dietz [9] tackle the problem of appointment scheduling in healthcare with an assumption that the customer arrival is deterministic. They concentrate on setting appointment durations such that the waiting time is minimized. However, in rehab outpatient clinics, patients undergo treatments for a fixed duration and hence the appointment time for the next customer can be determined easily. We can also assume that the customers arrive promptly at the established time and thus do not have to wait for treatments. The appointment scheduling in this scenario does not include setting appointment durations, but given the appointment duration and the capacity available, an appointment slot and a therapist is allocated to customers.

The appointment allocation in rehabilitation outpatient clinics is similar to the timetabling problem in educational institutions. Timetabling is one of the complex problems being faced by educational institutions. This problem involves assigning a faculty to a course/subject and a room for a fixed time period. Each faculty differs in their skill level [17]; there could be many different sections for each course/subject; there could be a number of rooms available [11, 17]. Some faculty may prefer to teach more than one course in successive time periods, while others may need a break between two successive lectures [1, 2, 11, 17]. Abramson [1] and Tillett [26] address the assignment problem in a typical school which involves scheduling a combination of students, teachers, subjects, and rooms to a time period. Badri et al. [2] focus on the faculty-course-time assignments in different departments of colleges and universities. Though the assignment of students to sections has been identified as one of the factors in faculty assignment problem, Breslaw [11] realizes that the root of the problem lies in the allocation of faculty to courses prior to registration by the student. Abramson [1] define the combination of a teacher, a subject, a room, and a class as an 'element' and frequency of the element as 'requirement' such that scheduling the requirements in such a way that no requirement, teacher, class or room appears more than once per period.

Similar to the educational institutions, scheduling appointments in rehab clinics involves scheduling a combination of therapists, patients and treatments to a time period. Here, therapists perform the function of the faculty members, treatments are considered to act as courses and the patients are the students.

2.3 Revenue Management

Pak and Piersma [23] define revenue management (RM) as the art of maximizing the revenue generated from a limited capacity of a product by selling each product to the right customer at the right time for the right price. "Revenue Management traditionally involves segmenting customer, setting prices controlling capacity to maximize the revenue generated from a fixed capacity" [27]. RM originated from the airline industry in the 1970s and since then it has been a key tool for management in achieving maximum revenue. Traditionally applied to the travel and hospitality industries, RM is being used across a growing range of industries [7].

RM is applicable in areas where the capacity is constrained and the product is highly perishable in nature [30]. Major applications of RM can be witnessed in the airline industry, hotels [18] and restaurants [19], car-rentals [7], railway and cruise-line industries [23], but its application does not limit only to tourist industries. This concept can also be extended to fast moving consumer goods [21] and healthcare organizations [20]

The objective of any airline company is to maximize the revenue generated from the sales of seats/tickets on every flight. The goal of hotels is no different than airlines except that the revenue generated by a hotel is through the sale of rooms for a particular length of period. Both the seats on flights and rooms in hotels are perishable resources. If an unused resource leads to a lost opportunity to generate revenue, the resource is said to be perishable. If a flight takes off with empty seats, airlines do not get revenue from the unsold seats. Similarly if a hotel room is unsold for a day, the opportunity to generate revenue from that room on that day is lost forever.

Though the bottom line of RM in any industry is the same, there is a slight difference in the approach adopted by different organizations. Following the deregulation of the airline industry, RM has underlined its importance and many companies depend on this technique for its development [7]. Lieberman [20] brings out the scope of revenue management in healthcare. The success of revenue management in any industry depends on the following questions:

- Is there a clear distinction between different customer classes? In other words, can the customer base be segmented to different categories based on certain criteria?
- How accurate is the demand forecast?

- Does the industry practice a clearly defined booking policy or capacity allocation procedure?

These questions are related to the customer segmentation, demand forecasting and the booking policy, which will be discussed in detail in the following sections.

2.3.1 Customer Segmentation

Airlines can segregate the customer into different classes such as business, first, regular and cabin coach [16]. Pak and Piersma [23] argue that fare class does not only include the above classes but also the classes with difference in fares due to cancelation options or overnight stay options. Total number of seats and seats allocated to each class are the two main constraints that would affect the airline revenue management [16]. Gosavi et al. [15] define the seat allocation problem as the sale of seats to customers belonging to different fare classes at different prices. The time of request for reservation is one of the bases for this fare classification. Kimes [18] classify the fare classes as full-rate, maxi-saver, and super-saver, where maxi-saver and super-saver represent the reduced fare.

2.3.2 Demand Forecasting

The effectiveness of revenue management depends on customer demand. According to Weatherford et al. [28], pricing and duration of customer usage are the two strategic levers of business. Prices can either be fixed wherein everyone enjoys the same price or variable wherein every individual is charged a different amount depending on the segment to which the customer belongs. Furthermore, duration can be predictable or unpredictable and hospitality industries tend to use variable pricing with a predictable duration [28].

The major challenge that would form a constraint in implementing RM in any industry is the arrival pattern of customers [19]. The length of stay or the duration of use of a particular service adds to the complexity of the problem [29]. Accurate forecasting is the key in RM and it helps in guessing the duration of use. Poor estimates of the demand results in poor performance of the booking control strategy [23].

One has to be very careful while selecting a forecasting method. Usually in revenue management, either a bottom-up or a top-down forecasting approach is adopted. In the bottom-up approach, demand for different categories/customer segments are forecasted each period and then summed up. On the other hand, in the top-down approach, an aggregate forecast is made and is then broken down into individuals by means of probability distributions [28].

2.3.3 Booking policies

The most challenging task for any hospitality industry is the decision that is to be made on accepting or rejecting the customer request. In case of airline industry, the customer request can be represented as the request for a seat in the flight. Hotels mainly deal with request for rooms for a particular length of stay. The hotel management should take into account the reservations made earlier and the potential customers who will arrive without any reservation [14]. It is common for airlines and hotels to overbook anticipating few no-shows or cancelations [23]. Effective RM provides the industry with an opportunity to compensate for the loss incurred because of cancelations [16]. In this research, customers are assumed to arrive promptly for an appointment at the established time and hence no-shows and cancelations are not considered. The common booking policies adopted in industries, i.e., bid pricing and nested booking [14] are explained in this section.

Bid prices

In bid price models a booking is accepted only if the revenue it generates is above the sum of the bid prices of the inputs that it uses, in other words if it is more than the opportunity cost. Opportunity cost can be referred to as the shadow price, which is the expected gain that can be obtained if an additional resource is available [14].

Nested booking limits

There could be different categories of customers based on the price they are willing to pay for the same service. Usually each category will have a fixed capacity and once this capacity is reached, the customers belonging to this category are rejected. It is highly impractical to reject a booking request when resources allocated to other less profitable classes are still available. Therefore everyone should be allowed to use resources allocated to any less profitable class. This approach is defined as nesting policy [14]. The nesting policy is usually followed by airlines and hotels for reservation of seats and rooms respectively but there is no reported utilization of this policy in healthcare. The nested booking concept is explained in detail in chapter 4.

2.3.4 Revenue Management in Healthcare

Revenue Management works best when there is a limited available capacity and when the customers are ready to pay different amount for the same service. This section draws an analogy between healthcare and other hospitality industries and explains how healthcare in general and rehab outpatient clinics in particular are potential candidates for the application of revenue management.

In all hospitality organizations, the capacity is limited. In airlines, the numbers of seats constitute the capacity, in hotels it is the number of rooms, in restaurants it is the number of seats and in hospitals it is the number of beds. It is highly unrealistic to have unlimited capacity and this limited capacity is one of the major constraints in maximizing the revenue.

Outpatient clinics operate differently from airlines and hotels. Unlike airlines and hotels wherein the service is sold in the form of seats and rooms respectively, outpatient clinics operate by selling appointments of short period for different treatments, which usually last from 15 minutes to hours. The challenge faced by any outpatient clinic including rehab outpatient clinics is to maximize the profit by allocating the appointments optimally.

Airlines have different classes catering to the people belonging to different segments. Even hotels have different accommodation, which is referred in [28] as price category for each class of customers. We can see a similar segmentation of customers in healthcare as well. Healthcare providers do not usually receive payments from the patients directly. Instead, a third party insurer will pay for the treatments that patients receive. The third party insurers could be private commercial companies or their government equivalents like Medicare or Medicaid. No two payment sources, i.e., insurance companies, may pay the same amount for the same service. It depends on the contract between the hospital and private insurers or the rate set by the government in case of Medicare and Medicaid. Based on the customers' insurances, the following three segments are considered for this study:

- Customer with Medicare - Medicare is run by the federal government and can cover a portion of medical charges.
- Customer with Medicaid - Medicaid is a joint program run by both state and federal government.
- Customer with Commercial Insurances - This is the segment from which hospitals can expect to get more revenue. Every hospital will have a negotiated amount for a set of diagnosis.

In addition to these classes, customers in healthcare can also be classified as 'New' and 'Return' patients [13]. New patients are the first time visitors to the hospitals and return patients are the ones that come to the hospital with new problems or for follow-ups. In this thesis, only the patients who come for follow-ups are considered as return patients and those who come with a new case are considered as new customers.

2.4 Summary

In this chapter, an introduction to the revenue management concept is presented. In addition, scheduling, and timetabling which are the other are introduced. The chapter emphasizes the points that make rehab outpatient clinics a candidate for practicing revenue management.

CHAPTER 3
AN OPTIMIZATION APPROACH TO APPOINTMENT SCHEDULING

3.1 Introduction

Customers in rehabilitation outpatient clinics can be segmented into different groups based on their payment source and revenue contribution. Rehab outpatient clinics usually provide individual attention to all its customers irrespective of the segment they belong to. In the current business setting, it is possible for a therapist to give certain treatments to more than one patient simultaneously (in a group setting) without affecting the quality of the treatment, in which case the patients receive a group therapy (GT). If a therapist is treating only one patient at a time, the patient receives an individual therapy (IT). The goal of the rehab outpatient clinics is to maximize their profit by providing health services to patients. Thus, if it is possible to increase overall profit by grouping, they might choose to group patients based on their treatments and insurances. Some insurances pay the individual therapy rate although the patient is receiving a group therapy, while some insurances will make partial payments if the patient is receiving a group therapy. When the demand is high, rehab outpatient clinics might consider scheduling patients for group therapy to increase their profit. Currently, the outpatient clinics do not have an efficient decision support system on how to decide which patients receive group therapy to increase the revenue stream. In this chapter, we present several mathematical models to help the management in making grouping decisions.

Three different customer segments, customers with Medicare, customers with Medicaid, and customers with commercial insurance are considered in developing mathematical models for appointment scheduling in rehab outpatient clinics. Different models discussed in this chapter aim at maximizing the profit generated by making an optimal decision on GT and IT scheduling. The models are evaluated for various scenarios and the results are analyzed.

This chapter is organized as follows. In the next section, the notations that are used in mathematical models are explained. This is followed by a detailed discussion of the proposed deterministic models for profit maximization and the experimental results.

3.2 Notations

The following notations are used in the proposed mathematical models.

Sets

- T Set of treatments
- A Set of appointment slots
- D Set of therapists
- J Set of insurance sources
- I Set of pairings
- C_1 Set of pairings containing Medicare
- C_2 Set of pairings containing Medicaid
- C_3 Set of pairings containing Private insurance type

Indices

- t Treatments
- a Appointment Slot
- i Pairing
- j Insurance
- d Therapist
- s Salaried Therapist

Parameters and Constants

$\|T\|$	Total number of treatments
$\|A\|$	Maximum number of appointment slots available in a day
$\|D\|$	Maximum number of therapists available
$\|J\|$	Number of insurance sources
$\|I\|$	Total number of pairing possible
Cap_d	Maximum number of patients that a therapist $d \in \|D\|$ can treat in a day
Dem_t	Daily Demand for treatment $t \in \|T\|$
$DemIns_j$	Demand of patients with insurance $j \in \|J\|$ per day
$DemIns_{tj}$	Demand for treatment t using insurance j per day
R_i	Revenue from pairings $i \in \|I\|$
C_d	Expenses per therapist $d \in \|D\|$
Z_{dt}	$\begin{cases} 1 & \text{if therapist } d \text{ can be assigned for treatment } t \\ 0 & \text{Otherwise} \end{cases}$
A_{ti}	$\begin{cases} 1 & \text{if pairing } i \text{ can be is assigned to treatment } t \\ 0 & \text{Otherwise} \end{cases}$
P_u^-	Penalty for under utilizing full time therapist by one unit
P_d^-	Penalty for under filling the demand by one unit
Ω_s	Target utilization for salaried therapist s
ξ_s	Total number of salaried therapists available
$Size_i$	Number of patients in pairing i
$Size'_{ji}$	Number of patients from insurance j in pairing i
Ψ	Total number of patients that can be treated together in a group therapy
λ	Maximum number of patients allowed in a group therapy

Variables

$$X_{dtaj} \begin{cases} 1 & \text{If therapist } d \text{ is giving treatment } t \text{ to the patient with} \\ & \text{insurance } j \text{ in slot } a \\ 0 & \text{Otherwise} \end{cases}$$

$$\bar{X}_{dtai} \begin{cases} 1 & \text{If therapist } d \text{ is giving treatment } t \text{ to pairing } i \text{ in slot } a \\ 0 & \text{Otherwise} \end{cases}$$

$$Y_d \begin{cases} 1 & \text{If therapist } d \text{ is selected} \\ 0 & \text{Otherwise} \end{cases}$$

cap_d^+ Over utilization of therapist d

cap_d^- Under Utilization of Therapist d

dem_t^+ Over filled demand for treatment t

dem_t^- Under filled demand for treatment t

3.3 Optimization Models for appointment scheduling

Two analytical models, Model with No Group Therapy (ModelNGT), and Model With Group Therapy (ModelWGT) are proposed. Some of the assumptions made in these model include

- No walk-ins.
- Every patient should have a prior appointment.
- Patients arrive promptly at the established times.
- Service time is identical and deterministic for all treatments.
- Demand is deterministic.

3.3.1 Model with No Group therapy

In addition to the above global assumptions, this model assumes that therapists are assigned to a single patient at any time. In other words, every patient receives individual attention for each treatment and hence no group therapy exists in the schedule.

Objective Function

The objective of the ModelNGT is to maximize the overall profit generated by rehab outpatient clinics. The objective function has two components, a revenue component and a cost component. The objective is to maximize the profit obtained by allocating different customer segments optimally to different appointment slots while minimizing the number of therapists used in order to meet the demand.

$$\max \qquad \sum_{d\in D}\sum_{t\in T}\sum_{a\in A}\sum_{j\in J} R_j \cdot X_{dtaj} - \sum_{d\in D} C_d \cdot Y_d \tag{3.1}$$

Constraints

- Therapist Selection: Total number of therapists used by the system cannot exceed the number of available therapists.

$$\sum_{d\in D} Y_d \leq |D| \tag{3.2}$$

- Capacity Constraint: Total number of patients seen by a therapist cannot exceed the capacity of the therapist. For example, if there are 10 appointment slots available and a therapist can treat at the most one patient at a time, then maximum number of patients that a therapist can treat is 10.

$$\sum_{t\in T}\sum_{a\in A}\sum_{j\in J} X_{dtaj} \leq Cap_d \qquad \forall d \in D \tag{3.3}$$

- Demand constraint: Total number of appointment allocation should not exceed the total demand.

$$\sum_{d\in D}\sum_{a\in A}\sum_{j\in J} X_{dtaj} \leq Dem_t \qquad \forall t \in T \tag{3.4}$$

- The following set of equations ensures that the total number of patients seen that belong to one of the insurance sources do not exceed the demand for that particular insurance. These constraints work as a supplement to the total demand constraint.

$$\sum_{d\in D}\sum_{a\in A} X_{dtaj} \leq DemIns_{tj} \qquad \forall t \in T, j \in J \tag{3.5}$$

- A patient is scheduled for an appointment with a therapist only if that particular therapist is selected.

$$X_{dtaj} \leq Y_d \qquad \forall d \in D, t \in T, a \in A, j \in J \tag{3.6}$$

- A treatment is assigned to a therapist only if the therapist is skilled to handle the treatment.

$$X_{dtaj} \leq Z_{dt} \qquad \forall d \in D, t \in T, a \in A, j \in J \tag{3.7}$$

- This makes sure that no therapist is assigned to more than one patient at the same time.

$$\sum_{t\in T}\sum_{j\in J} X_{dtaj} \leq 1 \qquad \forall d \in D, a \in A \tag{3.8}$$

As a result, the total number of variables and constraints in ModelNGT is given by,

$$\begin{aligned}\text{Number of Variables} &= |D||T||A||J| + |D| \\ \text{Number of Constraints} &= 1 + |D| + |T| + |T||J| + 2|D||T||A||J| + |D||A|\end{aligned}$$

Let us consider a case where four therapist are available in a rehab facility that offers four different treatments to customers belonging to three insurances, Medicare, Medicaid, and Private insurances. An eight hour work shift with 15 minutes for each appointment slot would give 32 appointment slots in a day. This simple scenario consists of 3221 constraints and 1540 variables.

3.3.2 Model With Group Therapy

In the current business setting, it might be possible for a therapist to provide certain treatments to more than one patient in a group simultaneously. In this case, it is essential to identify an optimal mix of patients that can be grouped together so that the total profit to the outpatient clinic is maximized. This model assumes that a therapist cannot give two different treatments to two patients at the same time.

As the patients belong to different segments based on the source of payment, it becomes important to decide on the number of patients from each segment that can be treated simultaneously. In order to account for this, the term *pairing* is introduced. A *pairing* defines the number of patients that can be treated in a particular appointment slot and their insurances. In case of IT, patients could be with any of the insurance sources. In GT, patients may have insurance from the same source or from different sources. If there are three different insurance sources, i.e., patient segments, 1, 2, and 3, and not more than two can be grouped together, the set of *pairing* includes (1), (2), (3), (1,1), (1,2), (1,3), (2,2), (2,3), and (3,3). Note that *pairings* with one insurance source is used for IT while *pairings* with more than one insurance source is scheduled for GT.

Revenue from each insurance source is different and hence the revenue from different *pairings* also vary. Furthermore, revenue from an IT could be different from revenue from GT depending on the customer's insurance. Medicare usually pays different amounts for IT and GT, while there is no change in the payments from non medicare insurance sources for

IT and GT. For instance, if insurance sources 1,2, and 3 pay α, β, and γ for IT and source 1 pays α' for GT, revenue from *pairing* (1) is α, and from *pairing* (1,3) is $(\alpha + \gamma)$.

Objective Function

The objective of ModelWGT is to maximize the overall profit by scheduling qualified customers for group therapy. The following equation represents the objective function of the model.

$$\max \quad \sum_{d \in D} \sum_{t \in T} \sum_{a \in A} \sum_{i \in I} R_i \cdot \bar{X}_{dtai} - \sum_{d \in D} C_d \cdot Y_d \tag{3.9}$$

Constraints

- Therapist Selection: Similar to the therapist constraint in ModelNGT, ModelWGT restricts the number of therapists used to the total number of therapists available.

$$\sum_{d \in D} Y_d \leq |D| \tag{3.10}$$

- Capacity Constraint: A therapist cannot handle appointments beyond his/her capacity. In other words, total number of patients treated in IT and GT together cannot be more than the capacity of the therapist. For example, if 10 appointment slots are available and a therapist can treat two patients simultaneously, then the maximum number appointments that he/she can handle is 20. If the therapist gives an IT in 5 appointment slots, then the maximum number of patients treated by the therapist is 15, which is less than the capacity of the therapist. Let $Size_i$ define the number of patients in a pairing. The following equation addresses the capacity constraint.

$$\sum_{t \in T} \sum_{a \in A} \sum_{i \in I} Size_i \cdot \bar{X}_{dtai} \leq Cap_d \qquad \forall d \in D \tag{3.11}$$

- Demand Constraint: This ensures that the total number of appointments allocated does not exceed the actual demand.

$$\sum_{d \in D} \sum_{a \in A} \sum_{i \in I} Size_i \cdot \bar{X}_{dtai} \leq Dem_t \qquad \forall t \in T \tag{3.12}$$

- The following equation imposes a restriction on the number of appointments allocated to a particular customer segment. The number of allocation should not exceed the demand from a particular insurance.

$$\sum_{d \in D} \sum_{a \in A} \sum_{i \in C_j} Size'_{ji}, \cdot \bar{X}_{dtai} \leq DemIns_{tj} \qquad \forall t \in T, j \in J \tag{3.13}$$

- Patients are scheduled for an appointment with a therapist only if that particular therapist is selected.

$$\bar{X}_{dtai} \leq Y_d \qquad \forall d \in D, t \in T, a \in A, i \in I \tag{3.14}$$

- A treatment is assigned to a therapist only if the therapist is trained to give that particular treatment.

$$\bar{X}_{dtai} \leq Z_{dt} \qquad \forall d \in D, t \in T, a \in A, i \in I \tag{3.15}$$

- Not all treatments can be given as a GT. This equation ensures that a patient requiring a treatment that cannot be scheduled for a GT, is given individual attention.

$$\bar{X}_{dtai} \leq A_{ti} \qquad \forall d \in D, t \in T, a \in A, i \in I \tag{3.16}$$

- Therapists can either give an IT or GT in a particular appointment slot. The following equation ensures that there is no clash in the therapists schedule.

$$\sum_{t\in T}\sum_{i\in I}\bar{X}_{dtai} \leq 1 \qquad \forall d \in D, a \in A \tag{3.17}$$

- This imposes a restriction on the number of patients that can be treated together in a GT. Let Ψ represent the number of patients that can be grouped together.

$$\sum_{i} Size_i \cdot \bar{X}_{dtai} \leq \Psi \qquad \forall d \in D, t \in T, a \in A \tag{3.18}$$

In this model,

$$\begin{aligned}
\text{Number of Variables} &= |D||T||A||I| + |D| \\
\text{Number of Constraints} &= 1 + |D| + |T| + |T||J| + 3|D||T||A||I| \\
&\quad +|D||A| + |D||T||A|
\end{aligned}$$

If three insurances are available, and at the most two patients can be in a group, then there is a possibility of nine pairings. (three with one insurance, and six with two insurances). For the scenario explained earlier, i.e., four therapists, four treatments, three insurance types and 32 appointment slots, ModelWGT generates 14485 constraints and 4612 variables.

3.3.3 Revised Models

In addition to the full time salaried therapists, when part time therapists are also available, the above models should use the salaried therapist to the maximum extent possible and part time therapists should be used only when there is an excess demand that cannot be handled by the full time staff.

If ξ_s is the total number of salaried therapists available, then the number of therapists used should not exceed ξ_s. Equations 3.2 and 3.10 now take the form,

$$\sum_{s\in D} Y_d \leq \xi_s \tag{3.19}$$

Each salaried therapist should at least meet a pre set utilization in order to justify the requirement for a part time therapist. Let Ω_s be the ideal utilization for salaried therapists, and cap_s^+ and cap_s^- represent the over and under utilization of salaried therapist s by one unit. The following two equations represent the utilization constraint for ModelNGT and ModelWGT respectively.

$$\sum_{t\in T}\sum_{a\in A}\sum_{j\in J} X_{staj} - cap_s^+ + cap_s^- = \Omega_s \cdot |A| \qquad \forall s \in D \tag{3.20}$$

$$\sum_{t\in T}\sum_{a\in A}\sum_{i\in I} \bar{X}_{stai} - cap_s^+ + cap_s^- = \Omega_s \cdot |A| \qquad \forall s \in D \tag{3.21}$$

Let dem_t^+ and dem_t^- represent the over and under filled demand for treatment t. Equations 3.4 and 3.12 change as follows.

$$\sum_{d\in D}\sum_{a\in A}\sum_{j\in J} X_{dtaj} - dem_t^+ + dem_t^- = Dem_t \qquad \forall t \in T \tag{3.22}$$

$$\sum_{d\in D}\sum_{a\in A}\sum_{i\in I} Size_i\, \bar{X}_{dtai} - dem_t^+ + dem_t^- = Dem_t \qquad \forall t \in T \tag{3.23}$$

In order to ensure that part time therapists are used only when salaried therapists cannot handle the demand, penalty factors are introduced for under-utilizing the salaried therapist and under-achieving the demand. Let P_u^- and P_d^- be the penalty in dollars for under-utilizing the therapist and under-achieving the demand by one time unit.

The objective function of ModelNGT equation (3.1) will now take the form,

$$\max \qquad \sum_{d\in D}\sum_{t\in T}\sum_{a\in A}\sum_{j\in J} R_j\, X_{dtai} - \sum_{d\in D} C_d\, Y_d - P_u^- \sum_{s\in D} Cap_s^- - P_d^- \sum_{t\in T} Dem_t^- \tag{3.24}$$

and the objective function of ModelWGT (equation 3.9) will change to

$$\max \qquad \sum_{d\in D}\sum_{t\in T}\sum_{a\in A}\sum_{i\in I} R_i\,\bar{X}_{dtai} - \sum_{d\in D} C_d\,Y_d - P_u^- \sum_{s\in D} Cap_s^- - P_d^- \sum_{t\in T} Dem_t^- \tag{3.25}$$

3.4 Experimentation

The models discussed above are tested for various scenarios. The factors considered in the study include, grouping, number of salaried and part time therapists available, and the demand. Table 3.1 summarizes the experimental setup.

Initially it is assumed that every patient is given individual attention and the ModelNGT is evaluated. This assumption is later relaxed and the ModelWGT is tested for various scenarios where group size is varied from two to four. The availability of salaried therapists and part time therapists is varied at 3 levels, 3, 4, 5 and 0, 1, 2, respectively. Demand is a function of the total capacity available. If ξ_s salaried therapists and ζ appointment slots are available on day $\tilde{d}$, and not more than λ can be accommodated in a group, and η is the demand factor, the demand value at different levels Dem_η is given by,

$$Dem_\eta = \eta \cdot \xi_s \cdot \zeta \cdot \lambda \tag{3.26}$$

Four different demand levels, 0.5, 0.75, 1, and 1.25, are considered in this research.

Recalling the general assumption for ModelNGT, and ModelWGT, the service time for each treatment is set as 15 mins. A total of four different treatments, T1, T2, T3, and T4, are considered for the experimentation. Of these four treatments, only three treatments are assumed to be candidates for GT. In other words only three treatments, T1, T2, and T4, can be given in group and treatment T3 requires individual attention. Assuming that each therapist works for seven hours effectively on treatments every day, we can consider 28 possible appointment slots of 15 mins for each therapist.

Table 3.1: Experimentation Setup for Evaluation of Mathematical Models

Criteria	Number of Levels	Levels
Grouping	3	No Group, λ=1 Not more than 2 in group, λ=2 Not more than 4 in group, λ=4
Salaried Therapists	3	3,4,5
Part Time Therapist	3	0,1,2
Demand	4	η = 0.5, 0.75, 1.0, 1.25

In this experimentation, it is assumed that every therapist has to be occupied for at least 85% of the time in order to justify having a full time therapist. For instance, if there are 28 appointment slots available in a day, a therapist should be occupied for at least 24 slots. There is a penalty of \$20 for under-utilizing the therapist by one unit/slot, i.e., $P_u^- = \$20$. Similarly, there is a penalty of \$20 for every unit of demand that is not met, i.e., $P_d^- = \$20$.

It is assumed that a salaried therapist is paid less than a part time therapist per unit time. Assuming that the salaried therapists are paid \$25 per hour and part time therapists are paid \$35 per hour, the cost of having a salaried therapist for a day of eight hours is \$200, while a part time therapist cost \$280 a day.

Financial data of a local rehabilitation outpatient clinic is collected and analyzed. Patients are charged for every 15 minutes of service they receive. The rehab facility receives only a part of the billed amount depending on the patients' insurance. Table 3.2 lists the percentage of the charged amount that different insurances pay for the rehabilitation service.

Table 3.2: Revenue from different insurance types

Insurance	% Collection
Medicare	46
Medicaid	28
Private Insurance	71

Let each treatment be priced at \$100 for every 15 minutes of service. From table 3.2, we can determine the amount that the hospital receives from different insurance companies, in other words from customers of different segments. Of an \$100 billed amount, Medicare pays only \$46, Medicaid pays \$28 and private insurance companies pay on average \$71. If grouping is considered, Medicare restricts the amount paid for the service to 50% of the amount that it pays if the patient is provided individual attention. However, patients holding other insurances can be given group attention for the same price.

The revised models, ModelNGT and ModelWGT are programmed in GAMS[1] and solved as a mixed integer program using CPLEX[2] solver. Table 3.3 lists the demand generated for different experimental setups. Tables 3.4, A.1, and A.3 compare the profit generated by different models when the demand is a function of the model characteristics. In these tables, NGT represent ModelNGT, while WGT2 and WGT4 represent ModelWGT when not more than two and not more than four patients can be grouped together. These tables also indicate the number of salaried and part time therapists available for each scenario. The models decide the optimal number of part time and salaried therapists required to generate the maximum possible profit for each scenario. The number of salaried and part time therapists used is summarized in tables 3.5, A.2, and A.4.

Table 3.4 presents a detailed information on the profits generated by the two models for different operating scenarios. The demand presented in this table is a function of the ModelNGT characteristics, i.e., $Dem_{\eta} = \eta \cdot \xi_s \cdot \zeta \cdot \lambda$, where $\lambda = 1$. It is clear from the table that for a given demand, scheduling the qualified patients for GT results in higher profit compared to when the patients are scheduled for IT alone. Table A.1, and A.3 in Appendix A, present the information on the profits generated when the demand is determined using λ=2, and λ=3 respectively.

[1]GAMS is a high level modeling system for mathematical programming and optimization. Website: www.gams.com

[2]ILOG CPLEX 9.0. Website: www.cplex.com

Table 3.3: Demand data for mathematical models

Number in Group, λ	Salaried Therapist	Demand Level, η	Demand			
			Private	Medicare	Medicaid	Total
1	3	0.5	17	21	4	42
		0.75	25	32	6	63
		1	34	42	8	84
		1.25	42	53	11	106
	4	0.5	22	28	6	56
		0.75	34	42	8	84
		1	45	56	11	112
		1.25	56	70	14	140
	5	0.5	28	35	7	70
		0.75	42	53	11	106
		1	56	70	14	140
		1.25	70	88	18	176
2	3	0.5	34	42	8	84
		0.75	50	63	13	126
		1	67	84	17	168
		1.25	84	105	21	210
	4	0.5	45	56	11	112
		0.75	67	84	17	168
		1	90	112	22	224
		1.25	112	140	28	280
	5	0.5	56	70	14	140
		0.75	84	105	21	210
		1	112	140	28	280
		1.25	140	175	35	350
4	3	0.5	67	84	17	168
		0.75	101	126	25	252
		1	134	168	34	336
		1.25	168	210	42	420
	4	0.5	90	112	22	224
		0.75	134	168	34	336
		1	179	224	45	448
		1.25	224	280	56	560
	5	0.5	112	140	28	280
		0.75	168	210	42	420
		1	224	280	56	560
		1.25	280	350	70	700

Table 3.4: Profit generated when the demand is a function of ModelNGT characteristics

Run No.	Salaried Therapist	Part Time Therapist	Total Available Capacity	Demand	Total Profit NGT	WGT2	WGT4
1	3	0	84	42	1608	1888	1888
2	3	0	84	63	2776	3000	3000
3	3	0	84	84	4092	4292	4292
4	3	0	84	105	4364	5140	5340
5	3	1	84	42	1688	1888	1888
6	3	1	84	63	2776	3000	3000
7	3	1	84	84	4092	4292	4292
8	3	1	84	105	4860	5140	5340
9	3	2	84	42	1688	1888	1888
10	3	2	84	63	2776	3000	3000
11	3	2	84	84	4092	4292	4292
12	3	2	84	105	4860	5140	5340
13	4	0	112	56	2704	2704	2802
14	4	0	112	84	4092	4292	4292
15	4	0	112	112	5236	5436	5436
16	4	0	112	140	5752	6824	7024
17	4	1	112	56	2704	2704	2802
18	4	1	112	84	4092	4292	4292
19	4	1	112	112	5236	5436	5436
20	4	1	112	140	6544	6824	7024
21	4	2	112	56	2704	2704	2802
22	4	2	112	84	4092	4292	4292
23	4	2	112	112	5236	5436	5436
24	4	2	112	140	6544	6824	7024
25	5	0	140	70	3268	3468	3468
26	5	0	140	105	4940	5140	5340
27	5	0	140	140	6624	6824	7024
28	5	0	140	175	7240	8808	8808
29	5	1	140	70	3268	3468	3468
30	5	1	140	105	4940	5140	5340
31	5	1	140	140	6624	6824	7024
32	5	1	140	175	8104	8808	8808
33	5	2	140	70	3268	3468	3468
34	5	2	140	105	4940	5140	5340
35	5	2	140	140	6624	6824	7024
36	5	2	140	175	8104	8808	8808

Table 3.5: Therapist Utilization with ModelNGT demand characteristics

Demand	Salaried Therapists				Part Time Therapists			
	Available	Used			Available	Used		
		NGT	WGT2	WGT4		NGT	WGT2	WGT4
42	3	2	1	1	0	0	0	0
63	3	2	2	2	0	0	0	0
84	3	3	2	2	0	0	0	0
105	3	3	3	2	0	0	0	0
42	3	1	1	1	1	1	0	0
63	3	2	2	2	1	0	0	0
84	3	3	2	2	1	0	0	0
105	3	3	3	2	1	1	0	0
42	3	1	1	1	2	1	0	0
63	3	2	2	2	2	0	0	0
84	3	3	2	2	2	0	0	0
105	3	3	3	2	2	1	0	0
56	4	2	2	1	0	0	0	0
84	4	3	2	2	0	0	0	0
112	4	4	3	3	0	0	0	0
140	4	4	4	3	0	0	0	0
56	4	2	2	1	1	0	0	0
84	4	3	2	2	1	0	0	0
112	4	4	3	3	1	0	0	0
140	4	4	4	3	1	1	0	0
56	4	2	2	1	2	0	0	0
84	4	3	2	2	2	0	0	0
112	4	4	3	3	2	0	0	0
140	4	4	4	3	2	1	0	0
70	5	3	2	2	0	0	0	0
105	5	4	3	2	0	0	0	0
140	5	5	4	3	0	0	0	0
175	5	5	4	4	0	0	0	0
70	5	3	2	2	1	0	0	0
105	5	4	3	2	1	0	0	0
140	5	5	4	3	1	0	0	0
175	5	5	4	4	1	1	0	0
70	5	3	2	2	2	0	0	0
105	5	4	3	2	2	0	0	0
140	5	5	4	3	2	0	0	0
175	5	5	4	4	2	1	0	0

For example, let us consider the case where a rehab outpatient clinic gets a demand for 42 appointment slots and a capacity of 84 appointment slots (three full time therapists, working seven hours a day) is available. When GT is not allowed, a minimum of two therapists are required to fulfill the demand and this results in a profit of $1608.00. On the other hand, when the patients can be scheduled for GT, the demand can be satisfied with one therapist resulting in a profit of $1888.00. Let us consider another case where there is a demand for 140 appointment slots and the rehab facility has a capacity to fulfill a demand of 112 appointment slots, i.e., four salaried therapists working seven hours a day. In this case the demand exceeds the available capacity. It is not possible to satisfy the demand with IT scheduling alone. If the capacity is increased by employing two part time therapist, the maximum profit that can be generated by IT scheduling is $6544.00. On the other hand, when GT is permitted, the demand can be satisfied with the existing capacity and it is not necessary to employ additional therapists, i.e., part time therapists. When not more than two patients can be grouped together, ModelWGT results in a profit of $6824.00, i.e., an increase of 3%, and when a maximum of four patients are allowed in a group, ModelWGT generates a profit of $7024.00, i.e., an increase of 6%. When the capacity is tight and the demand is high, grouping more than one patient for a treatment yields a higher profit.

Table 3.5 presents details on the number of full time and part time therapists used in various scenarios. Although models with grouping do not utilize part time therapists in any of the scenarios presented in the table, when there is a very high demand, there is a significant utilization of part time therapists. This can be seen in tables A.2 and A.4 in appendix A. The results presented in tables 3.5, A.2, and A.4 show that when grouping is allowed, the number of therapists used to generate the maximum possible profit is minimum.

In figures 3.1, 3.2, and 3.3, each point represents the profit value for a combination of number of salaried and part time therapists and demand level. For example, a point representing 3*2**1*** indicates the profit generated when three salaried and two part time therapists are available and the demand level is one, i.e., demand is equal to the capacity of the system.

Figure 3.1 shows the profit generated by different models in various scenarios. The demand presented in this graph is determined using the equation 3.26 with λ=1. It can be seen from the graph that for a given level of resources, as the demand increases, profit generated by different models increases. In addition, for a given demand and resource levels, grouping customers yields a higher profit.

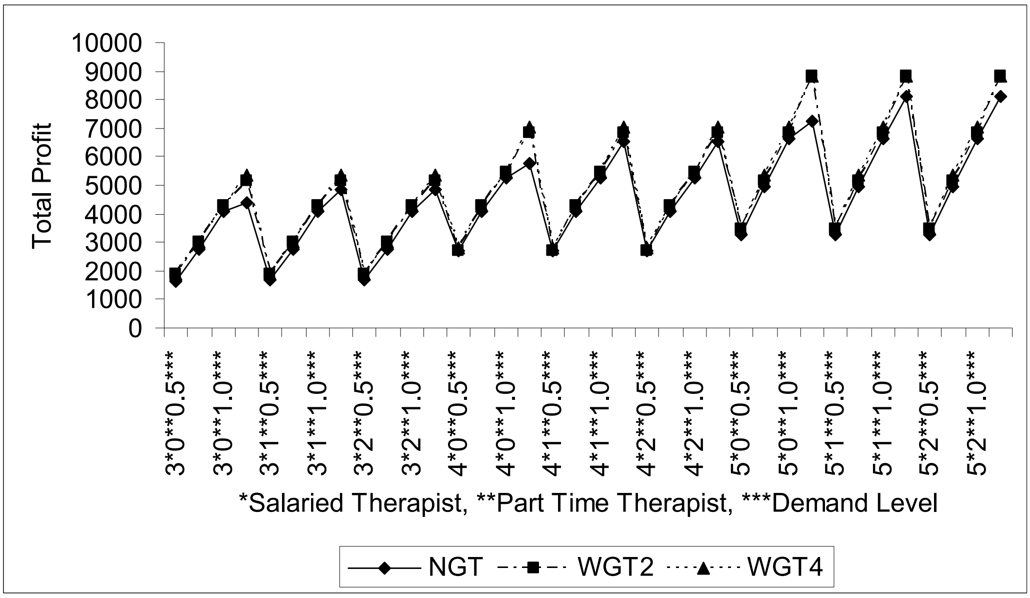

Figure 3.1: Comparison of model results for ModelNGT demand characteristics

The demand in figure 3.2 and 3.3 is determined using λ=2 and λ=4 respectively. It can be seen from the graph that when grouping is not allowed, an increase in demand results in a decrease in profit generated. The decrease in profit is mainly due to incapability of the rehab facility to fulfill the demand. Note that we have assumed that there is a penalty for not satisfying the demand (this can be seen in equation 3.24). On the other hand, when grouping is permitted, an increase in demand would yield higher profits.

It can be concluded from the graphical analysis that for a given resource level, ModelWGT generates more profit compared to ModelNGT. In other words, when grouping of customers

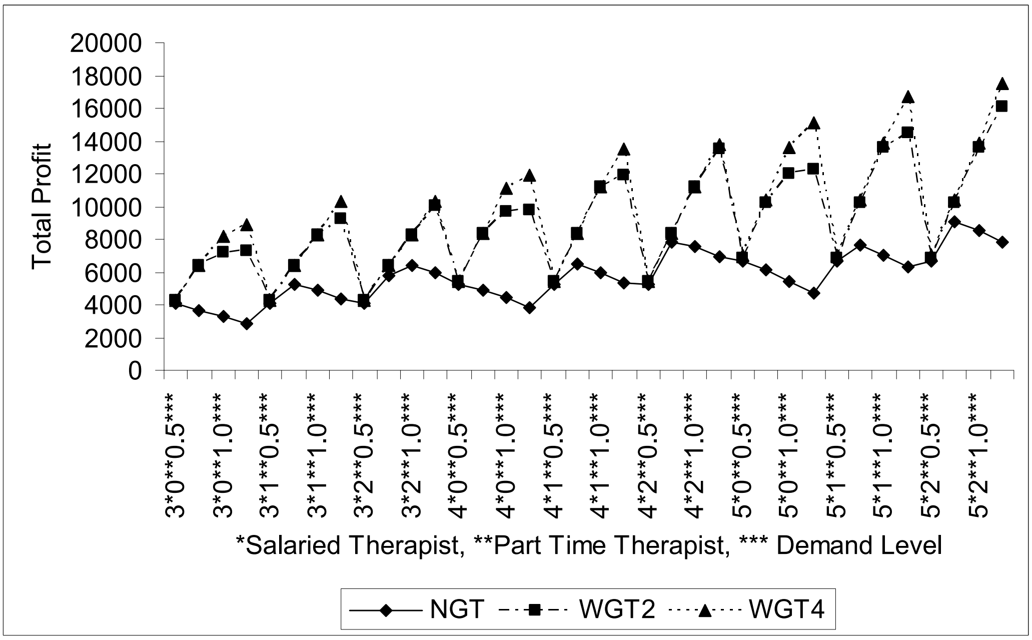

Figure 3.2: Comparison of model results for ModelWGT demand characteristics with not more than 2 in GT (λ =1)

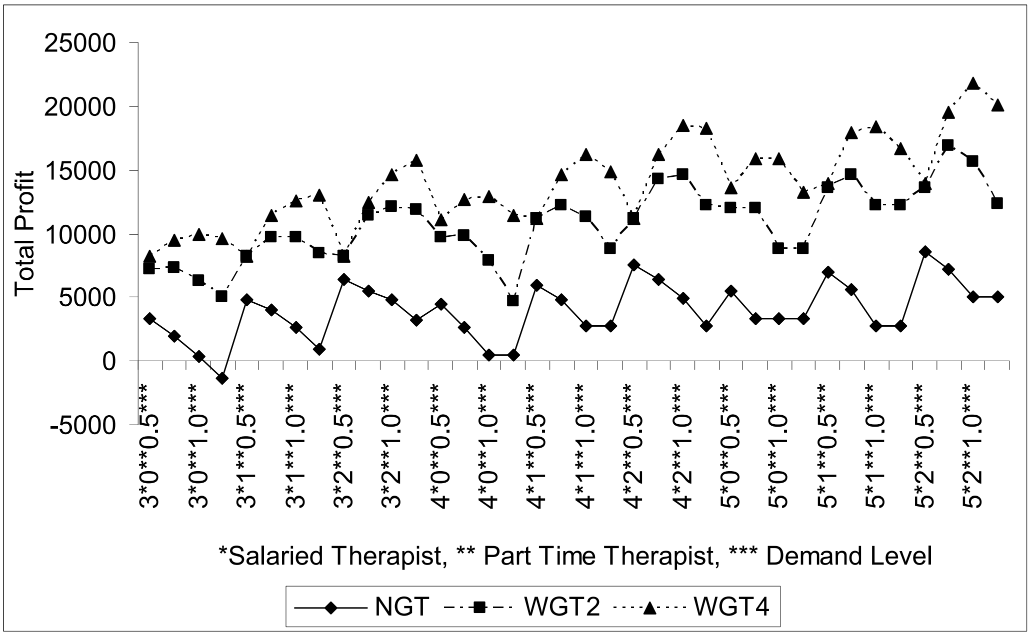

Figure 3.3: Comparison of model results for ModelWGT demand characteristics with not more than 4 in GT (λ=4)

is allowed, i.e., more than one patient can be treated simultaneously, rehab outpatient clinics can register higher profits.

3.5 Summary

In this chapter, the problem of appointment scheduling when the demand is known, is discussed. Mathematical models for generating appointment and therapist schedules with an objective to maximize overall profit and utilization of salaried therapist are developed and evaluated for various scenarios. However, these models do not consider the stochastic nature of customer request arrival. Analysis of deterministic mathematical models reveal that hospitals can generate more profit by scheduling qualified customers to group therapy when the capacity is tight and there is an excess demand.

CHAPTER 4
A REVENUE MANAGEMENT APPROACH TO APPOINTMENT ALLOCATION

4.1 Introduction

The linear programming models discussed in the previous chapter are appropriate when the demand is known for sure, i.e, the demand is deterministic. If the demand is uncertain and customer arrival is stochastic, the deterministic models might not produce practical results. The simulation model discussed in this chapter takes the uncertainty in demand and customer arrival into consideration.

One of the objectives of this research is to devise an appointment allocation policy, which results in increased fill rate of new customers, increased revenue and overall profit, while retaining all the return customers. Traditional appointment allocation procedures such as First Come First Serve (FCFS) do not distinguish between new customers and return customers and allocates appointments to customers in the order of arrival. As a result, it may not be possible to accommodate new customers who arrive towards the end of the period. In this chapter, a revenue management framework for appointment allocation, Capacity Partitioning and Resource Allocation Procedure (CPRAP) is introduced. This framework reserves a certain capacity to different customer segments based on their revenue contribution. The proposed framework is tested for various operating conditions using simulation analysis.

This chapter is organized as follows. In the next section, a detailed introduction to scope of revenue management in rehab outpatient clinics is presented. This is followed by a detailed explanation of the proposed revenue management framework and the discussion of experimental results.

4.2 Revenue Management in Rehabilitation Outpatient Clinics

Unlike airlines and hotels, revenue per unit of service is almost constant in healthcare industry and the price is an inflexible (static) parameter. Price for each service is preset by the contract between the service provider and the insurance companies. The price remains constant until new negotiations are made between hospitals and insurance companies. This makes it impractical to apply traditional revenue management framework with dynamic pricing approaches to the healthcare sector. In rehabilitation outpatient clinics, revenue management can be applied as a basis for setting the capacity partitioning rules. In this thesis, a capacity partitioning and resource allocation procedure for different classes of customers who pay different prices for the same service is designed. Barut and Sridharan [4, 5] propose a similar capacity apportionment framework for make-to-order manufacturing industry.

4.3 Capacity Partitioning and Resource Allocation Procedure

In outpatient clinics, the customers usually have insurance from different companies. Different insurances pay different amount for the same service. Keeping this in mind, customer segmentation is made based on unit revenue contribution of the customer. It is assumed that there are three different customer classes: high profit class (e.g., customer having private/commercial insurances), mid-profit class (e.g., patients with Medicare), and low profit class (e.g., patients with Medicaid and any other source that pays less). These customer classes are represented by H, M, and L. Customers can also be classified as 'New' and 'Return' patients. The new patient class is included as a separate class N (Class 1) for the study irrespective of the insurance they carry and return patients are segmented into classes H, M and L (Class 2, 3, and 4 respectively). As new customers are expected to return to the rehab facility for several follow-ups, which implies a higher potential revenue, it is assumed that they generate the highest revenue. The available capacity is divided in such a way that a portion of capacity is reserved for each customer segment. The reserved resource is then allocated to customers from different segments. The capacity partitioning and resource allocation rules are discussed in the following sections.

4.3.1 Capacity Partitioning

This section explains the proposed methodology for determining the base capacity that can be reserved for each customer class. Let C_{Total} be the total capacity available in time units, at the beginning of the planning horizon of n periods. Assuming that there are m customer classes, if E_d^i is the expected demand (in percentage) for class i in period d, then maximum capacity that can be consumed by the class i in period d is calculated by,

$$C_{max}^{id} = C_{Total} \sum_{i=i}^{m} E_d^i \tag{4.1}$$

For example, the total capacity which can be used by class 1, i.e., C_{max}^{1d} , is the sum of the capacity reserved for class 1 and the total capacity allocated to lower revenue generating classes, i.e., 100% of the total capacity. In other words, the new customer class will have access to the capacity reserved for classes 1, 2, 3, and 4. However, customers from a lower class cannot have access to the capacity reserved for any higher class. This approach is defined as the nested approach for capacity partitioning. Figure 4.1 gives a pictorial explanation of the nested approach. Let us assume that a total of 20 units are available and the expected demand of the four classes is 30%, 30%, 20%, and 20% respectively. The least revenue generating class, i.e., class 4 can have access to a maximum of four units, class 3 will have four units reserved and in addition, will have access to entire capacity reserved for class 4. As class 1 is assumed to generate maximum revenue, any customer from this class will have utmost priority and can have access to the entire capacity available in the system.

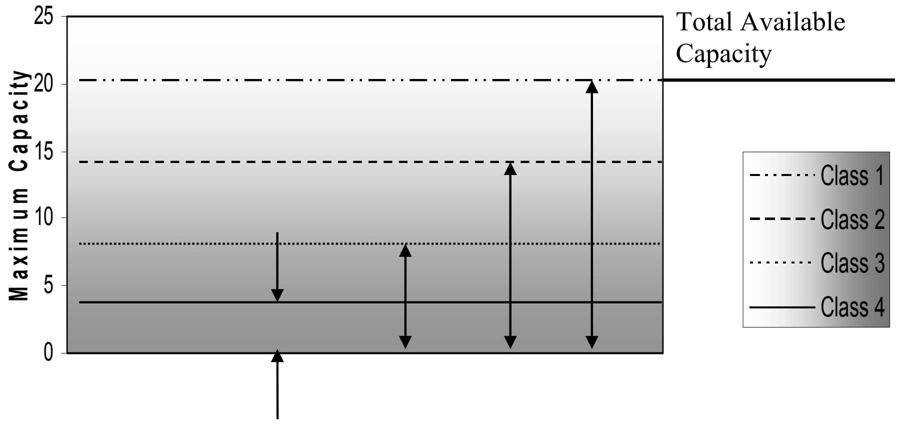

Figure 4.1: Nesting concept in resource allocation

4.3.2 Resource Allocation

Once the maximum capacity that can be utilized by different customer segments is determined, the incoming request for an appointment is checked against the available resource. Figure 4.2 presents a sequence of steps that is adopted in this study for allocating appointments. When a customer requests for an appointment, the segment to which the customer belongs is determined. Note that the new customers have priority over the return customers, no matter which customer segment they belong to. Depending on the treatment for which the customer requests for an appointment, the capacity that is to be allocated is determined. If there is sufficient capacity to allocate the appointment to the customer, an appointment is issued and the remaining capacity available for all the segments is updated. However, if the capacity available on a particular day for a particular customer class is not sufficient to accommodate the request, the required capacity is checked against the capacity available in the next period of the planning horizon. If there is no capacity available to allocate the appointment in the entire horizon, part time therapists are employed to meet the excess demand. This procedure is similar to the one adopted by Barut, and Sridharan [4] wherein the incoming order is either accepted or rejected subject to the availability of resources.

However, the methodology adopted in this paper does not reject any customer requests. Instead, recommends increasing the available resources by means of part time therapists.

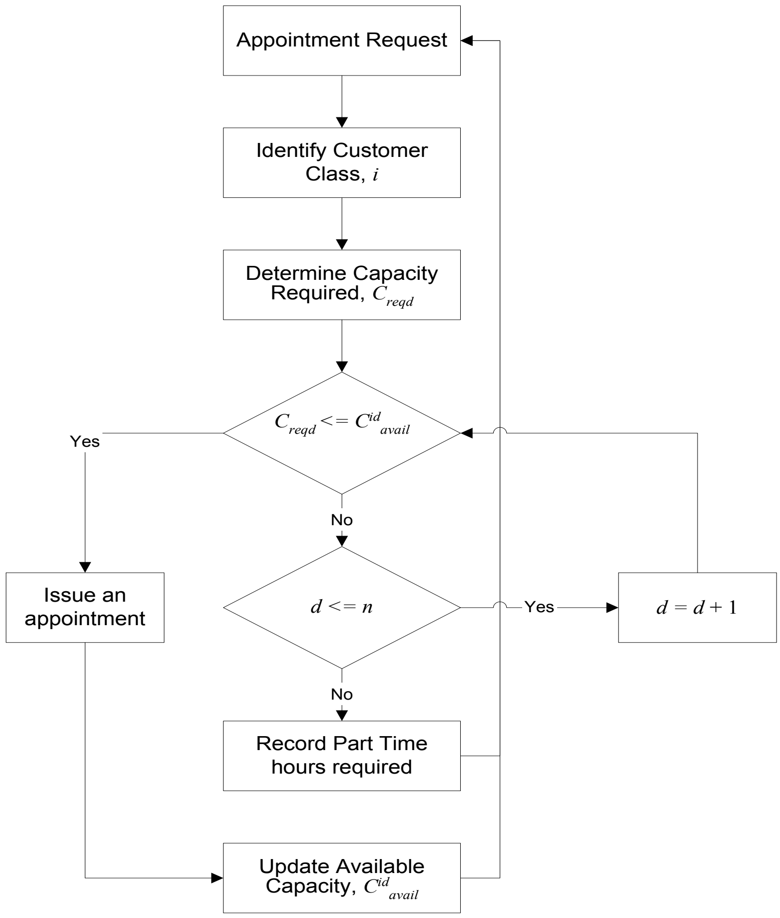

Figure 4.2: Appointment allocation procedure

4.4 Simulation Study

The performance of CPRAP is evaluated and compared with the FCFS policy. Metrics that are used for comparison of the two policies include percentage increase in the revenue generated with the existing resources, percentage increase in profit, and increase in the new customer fill rate. Percentage increase for metric j is determined by,

$$\% \ increase_j = \frac{CPRAP_j - FCFS_j}{FCFS_j} \times 100 \tag{4.2}$$

The profit, in addition to the revenue generated from the existing capacity also includes the revenue from the part time capacity and cost of the additional capacity. Operating factors that are considered in the simulation study are demand, resource availability, and revenue attractiveness.

Demand represents the forecasted daily demand. This factor is varied at three different levels, 50, 75, and 100 customer requests per day. Resource availability is a function of the number of salaried therapists in the system. If four salaried therapists are present in the system and each therapist works for seven hours a day, then the total resource available in a day is given by 4*7*60 = 1680 minutes. This factor is varied at three levels: 4, 6, and 8 salaried therapists. The revenue attractiveness factor is similar to the profit attractiveness factor used by Barut, and Sridharan [4]. This factor indicates the rate of change of revenue generated by two successive customer classes. If R_i is the revenue generated by customer class i, then revenue attractiveness, π is given by,

$$\pi = \frac{R_{i+1}}{R_i} \tag{4.3}$$

When R_i is equal to one, there is no difference in the revenue generated by different classes. In this study, the revenue attractiveness factor is varied at four levels: 0.5, 0.7, 0.9, and 1.0. The experimental factors and their levels used in this paper are summarized in Table 4.1

Table 4.1: Experimentation Setup for Simulation Study

Criteria	Number of Levels	Levels
Demand	4	50, 75, 100
Revenue Attractiveness	5	0.5, 0.7, 0.9, 1.0
Salaried Therapists	3	4, 6, 8

The following assumptions are made for performing the simulation study.

- The arrival of the patients follows an exponential distribution with different parameters for different scenarios.
- Appointment requests are made at least one day in advance.
- All requests have to be accommodated within three days from the day preferred by the customer.
- The appointment requests by the return patients are always honored.
- If a new customer is not given an appointment on his/her preferred day, there is only a 50% chance that the customer would accept an appointment on the next day. If a new customer is not given an appointment in three days following the preferred day, the customer would leave the system.
- All new customers must undergo a new patient evaluation, which usually takes 60 minutes. The return customers can request for appointment for either 30 minutes or 60 minutes. This is defined by a discrete probability distribution function.
- A planning horizon of one month, i.e., 25 business days is considered.
- The average cost of part time resource is estimated at $35.00 per hour. This is the cost of expanding the capacity by one hour.

The simulation model is run on Arena 7.0 [1]

We will illustrate how appointment allocation procedures, FCFS and CPRAP, work on a problem with four salaried therapists working four hours a day. The total capacity is 960 minutes (4x4x60). We also assume that the customers prefer to have an appointment on the next day. We consider the demand to be 50 requests per day and revenue attractiveness factor of 0.7.

[1] Arena - Version 7.01.00, Rockwell Software Inc.

In FCFS appointment allocation procedure (refer Table 4.2), customers from different segments will have the same priority, and an appointment is allocated if the available capacity is sufficient to satisfy the demand. In the example that we consider, the first customer who requests for an appointment belongs to the customer segment 2, which is the high revenue class, and requires treatment 2, which lasts for 30 minutes. Since at beginning of the period, entire capacity is available, an appointment of 30 minutes is allocated to the customer and the available capacity is updated to be 930 minutes. First 20 customers make appointments for scheduling their treatments. The 21^{st} customer utilizes all the remaining capacity. As a result, any request following customer 21 cannot be accommodated on the preferred day. We also notice that customers 35 and 38 who are new customers opt out of the system due to unavailability of capacity on their preferred day.

In CPRAP appointment allocation framework (refer Table 4.3), a customer is accommodated only if there is sufficient capacity available for the customer's segment. For example, for customer 8 (a low revenue class customer), is not accommodated on the preferred day due to unavailability of capacity for this particular segment. Customer 38, a new customer, is lost as a result of not having enough capacity to accommodate the customer on his/her preferred day. Customers 44, 47, and 48 are treated by part time therapists. We can see from the tables 1 and 2 that CPRAP results in an increase of 2.65% in revenue and 100% increase in the new customers' fill rate.

4.5 Computational Results

Each scenario presented in Table 4.1 is replicated three times and a total of 108 runs are performed. The simulation results are given in Table 4.4. The percentage increase in revenue (PIR) generated from the existing resources ranged from -2.82% to 20.92% with an average increase of 2.94%. 75% of the time, the CPRAP generates at least as much revenue as the FCFS. When the revenue attractiveness is close to one, i.e., there is no differentiation between successive customer segments in terms of revenue generated, CPRAP

Table 4.2: FCFS Procedure for Appointment Allocation

Customer No	Customer Type	Treatment	Service Time	Preferred Day	Scheduled Day	Beginning Capacity	Ending Capacity	Revenue	Cumulative Revenue
1	2	2	30	1	1	960	930	140	140
2	2	2	30	1	1	930	900	140	280
3	3	3	60	1	1	900	840	196	476
4	2	3	60	1	1	840	780	280	756
5	2	2	30	1	1	780	750	140	896
6	2	2	30	1	1	750	720	140	1036
7	4	3	60	1	1	720	660	137.2	1173.2
8	4	3	60	1	1	660	600	137.2	1310.4
9	3	2	30	1	1	600	570	98	1408.4
10	1	1	60	1	1	570	510	400	1808.4
11	3	2	30	1	1	510	480	98	1906.4
12	3	2	30	1	1	480	450	98	2004.4
13	3	2	30	1	1	450	420	98	2102.4
14	3	3	60	1	1	420	360	196	2298.4
15	2	2	30	1	1	360	330	140	2438.4
16	4	3	60	1	1	330	270	137.2	2575.6
17	3	3	60	1	1	270	210	196	2771.6
18	2	3	60	1	1	210	150	280	3051.6
19	3	2	30	1	1	150	120	98	3149.6
20	2	3	60	1	1	120	60	280	3429.6
21	3	3	60	1	1	60	0	196	3625.6
22	4	2	30	1	2	960	930	68.6	3694.2
23	2	2	30	1	2	930	900	140	3834.2
24	3	2	30	1	2	900	870	98	3932.2
25	2	2	30	1	2	870	840	140	4072.2
26	2	2	30	1	2	840	810	140	4212.2
27	4	2	30	1	2	810	780	68.6	4280.8
28	4	2	30	1	2	780	750	68.6	4349.4
29	2	3	60	1	2	750	690	280	4629.4
30	2	3	60	1	2	690	630	280	4909.4
31	3	3	60	1	2	630	570	196	5105.4
32	2	3	60	1	2	570	510	280	5385.4
33	4	3	60	1	2	510	450	137.2	5522.6
34	3	2	30	1	2	450	420	98	5620.6
35	1	1	60	1	2				
36	3	2	30	1	2	420	390	98	5718.6
37	2	3	60	1	2	390	330	280	5998.6
38	1	1	60	1	2				
39	3	2	30	1	2	330	300	98	6096.6
40	3	2	30	1	2	300	270	98	6194.6
41	4	2	30	1	2	270	240	68.6	6263.2
42	3	3	60	1	2	240	180	196	6459.2
43	2	2	30	1	2	180	150	140	6599.2
44	4	2	30	1	2	150	120	68.6	6667.8
45	3	2	30	1	2	120	90	98	6765.8
46	3	2	30	1	2	90	60	98	6863.8
47	4	2	30	1	2	60	30	68.6	6932.4
48	4	2	30	1	2	30	0	68.6	7001
49	2	2	30	1	3	960	930	140	7141
50	3	3	60	1	3	930	870	196	7337

Table 4.3: CPRAP for Appointment Allocation

Customer	Customer	Treatment	Service	Scheduled	Beginning Capacity				Ending Capacity				Revenue	Total
No	Type		Time	Day	Class I	Class 2	Class 3	Class 4	Class I	Class 2	Class 3	Class 4		Revenue
1	2	2	30	1	960	816	510	126	930	786	480	96	140	140
2	2	2	30	1	930	786	510	126	900	756	480	96	140	280
3	3	3	60	1	900	756	480	156	840	696	420	96	196	476
4	2	3	60	1	840	696	480	156	780	636	420	96	280	756
5	2	2	30	1	780	636	450	126	750	606	420	96	140	896
6	2	2	30	1	750	606	450	126	720	576	420	96	140	1036
7	4	3	60	1	720	576	420	96	660	516	360	36	137.2	1173.2
8	4	3	60	2	960	816	480	96	900	756	420	36	137.2	1310.4
9	3	2	30	1	660	516	360	66	630	486	330	36	98	1408.4
10	1	1	60	1	630	546	390	96	570	486	330	36	400	1808.4
11	3	2	30	1	570	486	330	66	540	456	300	36	98	1906.4
12	3	2	30	1	540	456	300	66	510	426	270	36	98	2004.4
13	3	2	30	1	510	426	270	66	480	396	240	36	98	2102.4
14	3	3	60	1	480	396	240	96	420	336	180	36	196	2298.4
15	2	2	30	1	420	336	210	66	390	306	180	36	140	2438.4
16	4	3	60	3	960	816	480	96	900	756	420	36	137.2	2575.6
17	3	3	60	1	390	306	180	96	330	246	120	36	196	2771.6
18	2	3	60	1	330	246	180	96	270	186	120	36	280	3051.6
19	3	2	30	1	270	186	120	66	240	156	90	36	98	3149.6
20	2	3	60	1	240	156	150	96	180	96	90	36	280	3429.6
21	3	3	60	1	180	96	90	96	120	36	30	36	196	3625.6
22	4	2	30	1	120	36	30	36	90	6	0	6	68.6	3694.2
23	2	2	30	2	900	756	450	66	870	726	420	36	140	3834.2
24	3	2	30	2	870	726	420	66	840	696	390	36	98	3932.2
25	2	2	30	2	840	696	420	66	810	666	390	36	140	4072.2

Table 4.3: CPRAP for Appointment Allocation (Continued from the previous page)

Customer	Customer	Treatment	Service	Scheduled	Beginning Capacity				Ending Capacity				Revenue	Total
No	Type		Time	Day	Class I	Class 2	Class 3	Class 4	Class I	Class 2	Class 3	Class 4		Revenue
26	2	2	30	2	810	666	420	66	780	636	390	36	140	4212.2
27	4	2	30	2	780	636	390	36	750	606	360	6	68.6	4280.8
28	4	2	30	3	900	756	420	36	870	726	390	6	68.6	4349.4
29	2	3	60	2	750	606	420	66	690	546	360	6	280	4629.4
30	2	3	60	2	690	546	420	66	630	486	360	6	280	4909.4
31	3	3	60	2	630	486	360	66	570	426	300	6	196	5105.4
32	2	3	60	2	570	426	360	66	510	366	300	6	280	5385.4
33	4	3	60	4	960	816	480	96	900	756	420	36	137.2	5522.6
34	3	2	30	2	510	366	300	36	480	336	270	6	98	5620.6
35	1	1	60	1	90	66	60	66	30	6	0	6	400	6020.6
36	3	2	30	2	480	336	270	36	450	306	240	6	98	6118.6
37	2	3	60	2	450	306	300	66	390	246	240	6	280	6398.6
38	1	1	60	1										
39	3	2	30	2	390	246	240	36	360	216	210	6	98	6496.6
40	3	2	30	2	360	216	210	36	330	186	180	6	98	6594.6
41	4	2	30	4	900	756	420	36	870	726	390	6	68.6	6663.2
42	3	3	60	2	330	186	180	66	270	126	120	6	196	6859.2
43	2	2	30	2	270	126	150	36	240	96	120	6	140	6999.2
44	4	2	30	1										
45	3	2	30	2	240	96	120	36	210	66	90	6	98	7097.2
46	3	2	30	2	210	66	90	36	180	36	60	6	98	7195.2
47	4	2	30	1										
48	4	2	30	1										
49	2	2	30	2	180	36	66	36	150	6	36	6	140	7335.2
50	3	3	60	3	870	726	390	66	810	666	330	6	196	7531.2

may not yield a better result. In other words, revenue management may not be applicable to cases when there's no significant difference in the revenue contribution by two successive customer classes. This observation agrees with that made by Barut and Sridharan [4]. The other performance metric, i.e., percentage increase in profit (PIP) ranged between 0% and 17.25% with an average increase of 6%. This shows that the profit generated under CPRAP is always greater than or equal to the profit generated under FCFS. In addition to the financial metrics, fill rate is the other important measure that was analyzed in the study. The percentage increase in fill rate as a result of adopting CPRAP recorded low and high values of 0% and 100% respectively with the average increase in fill rate being 46.98%. When there is enough capacity to fulfill the demand, i.e., the capacity is larger than the demand, both FCFS and CPRAP perform at the same level and hence no improvement in the fill rate is recorded. When the capacity is constrained, and the demand is high, FCFS may not allocate appointments to new customers. CPRAP maintains a minimum capacity that is accessible by the new customers and hence accepts more number of new customers compared to FCFS. The simulation results are summarized in Table 4.5.

In order to verify that the CPRAP performs better than the FCFS, a t-test was performed on the percentage increase in revenue as a result of following CPRAP framework instead of FCFS appointment allocation policy. The following hypotheses are considered for the statistical analysis.

- Null Hypothesis: The percentage increase in revenue is 0. In other words, there is no change in the revenue generated by the two approaches.
- Alternate Hypothesis: The percentage increase in profit is greater than 0. In other words, CPRAP generates more revenue compared to the FCFS.

The t-test indicates that there is a significant increase in revenue under CPRAP with a p-value of $2.21\text{x}10^{-6}$. In addition, a further analysis on the effect of different factors such as demand, resource level, and revenue attractiveness, on the percentage increase in revenue

Table 4.4: Simulation Results

Demand	Resource	π	PIR			PIP		
			Set I	Set II	Set III	Set I	Set II	Set III
50	4	0.5	8.83	12.11	6.93	12.86	16.01	9.83
		0.7	2.33	3.82	1.88	8.21	10.04	6.38
		0.9	-1.48	-1.06	-1.25	5.65	6.82	4.43
		1	-2.82	-2.79	-2.39	4.78	5.75	3.76
	6	0.5	0.30	0.00	0.00	0.30	0.00	0.00
		0.7	0.21	0.00	0.00	0.21	0.00	0.00
		0.9	0.15	0.00	0.00	0.15	0.00	0.00
		1	0.13	0.00	0.00	0.13	0.00	0.00
	8	0.5	0.00	0.00	0.00	0.00	0.00	0.00
		0.7	0.00	0.00	0.00	0.00	0.00	0.00
		0.9	0.00	0.00	0.00	0.00	0.00	0.00
		1	0.00	0.00	0.00	0.00	0.00	0.00
75	4	0.5	15.30	19.36	15.98	15.09	16.88	15.49
		0.7	5.91	7.73	6.17	10.00	10.00	9.33
		0.9	0.57	1.17	0.78	6.10	6.60	6.23
		1	-1.28	-1.12	-1.05	5.11	5.50	5.23
	6	0.5	11.56	10.79	10.42	16.11	13.95	13.76
		0.7	3.71	3.37	3.59	10.19	8.84	8.84
		0.9	-0.75	-0.96	-0.35	6.96	6.04	6.11
		1	-2.28	-2.48	-1.72	5.88	5.10	5.18
	8	0.5	1.41	0.21	1.40	1.41	0.21	1.40
		0.7	0.97	0.14	0.96	0.97	0.14	0.96
		0.9	0.69	0.10	0.68	0.69	0.10	0.68
		1	0.60	0.09	0.59	0.60	0.09	0.59
100	4	0.5	17.35	20.92	16.64	13.52	14.66	13.13
		0.7	6.76	8.44	6.34	7.91	8.44	7.68
		0.9	0.80	1.47	0.62	5.20	5.49	5.05
		1	-1.26	-0.96	-1.33	4.33	4.56	4.21
	6	0.5	16.28	15.79	15.51	16.84	17.25	17.04
		0.7	6.17	5.92	6.31	10.23	10.44	10.45
		0.9	0.53	0.40	1.17	6.85	6.97	7.04
		1	-1.40	-1.50	-0.60	5.74	5.84	5.92
	8	0.5	12.43	12.04	9.70	16.70	16.08	13.02
		0.7	4.40	4.02	3.47	10.57	10.14	8.40
		0.9	-0.14	-0.53	-0.17	7.22	6.91	5.81
		1	-1.71	-2.10	-1.44	6.10	5.83	4.93
	Average		2.90	3.18	2.75	6.18	6.24	5.58
				2.94			6.00	

Table 4.5: Summary of simulation results

Performance Measure	Minimum	Maximum	Average
Percentage Increase in Revenue (PIR)	-2.82	20.92	2.94
Percentage Increase in Profit (PIP)	0.00	17.25	6.00
Percentage Increase in new customer fill rate	0.00	100.00	46.98

is performed using ANOVA. The ANOVA results revealed that the third order interaction of all the factors is significant, which means that all the factors together contribute to the percentage increase in the revenue generated. This shows that none of the significant factors are neglected in the model. The ANOVA results are presented in Table 4.6. The simulation results also reveal that tighter the capacity greater the percentage increase in revenue and ANOVA results support this observations.

Table 4.6: Analysis of Variance

Source	Sum of Squares	DF	Mean Square	F Value	Prob > F
Model	2556.01749	35	73.02907	334.235	< 0.0001
Demand (D)	287.5984926	2	143.7992	658.1317	< 0.0001
Resource (R)	117.7456089	2	58.8728	269.4455	< 0.0001
Attractiveness (A)	1324.165435	3	441.3885	2020.12	< 0.0001
D x R	36.53807931	4	9.13452	41.80632	< 0.0001
D x A	408.6582106	6	68.1097	311.7204	< 0.0001
R x A	257.1685779	6	42.86143	196.1656	< 0.0001
D x R x A	111.9755527	12	9.331296	42.70691	< 0.0001
Pure Error	14.85773875	68	0.218496		
Total	2570.875229	103			

Figure 4.3 shows the interaction of resource availability and revenue attractiveness factors when demand is constant. It can be seen that when there is a clear distinction between the revenue contribution of two customer segments, CPRAP generates more revenue when the capacity is tight, i.e., at 4 salaried therapist level. However, when the capacity is no longer tight, i.e., at 6 salaried therapist level, FCFS and CPRAP generate the same revenue.

Figure 4.4 shows the interaction between demand and revenue attractiveness factors for a given level of resources. It can be seen from Figure 4.4 that for a fixed level of resource, the

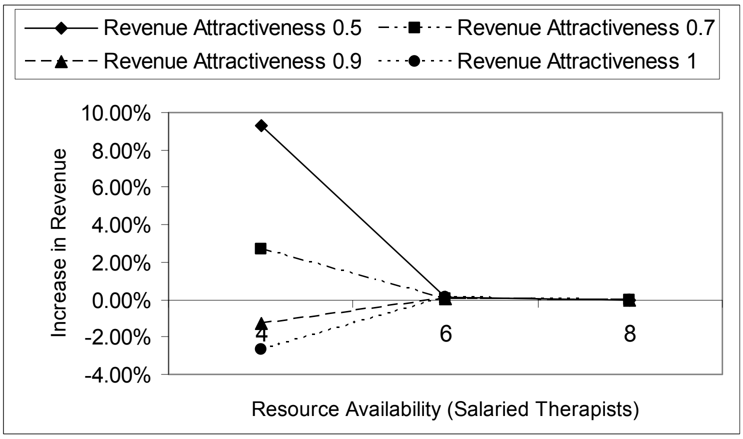

Figure 4.3: Interaction plot of resource availability and revenue attractiveness

percentage change in revenue increases as the demand increases and the percentage change is at maximum when the revenue attractiveness is at minimum.

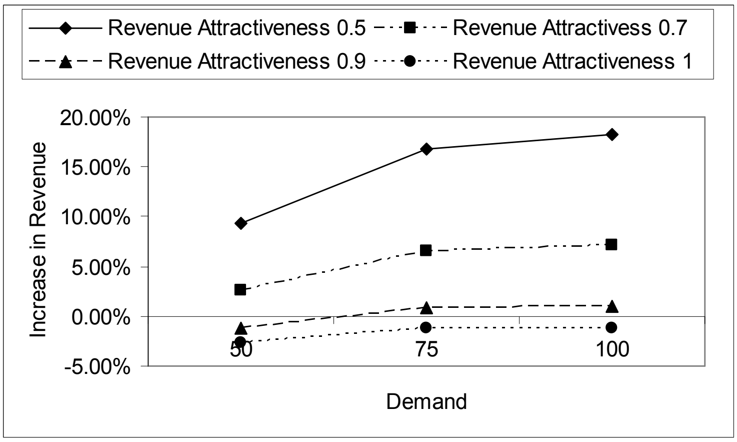

Figure 4.4: Interaction plot of demand and revenue attractiveness

Figure 4.5 shows the interaction of demand and resource availability when the revenue attractiveness parameter is kept constant. It can be inferred from the graph that for a given revenue attractiveness, the percentage increase in profit increases as the demand increases. For any demand level, tighter capacity generates more revenue than relaxed capacity.

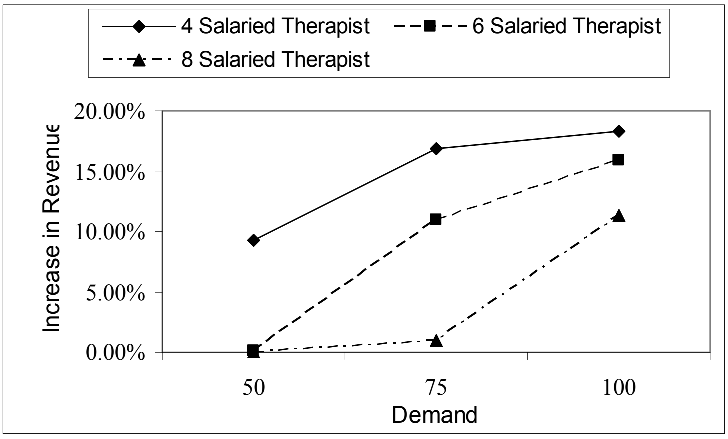

Figure 4.5: Interaction plot of demand and resource availability

4.6 Summary

In this chapter, the problem of appointment allocation in rehab outpatient clinics when the customer arrival is stochastic is discussed. A revenue management framework, capacity partitioning and resource allocation algorithm (CPRAP) is proposed for appointment allocation. A simulation model of the framework was developed and evaluated for various operating scenarios. The simulation results indicate that CPRAP generates more revenue and profit when there is a scarce resource, demand is high, and there is a clear distinction in the revenue contribution of different customer segments. It is also observed that CPRAP improves new customer fill rate.

CHAPTER 5
CONCLUSION AND FUTURE RESEARCH DIRECTIONS

5.1 Introduction

In this thesis, an appointment scheduling framework and capacity portioning procedure are proposed. In the optimization approach, several mathematical models are developed to generate appointment and therapist schedules when the demand is deterministic. On the other hand, revenue management approach proposes a framework for capacity partitioning and resource allocation when the customer arrival is stochastic. In this chapter, the outcomes of the two approaches are discussed in separate sections. Healthcare providers that concentrate on maximizing the revenue might have to address a few issues concerning the ethics. Section 5.4 discusses these issues. In the final section of this chapter, potential areas for future research are identified.

5.2 Optimization Approach to Appointment Scheduling

When the demand is deterministic, appointment scheduling problem can be solved as a timetabling problem. The proposed mathematical models generate appointment and therapist schedules. These models along with generating schedules, maximize the overall profit. The mathematical models are evaluated under various scenarios. The results indicate that when the capacity is tight, and the demand is high, grouping more than one patient for a treatment yields higher profit. Furthermore, when grouping is allowed, the use of part time therapists is minimal. The results also show that the profit generated by the models that consider grouping patients is at least equal to the profit generated by the model that does not consider grouping.

5.3 Revenue Management Approach to Appointment Allocation

Revenue management is an important, widely used customer acceptance and resource allocation tool to optimize profit, when there are different customer classes that are willing to pay different amounts for the same service. This research focuses on rehabilitation outpatient clinics where the customer base can be segmented into different groups based on their insurance. In this study, a new approach to the appointment allocation procedure in rehabilitation outpatient clinics is introduced. It is assumed that none of the existing patients in the system will be denied service while maximizing the number of new patient evaluations. This approach enables rehabilitation outpatient clinics to maximize the revenue and profit generated using full time and part time therapists. In order to achieve this objective, a revenue management framework, Capacity Partitioning and Resource Allocation Procedure (CPRAP) is developed. In addition to the financial aspects, this research also intended at improving the fill rates of new customers. CPRAP is tested for various scenarios using simulation analysis. The results revealed that the CPRAP generates close to 3% more revenue, over 6% more profit, and over 46% more new customers compared to FCFS. It can also be concluded that tighter the capacity and the higher the demand, the greater is the increase in revenue and overall profit generated.

5.4 Ethical Issues

Most healthcare providers do not consider maximizing revenue and profit as a key business objectives. The healthcare providers focus on providing quality treatments to the customers regardless of the customers' payment source. Since the value of life of a human being is considered to be priceless, healthcare providers might consider revenue maximization, segmentation of customers as a violation of the ethics. The two main ethical issues that need to be addressed to implement any revenue management framework are:

1. Is it ethical to discriminate customers based on what they pay?

2. How does customer discrimination affect the quality of the treatments?

In this thesis, the new customers are not discriminated based on their insurance. Irrespective of the payment source, appointments are given to new customers subject to the resource availability. On the other hand, though the return customers are discriminated based on their revenue contribution, their requests are always honored and no request from the return customers is turned down.

Customer discrimination plays a major role only in deciding if the existing capacity is sufficient to satisfy the demand. In this thesis, it is assumed that therapists will have no information on the payment source of customers and hence one can be sure that all of the customers, irrespective of their insurances, are treated at the same level. In other words, a patient from the low revenue class would receive the same level of service as that of a high revenue class customer.

5.5 Areas for Future Research

In the literature, objectives of traditional appointment scheduling systems in outpatient clinics include minimizing waiting time of customers and maximizing the resource utilizations. In this thesis, we propose an optimization approach and a revenue management approach for scheduling appointments in rehab outpatient clinics while maximizing the profit.

In the proposed CPRAP revenue management framework, capacity partitioning is static, i.e., the capacity reserved for different customer segments remains constant and it depends on the expected demand. It would be interesting to study the effect of capacity partitioning under a dynamic environment, i.e., the capacity reserved for various segments is determined dynamically depending on the available capacity at any particular time.

The methodology proposed in this thesis assumes that a customer requests a single appointment and generates schedules for one visit. Some customers might want to schedules multiple appointments. The proposed models are not robust enough to honor such a request.

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APPENDICES

APPENDIX A
MATHEMATICAL MODEL RESULTS

Table A.1: Profit generated when the demand is a function of ModelWGT characteristics when not more than two can be accommodated in a single appointment slot (λ=2)

Run No.	Salaried Therapist	Part Time Therapist	Total Available Capacity	Demand	Total Profit		
					NGT	WGT2	WGT4
1	3	0	168	84	4092	4292	4292
2	3	0	168	126	3684	6372	6372
3	3	0	168	168	3284	7226	8216
4	3	0	168	210	2804	7307	8870
5	3	1	168	84	4092	4292	4292
6	3	1	168	126	5252	6372	6372
7	3	1	168	168	4852	8260	8260
8	3	1	168	210	4372	9250	10348
9	3	2	168	84	4092	4292	4292
10	3	2	168	126	5812	6372	6372
11	3	2	168	168	6420	8260	8260
12	3	2	168	210	5940	10068	10348
13	4	0	224	112	5236	5436	5436
14	4	0	224	168	4932	8340	8340
15	4	0	224	224	4412	9686	11072
16	4	0	224	280	3792	9819	11928
17	4	1	224	112	5236	5436	5436
18	4	1	224	168	6500	8340	8340
19	4	1	224	224	5980	11164	11164
20	4	1	224	280	5360	11912	13496
21	4	2	224	112	5236	5436	5436
22	4	2	224	168	7780	8340	8340
23	4	2	224	224	7548	11164	11164
24	4	2	224	280	6928	13480	13816
25	5	0	280	140	6624	6824	7024
26	5	0	280	210	6100	10228	10428
27	5	0	280	280	5440	11992	13576
28	5	0	280	350	4700	12251	15104
29	5	1	280	140	6624	6824	7024
30	5	1	280	210	7668	10228	10428
31	5	1	280	280	7008	13560	13896
32	5	1	280	350	6268	14494	16672
33	5	2	280	140	6624	6824	7024
34	5	2	280	210	9092	10228	10428
35	5	2	280	280	8576	13616	13896
36	5	2	280	350	7836	16062	17484

Table A.2: Therapist Utilization with ModelWGT (not more than 2 in GT) demand characteristics

Demand	Salaried Therapists				Part Time Therapists			
	Available	Used			Available	Used		
		NGT	WGT2	WGT4		NGT	WGT2	WGT4
84	3	3	2	2	0	0	0	0
126	3	3	3	3	0	0	0	0
168	3	3	3	3	0	0	0	0
210	3	3	3	3	0	0	0	0
84	3	3	2	2	1	0	0	0
126	3	3	3	3	1	1	0	0
168	3	3	3	3	1	1	1	1
210	3	3	3	3	1	1	1	1
84	3	3	2	2	2	0	0	0
126	3	3	3	3	2	2	0	0
168	3	3	3	3	2	2	1	1
210	3	3	3	3	2	2	2	1
112	4	4	3	3	0	0	0	0
168	4	4	4	4	0	0	0	0
224	4	4	4	4	0	0	0	0
280	4	4	4	4	0	0	0	0
112	4	4	3	3	1	0	0	0
168	4	4	4	4	1	1	0	0
224	4	4	4	4	1	1	1	1
280	4	4	4	4	1	1	1	1
112	4	4	3	3	2	0	0	0
168	4	4	4	4	2	2	0	0
224	4	4	4	4	2	2	1	1
280	4	4	4	4	2	2	2	2
140	5	5	4	3	0	0	0	0
210	5	5	5	4	0	0	0	0
280	5	5	5	5	0	0	0	0
350	5	5	5	5	0	0	0	0
140	5	5	4	3	1	0	0	0
210	5	5	5	4	1	1	0	0
280	5	5	5	5	1	1	1	1
350	5	5	5	5	1	1	1	1
140	5	5	4	3	2	0	0	0
210	5	5	5	4	2	2	0	0
280	5	5	5	5	2	2	2	1
350	5	5	5	5	2	2	2	2

Table A.3: Profit generated when the demand is a function of ModelWGT characteristics when not more than four can be accommodated in a single appointment slot (λ=4)

Run No.	Salaried Therapist	Part Time Therapist	Total Available Capacity	Demand	Total Profit		
					NGT	WGT2	WGT4
1	3	0	336	168	3284	7226	8216
2	3	0	336	252	2004	7323	9477
3	3	0	336	336	324	6318	9990
4	3	0	336	420	-1356	5033	9641
5	3	1	336	168	4852	8260	8260
6	3	1	336	252	3972	9690	11370
7	3	1	336	336	2592	9734	12620
8	3	1	336	420	912	8449	13039
9	3	2	336	168	6420	8260	8260
10	3	2	336	252	5540	11408	12500
11	3	2	336	336	4760	12144	14588
12	3	2	336	420	3180	11865	15710
13	4	0	448	224	4412	9686	11072
14	4	0	448	336	2672	9814	12700
15	4	0	448	448	432	7907	12857
16	4	0	448	560	432	4744	11428
17	4	1	448	224	5980	11164	11164
18	4	1	448	336	4840	12224	14668
19	4	1	448	448	2700	11323	16191
20	4	1	448	560	2700	8760	14844
21	4	2	448	224	7548	11164	11164
22	4	2	448	336	6408	14292	16236
23	4	2	448	448	4968	14577	18459
24	4	2	448	560	2728	12176	18260
25	5	0	560	280	5440	11992	13576
26	5	0	560	420	3340	12025	15895
27	5	0	560	560	3340	8840	15895
28	5	0	560	700	3340	8840	13210
29	5	1	560	280	7008	13560	13896
30	5	1	560	420	5608	14668	17938
31	5	1	560	560	2808	12256	18340
32	5	1	560	700	2808	12256	16686
33	5	2	560	280	8576	13616	13896
34	5	2	560	420	7176	16936	19506
35	5	2	560	560	5076	15672	21756
36	5	2	560	700	5076	12362	20102

Table A.4: Therapist Utilization with ModelWGT (not more than 4 in GT) demand characteristics

Demand	Salaried Therapists				Part Time Therapists			
	Available	Used			Available	Used		
		NGT	WGT2	WGT4		NGT	WGT2	WGT4
168	3	3	3	3	0	0	0	0
252	3	3	3	3	0	0	0	0
336	3	3	3	3	0	0	0	0
420	3	3	3	3	0	0	0	0
168	3	3	3	3	1	1	1	1
252	3	3	3	3	1	1	1	1
336	3	3	3	3	1	1	1	1
420	3	3	3	3	1	1	1	1
168	3	3	3	3	2	2	1	1
252	3	3	3	3	2	2	2	2
336	3	3	3	3	2	2	2	2
420	3	3	3	3	2	2	2	2
224	4	4	4	4	0	0	0	0
336	4	4	4	4	0	0	0	0
448	4	4	4	4	0	0	0	0
560	4	4	4	4	0	0	0	0
224	4	4	4	4	1	1	1	1
336	4	4	4	4	1	1	1	1
448	4	4	4	4	1	1	1	1
560	4	4	4	4	1	1	1	1
224	4	4	4	4	2	2	1	1
336	4	4	4	4	2	2	2	2
448	4	4	4	4	2	2	2	2
560	4	4	4	4	2	2	2	2
280	5	5	5	5	0	0	0	0
420	5	5	5	5	0	0	0	0
560	5	5	5	5	0	0	0	0
700	5	5	5	5	0	0	0	0
280	5	5	5	5	1	1	1	1
420	5	5	5	5	1	1	1	1
560	5	5	5	5	1	1	1	1
700	5	5	5	5	1	1	1	1
280	5	5	5	5	2	2	2	1
420	5	5	5	5	2	2	2	2
560	5	5	5	5	2	2	2	2
700	5	5	5	5	2	2	2	2

APPENDIX B
LIST OF ABBREVIATIONS

ANOVA	Analysis Of Variance
CPRAP	Capacity Partitioning and Resource Allocation Procedure
FCFS	First Come First Serve
GT	Group Therapy
IT	Individual Therapy
ModelNGT	Model with No Group Therapy
ModelWGT	Model With Group Therapy
NGT	No Group Therapy
OT	Occupational Therapy
PIR	Percentage Increase in Revenue
PIP	Percentage Increase in Profit
PT	Physical Therapy
RM	Revenue Management
WGT2	Not more than 2 in Group Therapy
WGT4	Not more than 4 in Group Therapy