

T.R.
GEBZE TECHNICAL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**AN INTEGER PROGRAMMING MODEL OF
RECREATIONAL PLANNING IN
MEDICAL TOURISM**

EKİN YILDIRIM
**A THESIS SUBMITTED FOR THE DEGREE OF
MASTER OF SCIENCE**
INDUSTRIAL ENGINEERING DEPARTMENT

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ASSIST. PROF. DR. BURAK PAÇ

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2023

T.C.
GEBZE TEKNİK ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

TIBBİ TURİZMDE
REKREASYONEL PLANLAMANIN
TAM SAYI PROGRAMLAMA MODELİ

EKİN YILDIRIM
YÜKSEK LİSANS TEZİ
ENDÜSTRİ MÜHENDİSLİĞİ ANABİLİM DALI

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GEBZE
2023



YÜKSEK LİSANS JÜRİ ONAY FORMU

GTÜ Fen Bilimleri Enstitüsü Yönetim Kurulu'nun 07/03/2023 tarih ve 2023/17 sayılı kararıyla oluşturulan jüri tarafından 07/07/2023 tarihinde tez savunma sınavı yapılan Ekin YILDIRIM'ın tez çalışması Endüstri Mühendisliği Anabilim Dalında YÜKSEK LİSANS tezi olarak kabul edilmiştir.

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...../...../..... tarih ve/..... sayılı kararı.

SUMMARY

Planning access to different tourism activities for health tourists is a complex and challenging task that requires careful consideration of various factors such as capacity constraints, costs, demand, and medical restrictions. A mathematical model that takes these factors into account will optimize revenue for tourism firms while providing a quality tourism experience for health tourists. An integer programming model has been developed to consider the medical schedules and constraints of health tourists, the capacity of tourism activities, and fixed and variable costs, aiming to optimize profit. The developed model has been tested with generated data, and the solution times are presented in the computational results section based on the number of patients in the planning horizon.

Keywords: Medical Tourism, Integer Programming, Scheduling.

ÖZET

Sağlık turistlerinin farklı turistik aktivitelere erişimini planlamak, kapasite kısıtlamaları, maliyetler, talep ve sağlık kısıtlamaları gibi çeşitli faktörlerin dikkatli bir şekilde değerlendirilmesini gerektiren karmaşık ve zorlu bir problemdir. Bu faktörleri hesaba katan bir matematiksel model, sağlık turistleri için kaliteli bir turistik deneyim sunarken turizm firmaları için geliri eniyileyecektir. Sağlık turistlerinin tıbbî çizelge ve kısıtlarını, turistik aktivitelerin kişi sayısı kapasitelerini, sabit ve değişken maliyetlerini dikkate alan ve kâr eniyilemesini amaçlayan bir tamsayılı program modeli geliştirilmiştir. Geliştirilen model üretilen veri ile sınanmış ve planlama dâhilindeki hasta sayısına göre çözüm süreleri hesaplamalı sonuçlar bölümünde sunulmuştur.

Anahtar Kelimeler: Sağlık Turizmi, Tamsayılı Programlama, Çizelgeleme.

ACKNOWLEDGEMENTS

Thanks to my family, friends and professors who supported me along the way.



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1. INTRODUCTION

1.1. Medical Tourism

Medical tourism is the practice of traveling to other countries for clinical remedy. This kind of tourism has emerged as popular in latest years with people traveling from all around the world to take advantage of lower prices other countries offer on modern scientific methods, or access to treatments or approaches that cannot be had in their home countries.

Medical tourism, or health/healthcare tourism, has been growing swiftly in recent years as people travel abroad for medical treatments more often. The growth of this industry has caused a need for optimization of the plans for health travelers to participate in alternative touristic activities (shortly referred to as “tour”). This optimization is important to maximize the revenue generated from health tourists while considering medical constraints of the medical tourists. One of the forthcoming drivers of health tourism is the financial savings opportunity. In many countries, medical procedures are considerably less costly than in developed countries, making them a lower cost alternative for people looking for medical treatment. A knee replacement in U.S., for example, can cost \$50000 while the same treatment in Thailand may cost \$15000. Those savings are mainly attractive to those without insurance coverage for treatments, or who are in search of a lower price alternatives to costly treatments available in their home countries.

Another advantage of medical tourism is the access to treatments and approaches not available in other countries. Many countries have strict policies on some medical operations, which limits getting admission to these remedies for patients in those locations. By traveling to another country for treatment, people can get admission to these techniques, which might not be available in their home countries.

In addition to price savings and getting admission to treatments, medical tourism can offer the possibility for individuals to combine their medical treatment with a holiday. Many countries that are famous locations for medical tourism also offer spa centers, beaches and different attractions, making it possible for patients to recuperate

in a nice and cozy environment. If these health tourists can get directed to various tourism areas, naturally the revenue generated will be higher. Otherwise, -if health tourists visit a certain country for medical treatments, are not directed to other tourism areas-, it creates an opportunity cost.

The lack of alternative touristic activity offerings for medical tourists underlines the need for developing stronger methods to better guide those patients to other tourism regions and increase their participation. This would reduce the opportunity cost due to travelers not taking part in these activities, and also would increase financial gains from more efficient allocation of touristic activities to tourists.

One of the concerns in the distribution of health tourists is the capacity constraints of the different touristic activities. As an instance, a touristic area might have confined lodge rooms or transportation alternatives, and it is crucial to ensure that the quantity of health tourists directed to a specific area does not exceed its capacity. Exceeding capacity may lead to overcrowding that can negatively affect sales. The costs associated with directing health tourists to different tourist areas are another important consideration. These costs may include transportation, lodging, and tourism activities, and it is essential to ensure that the revenue generated from these tourists is greater than the costs associated with directing them.

It is also crucial to consider the health regulations of health tourists while directing them to touristic activities. For example, some medical procedures may restrict a tourist's ability to participate in some activities that include excessive sports activities or long walks, and it is essential to take this into consideration while directing them to different touristic areas.

Medical tourism offers people the opportunity to save money on medical approaches, access treatments not available in their domestic international locations, and combine medical treatment with a holiday. Optimizing the allocation of touristic activities to medical tourists is a complicated and challenging problem that calls for cautious consideration of various factors together with potential constraints. Mathematical methods that take those factors into consideration can help make sure that health travelers are directed to the attractive touristic areas in a manner that maximizes sales, making sure that the tourists make more out of their journey for medical tourism.

1.2. Medical Tourism in Türkiye

Medical tourism in Türkiye has experienced a massive boom in recent years, attracting patients from everywhere in the world searching out high quality medical treatment at low cost. Türkiye offers a unique combination of modern scientific facilities, skilled scientific experts, and a rich cultural heritage, making it an appealing vacation spot for health tourists. One of the major reasons for the growth of medical tourism in Türkiye is the high-quality clinical services that can be attained. Türkiye is home to many private hospitals and clinics, which offer state-of-the-art medical facilities and skilled scientific experts. It is a leading tourism spot for medical procedures such as cosmetic surgery, dental treatments and orthopedics.

More than 50% of foreign tourists visiting Türkiye come to see the must-see places, to relax or have a holiday. However, the individual expenditures of people traveling to receive services in specialized areas such as medical tourism are higher than those of tourists coming for vacation. The most important reason for this is that people with high financial power benefit more from medical tourism services.

Medical tourism also has a positive impact on the general quality of healthcare services in Türkiye. The country's healthcare sector has been modernizing and enhancing in latest years, and the boom of clinical tourism has been a massive motive force of this improvement. The demand for clinical offerings from health tourists has led to the development of modern scientific centers and the implementation of the latest technology and treatments.

Medical tourism in Türkiye also offers patients the opportunity to combine medical treatment with a holiday. The country is home to a rich cultural and historical past, with ancient towns, beautiful beaches, and famous landmarks, making it a perfect vacation spot for those seeking to combine clinical treatment with a chilled and rejuvenating holiday. Patients can take benefit of Türkiye's rich cultural background and ancient sites or enjoy one of the many spas and wellbeing facilities, supporting them to recover in an excellent environment. When those tourists, who tour for the goal of receiving medical treatment go back to their home countries without being able to gain access to other tourism areas, it causes an opportunity cost. The direct contribution of tourism to the growth of the economy increases the importance of

ensuring that patients coming from abroad take part in other tourism activities with the right guidance and reveals the necessity of developing strategies that will enable more patients to prefer these activities.

As these tourists come to the country mainly for clinical treatment, they will have limited time and unique restrictions on their schedule. Therefore, it is important to consider these constraints when developing strategies to guide them to other tourism areas. This is where the mathematical model proposed in the problem definition can play a critical role, by considering the patients' availability and restrictions, as well as the capacity and cost of the different tours, to find the optimal allocation of patients to tours.

Türkiye is a popular destination for several types of medical tourism, including:

Cosmetic surgery: Türkiye is widely recognized for its know-how in cosmetic surgical operation procedures, inclusive of rhinoplasty, liposuction, and breast augmentation. Patients from round the world visit Türkiye for these treatments due to the highly satisfactory hospital treatment and less expensive charges. Hair implants are also a famous type of health tourism in Türkiye. Türkiye has turned out to be a hub for hair transplant due to the know-how of its clinical specialists and the use of modern techniques, such as Follicular Unit Extraction (FUE) and Direct Hair Implantation (DHI).

In addition, Türkiye is known for its natural and high-quality hair transplant results, which are achieved by using techniques that are minimally invasive and result in a more natural-looking hairline. Patients can expect excellent results and a quick recovery time, making Türkiye a popular destination for hair implant procedures.

Dental tourism: Türkiye is a popular spot also for dental tourism, with many people traveling to the country for dental processes. The country offers a huge range of dental offerings at a low cost as compared to many western countries.

Orthopedic tourism: Orthopedic processes, which include joint replacements, spinal surgeries, and sports medicine procedures, are also famous in Türkiye. The country has a properly advanced healthcare system and especially skilled medical experts, making it a famous destination for these types of processes.

Fertility tourism: Türkiye is turning into a famous destination for fertility tourism, with many couples travelling to the country for assisted reproductive methods, which include in vitro fertilization (IVF).

Türkiye could benefit from directing visiting health tourists to touristic activities in other tourism areas. By doing so, Türkiye would be able to increase the economic impact of health tourism and provide a more comprehensive and diverse experience for visitors.

One way that Türkiye could achieve this is by offering medical packages that include tours of cultural and historical landmarks, visits to natural parks, or other tourist attractions. This would not only enhance the overall experience for the patient, but also encourage them to spend more time and money in the country, contributing to the local economy.

Another way that Türkiye could benefit from directing visiting health tourists to other tourism areas is by partnering with local hotels, restaurants, and tourist attractions. This would create a more integrated and seamless experience for visitors, which would allow visitors to spend more time and money during their stay.

Accordingly, in this study, a model has been created that will enable medical tourists with various medical service demands to participate in appropriate touristic activities in line with their medical appointments and restrictions, aiming to maximize profit. With the integer programming model developed, it is aimed to guide the operations of touristic service providers and to ensure that more medical tourists are directed to various tourism activities.

2. LITERATURE REVIEW

Scheduling problems involve determining the optimal arrangement of tasks or activities within a given set of constraints and objectives. Scheduling problems arise in different fields, including project management, manufacturing, transportation, and employee scheduling. The objective is to efficiently allocate resources and time, aiming to minimize costs, maximize efficiency, or achieve specific criteria. They typically involve factors like task dependencies, resource availability, deadlines, and the optimization of specific performance metrics.

Of the numerous branches, job-shop scheduling involves scheduling jobs on machines in a manufacturing setting. The objective is to minimize the makespan or total tardiness. Flow shop scheduling is the scheduling of jobs on machines with a fixed processing order. The goal is to minimize the makespan or total tardiness. Project scheduling involves scheduling tasks in a project to meet deadlines. The aim is to minimize project completion time or total project cost. School timetabling is the scheduling of classes for teachers and students in a school. The objective is to minimize conflicts and satisfy constraints [Pinedo, 1995].

There are numerous scheduling, assignment and resource allocations problems in the healthcare area, many involving integer/mixed-integer program modeling. In the healthcare area, scheduling problems occur in hospitals and clinics, such as surgical scheduling and room scheduling in hotels and resorts.

In an application of integer programming to surgical room planning [Blake et al., 2002], the authors discuss the challenges faced by hospitals with limited operating room (OR) time and the need to distribute it fairly among surgical groups. Traditionally, facilities have used formulas based on OR utilization, contribution margin, or other performance metrics to determine each group's share of block time. Once the allocated time for each group is determined, a surgical master schedule that assigns specific ORs on specific days to each group is created. However, the target allocation for a group often cannot be expressed as a whole block multiple. To address this issue, the paper explores the implementation of integer programming, to develop a consistent schedule that minimizes the discrepancy between each group's target and actual assignment of OR time.

A study focusing on the allocation and sequencing of elective operations in ORs addresses the problem by a mixed integer linear programming (MILP) model [Maaroufi et al., 2016]. The MILP model incorporates decisions regarding the allocation of operations to material and human resources, as well as determining the starting times for both the operations and individual surgeons. To evaluate the effectiveness of the MILP model, the authors compare it to a constraints programming approach.

In one study, a nurse-scheduling model based on mixed integer programming to automate and replace the manual approach in a general care ward is introduced [Choy and Cheong, 2012a]. The authors optimize both the hospital's requirements and nurse preferences, incorporating flexibility in nurse transfers between duties.

The model proposed in another paper considers the hospital's mission of ensuring continuous ward care service with the appropriate number of nursing staff and the right mix of skills while minimizing costs. Nurse preferences, such as the number of night shifts and consecutive rest days, are also considered. The problem of integrated staffing and scheduling under demand uncertainty is addressed by formulating it as a two-stage stochastic integer program with mixed-integer recourse [Kim and Mehrotra, 2015].

[Zen-El-Din et al., 2012] focus on the development of a computerized nurse scheduling model using binary integer programming. The model is specifically designed for the ICU in the New Kasr El-Eni University Educational Hospital in Cairo. The aim of the model is to enhance the existing manual scheduling process and the model considers both the objectives of the hospital and the preferences of the nurses.

In a study addressing the nurse scheduling problem by presenting and comparing multiple mixed integer programming models, the goal is to optimize work schedules for nurses, balancing workload and skill levels [Hasebe et al., 2017]. The proposed variable-fixing method aims to generate optimal solutions with flexibility for practical use by on-site schedulers.

Another operations research problem related to the problem defined in this study is the multiple knapsack problem (MKP), particularly due to the assignment/allocation of touristic activities (items) to increase revenue generated, in the meantime respecting budget capacities of numerous tourists (knapsacks). It is possible to consider the problem the other way around, allocating tourists to tours, where the tour capacity aligns with the knapsack capacity. MKP is an extension of

the traditional knapsack problem. It involves multiple knapsacks with different capacities and a set of items to be allocated among them. The objective is to maximize the total value of items placed in the knapsacks, while ensuring that the total weight of items in each knapsack does not exceed its capacity.

The 0-1 Multiple Knapsack Problem (MKP) is: given a set of n items and a set of m knapsacks ($m \leq n$), with

$$\begin{aligned} p_j &= \text{profit of item } j, \\ w_j &= \text{weight of item } j, \\ c_i &= \text{capacity of knapsack } i, \end{aligned} \tag{2.1}$$

select m disjoint subsets of items so that the total profit of the selected items is a maximum, and each subset can be assigned to a different knapsack whose capacity is no less than the total weight of items in the subset. Formally,

$$\begin{aligned} \text{maximize } z &= \sum_{i=1}^m \sum_{j=1}^n p_j x_{ij} \\ \text{subject to } &\sum_{j=1}^n w_j x_{ij} \leq c_i, \quad i \in M = \{1, \dots, m\}, \\ &\sum_{i=1}^m x_{ij} \leq 1, \quad j \in N = \{1, \dots, n\}, \\ &x_{ij} = 0 \text{ or } 1, \quad i \in M, j \in N, \end{aligned} \tag{2.2}$$

where

$$x_{ij} = \begin{cases} 1 & \text{if item } j \text{ is assigned to knapsack } i \\ 0 & \text{otherwise.} \end{cases} \tag{2.3}$$

[Martello and Toth, 1990].

The Multiple Knapsack Problem (MKP) is classified as NP-hard, indicating that no known polynomial-time algorithm can solve it. Nevertheless, there exist approximation algorithms that can provide solutions that are close to optimal.

One common approach to solving the MKP is to use a branch-and-bound algorithm. This algorithm starts with an initial feasible solution, and then iteratively refines it by branching on the variables (i.e., the items), and bounding the search space by using upper and lower bounds on the objective function [Martello and Toth, 1990].

Other approaches to MKP are using metaheuristics such as Genetic Algorithm, Particle Swarm Optimization, Ant Colony Optimization, Simulated Annealing, and so on [Coello Coello, Van Veldhuizen, and Lamont, 2007].

Khorramizadeh and Rakhshandehroo [Khorramizadeh and Rakhshandehroo, 2014] explore the impact of the feasibility pump (FP) method on solving the multidimensional mixed integer knapsack problem using the branch and cut approach. The FP is a heuristic method aimed at generating feasible solutions for mixed integer programming problems. The study examines two effective strategies for incorporating the feasibility pump within the branch and cut method and presents numerical results comparing these strategies for solving the multidimensional mixed integer knapsack problem. The findings indicate that, in most test cases, utilizing either the FP or an improved version of it enhances the efficiency of the branch and cut method for this problem.

Martin and Weismantel [Martin and Weismantel, 1997] deal with a general mixed integer knapsack polyhedron for which the authors introduce and analyze a new family of inequalities. They discuss the value of this family both from a theoretic and a computational point of view.

Adouani et al. [Adouani et al., 2020] present a new variant of the knapsack problem called the generalized multiple knapsack problem with setup (GMKPS). GMKPS arises from industrial production scenarios where items are categorized into classes and processed over multiple periods. A specific case, known as the multiple knapsack problem with setup (MKPS), is introduced where items from the same class cannot be processed in more than one period. The paper formulates both GMKPS and MKPS mathematically and proposes a metaheuristic approach combining Variable Neighborhood Descent (VND) with integer programming (IP). The metaheuristic employs local search techniques for assigning classes to knapsacks and utilizes IP for selecting items within each knapsack. Computational experiments on randomly generated instances demonstrate the effectiveness of the proposed metaheuristic compared to using a commercial solver directly. This problem is especially interesting from the perspective of our study, since the setup costs align with the fixed costs of opening tours.

Multiple Knapsack Problem with Assignment Restrictions (MKPAR) is a combinatorial optimization problem that involves finding the optimal allocation of items to multiple knapsacks with constraints on the number of items that can be assigned to each knapsack. In MKPAR, each item has a weight and a profit, and each knapsack has a limited capacity. The goal is to maximize the total profit while ensuring that the total weight assigned to each knapsack does not exceed its capacity. In addition

to the classic knapsack constraints, MKPAR also includes assignment restrictions, which dictate the minimum and maximum number of items that can be assigned to each knapsack [Martello and Toth, 1990].

MKPAR is a NP-hard problem, meaning that it is computationally difficult to find the exact solution in a reasonable amount of time for large-scale instances. Therefore, researchers have proposed various approximation algorithms and heuristics to solve MKPAR, including branch and bound, greedy algorithms, and metaheuristics such as genetic algorithms and simulated annealing.

The scheduling problem and the knapsack problem both involve resource allocation to achieve objectives. In scheduling, tasks are assigned resources, while in the knapsack problem, items are selected to maximize value within constraints. Both problems optimize resource allocation to meet goals. Scheduling problems involve allocating resources (such as time, labor, materials, and equipment) to a set of tasks or activities to meet certain objectives. Scheduling problems can be formulated as knapsack problems by considering the tasks or activities as items and the resources as the knapsack. For example, in a job-shop scheduling problem, the jobs can be considered as items and the machines as knapsacks with a limited capacity.

Both knapsack and scheduling problems are optimization problems where the goal is to select a subset of items from a given set of items such that the total value of the selected items is maximized or minimized subject to constraints. The difference is that the knapsack problem is a simpler problem with constraints on the total weight or size of the items, while scheduling problems have more complex constraints and objectives, like temporal constraints. Knapsack problem can also be seen as a variant of scheduling problem where the objective is to maximize the total value of items while considering the weight constraints.

The mathematical model devised in Section 4 will have a temporal aspect, since planning involved the days of the planning horizon. While there are no precedence relationships, medical appointments alter availability for touristic activities, and touristic activities assigned interfere with other touristic activities overlapping with their duration. However, the problem can be viewed as a multiple knapsack problem, if fixed costs are set aside: each patient can be assigned a subset of the touristic activities available if the patient budget allows. There are additional restrictions, in line with MKPAR, where certain tours (items) cannot be assigned to certain patients (knapsacks) due to medical restrictions.

3. PROBLEM DEFINITION

Our problem is about a tourism company that wants to assign health tourists to available tours of different types.

The medical tourists are to receive one or more of 15 different medical examinations or operations and the tourism company aims to assign one of 8 different touristic activities to the tourists. The medical examination/operations and touristic activities are displayed in Table 3.1 Types of medical examination/operations and touristic activities.

Table 3.1 Types of medical examination/operations and touristic activities.

Types of Medical Examinations	Types of Tours
Cardiac evaluation	Seaside tour
Endoscopic examination	Boat tour
Dermatological evaluation	Thermal tour
Dental examination	Trekking tour
Ophthalmic examination	Nature and history tour
Hair restoration surgery	City tour
Gastrointestinal endoscopy	Gastronomy tour
Dermatological intervention	Highland tour
Endodontic therapy	
Reconstructive plastic surgery	
Cosmetic surgery	
General health examination	

Each tour is available in various durations, up to seven days. Tours are available if completion does not exceed the end of the planning horizon.

Each tour has a price per attending tourist, a variable cost per tourist, a fixed cost for operating the tour and a capacity.

Each patient in the group of patients considered in the planning horizon has a fixed medical schedule on examination and operation appointments, and these appointments also interfere with touristic activities that follow/precede the appointment, depending on the type of medical produce due and touristic activity. Then, on a certain day, a medical tourist can attend only one touristic activity, on the condition that this activity is not ruled out by the medical schedule of the patient.

Each medical tourist has a fixed budget that should not be exceeded by the assigned tours, and a patient should not be assigned multiple times on a tour of specific type.

The goal is to find the optimal allocation of tourists to tours that maximizes the total profit generated, subject to medical schedule restrictions, capacity constraints, budget constraints, tour type constraints and daily availability.

4. THE INTEGER PROGRAMMING MODEL

In this section, we are modeling the problem introduced in Section 3 as an integer programming model.

Table 4.1 Indices, parameters and variables of the integer programming model. displays the parameters and variables used in the model.

Table 4.1 Indices, parameters and variables of the integer programming model.

Index Set	Explanation
$\{1, \dots, H\}$	The set of medical tourists.
$\{1, \dots, T\}$	The planning horizon, days.
$\{1, \dots, L\}$	The set of touristic activities, including various durations offered for the same type.
Parameter	Explanation
K_l	Capacity of tour l , $l \in \{1, \dots, L\}$.
f_l	Fixed cost of operating tour l .
c_l	Variable cost of tour l per person.
p_l	The price (revenue) per person of tour l .
d_l	The duration of tour l in days.
U_{hlt}	The medical schedule. Binary valued parameter representing availability of tourist h for starting tour l on day t .
Variable	Explanation
$y_{lt} \in \{0,1\}$	Binary variable indicating whether tour l starting on day t is operated.
$x_{hlt} \in \{0,1\}$	Binary variable indicating whether tourist h attends tour l starting on day t .

A health tourist visiting for a certain medical examination or operation may not be able to partake in certain touristic activity. This can be due to the appointment itself, keeping the tourist busy on the appointment day t , or ruling out the possibility of specific touristic activities on days preceding or following the appointment. This could be due to physical limitations, health restrictions, or the recovery process after the medical procedure. If the duration of the activity l starting on day t interferes with the medical restrictions of an appointment in the planning horizon, the patient cannot attend this activity. This is indicated by the parameter U_{hlt} , $h = 1, \dots, H, l = 1, \dots, L, t = 1, \dots, T$. Due to her/his medical schedule, tourist h can attend tour l starting on day t if medical restrictions permit ($U_{hlt} = 1$, in this case, 0 otherwise). Then, the binary variable x_{hlt} indicating whether tourist h attends tour l starting on day t is restricted by U_{hlt} as posed by inequality (2). In the mathematical model (1)-(6).

$$\max \sum_{h=1}^H \sum_{l=1}^L \sum_{t=1}^T (p_l - c_l) * x_{hlt} - \sum_{l=1}^L \sum_{t=1}^T f_l * y_{lt} \quad (4.1)$$

$$\text{s.t. } x_{hlt} \leq U_{hlt} \quad h = 1, \dots, H \quad l = 1, \dots, L \quad t = 1, \dots, T \quad (4.2)$$

$$\sum_{t=1}^T x_{hlt} \leq 1 \quad h = 1, \dots, H \quad l = 1, \dots, L \quad (4.3)$$

$$\sum_{l=1}^L \sum_{\tau=\max(t-d_l+1,1)}^t x_{hlt} \leq 1 \quad h = 1, \dots, H \quad t = 1, \dots, T \quad (4.4)$$

$$\sum_{h=1}^H x_{hlt} \leq K_l * y_{lt} \quad l = 1, \dots, L \quad t = 1, \dots, T - d_l + 1 \quad (4.5)$$

$$\sum_{l=1}^L \sum_{t=1}^T p_l * x_{hlt} \leq B_h \quad h = 1, \dots, H \quad (4.6)$$

$$x_{hlt} \in \{0,1\} \quad h = 1, \dots, H \quad l = 1, \dots, L \quad t = 1, \dots, T \quad (4.7)$$

$$y_{lt} \in \{0,1\} \quad l = 1, \dots, L \quad t = 1, \dots, T - d_l + 1 \quad (4.8)$$

Each tourist can attend a tour of specific type l at most once throughout the planning horizon, as restricted by constraint (3). A day t of a tourist h can be occupied by at most one tour, which might be a tour starting on day t , or it might start on a day $\tau < t$, and extend until day t , which is when $\tau \geq t - d_l + 1$ for a tour of type l . Inequality (4) poses this restriction on the choice of tour assignments. The tour of type l starting on day t has a capacity of K_l , given that this tour is offered by the tourism company, as constrained by inequality (5). Notice that the tour of type l starting on day t has a duration of d_l and it can be offered no later than $T - d_l + 1$. (6) sets the budget constraint for each tourist. Finally, (7) and (8) indicate that the model is a pure integer programming problem.

The objective function, (1), consists of two parts. The first part $\sum \sum \sum (p_l - c_l) * x_{hlt}$ represents the total profit generated by each individual tourist's participation in a tour. The profit generated by each tourist is calculated as the revenue generated per person on the tour, p_l , minus the variable cost per person, c_l .

The second part of the objective function, $\sum \sum f_l * y_{lt}$ represents the total fixed cost of all the tours decided to be offered on each day.

The goal of the model is to find the optimal allocation of tours to tourists in order to maximize the total profit generated, subject to the constraints (7)-(8) specified in the model.

4.1 Computational Results

Two data sets are generated for computational tests. The first dataset has the types of medical procedures, and respective tours which tourists should not be attending due to medical concerns that might occur due to respective medical procedure attended by the tourist.

For tour data we have generated data that consists of, “Tour day, Daily price, Multiple-day discount, Daily cost, Multiple-day daily cost discount, Fixed cost, Multiple-day fixed cost discount, Capacity”.

The medical procedures that each health tourist has come for have been determined by assigning probability values to each procedure.

The model was solved using Gurobipy python library with 11th Gen Intel(R) Core(TM) i7-11800H CPU @ 2.30GHz. Thread count: 8 physical cores, 16 logical processors, using up to 16 threads.

Planning horizon T is set to 25. The number of different tour types is 8.

Table 4.2: Optimal Values and Computation Times for Instances Solved presents computational results, for various problem sizes with respect to number of tourists in the planning horizon. optimal objectives and respective computation times for each different run with different values of n (number of patients).

Table 4.2: Optimal Values and Computation Times for Instances Solved.

# Tourists	Optimal objective value	Computation time (seconds)
2	6,768.80	0.10
4	16,753.17	1.16

Table 4.2: Continued.

5	24,033.07	3.38
6	36,083.23	7.71
7	45,552.04	9.14
8	45,102.06	42.39
9	52,041	6.82
10	62,065.72	13.99
15	83,438.15	275.98
20	130,690.16	233.82
21	143,832.33	469.66

Table 4.2: Continued.

22	154,159.11	2,499.62
23	149,757.42	311.09
24	144,589.02	525.54
25	213,888.56	1,408.63
26	194,400.92	3,892.92
27	199,097.00	17,987.51
28	208,360.05	16,500.91

Below you can find Figure 4.1 Number of patients vs. Run Time. and Figure 4.2 Number of patients vs. Optimal Solution., which show how the run time of the script changes depending on number of patients; and how optimal solution changes depending on number of patients respectively.

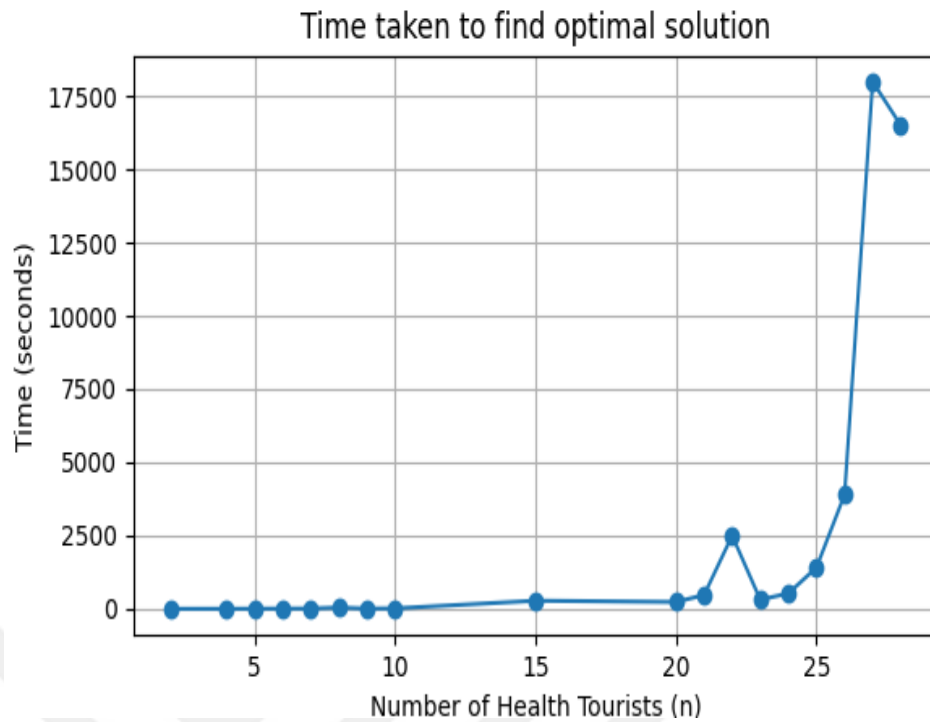


Figure 4.1 Number of patients vs. Run Time.

In Figure 4.1 Number of patients vs. Run Time., we can see that naturally, as number of health tourists increase, in general time taken to find optimal solution also increases. From the big spike around $n=27$ we can see that time taken to find optimal solution has an exponential increase.

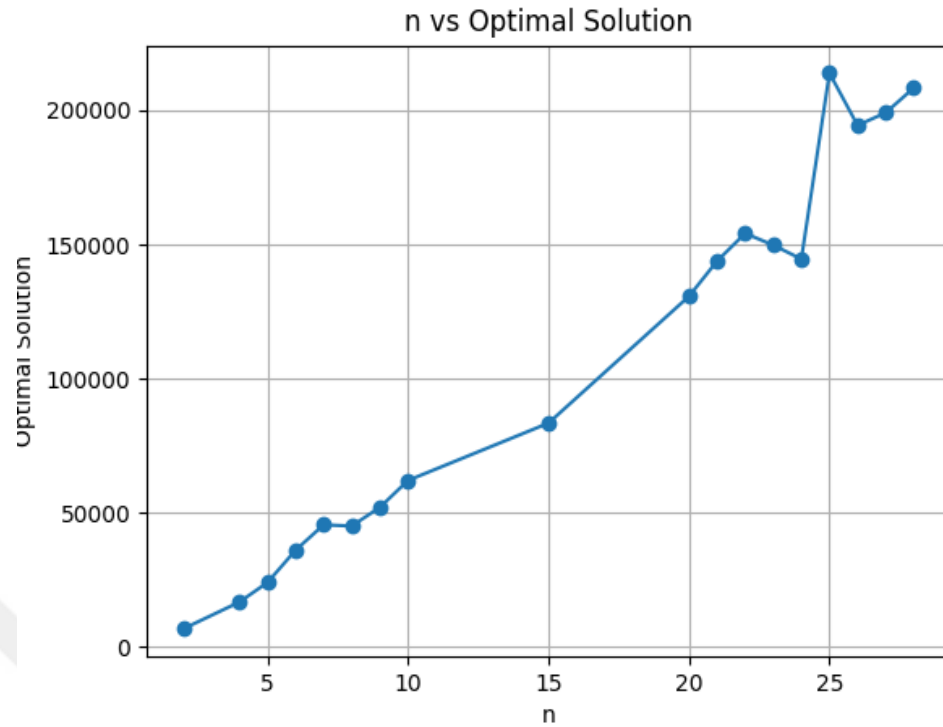


Figure 4.2 Number of patients vs. Optimal Solution.

In Figure 4.2 Number of patients vs. Optimal Solution., we can realize that although as n gets larger naturally the amount of revenue that can be gained increases, depending on restrictions, mainly budget, it might not be always the case.

Around $n=27$, we see a big spike in run time. Although these run times are acceptable, depending on the size of the company, real life cases could get much larger and the problem can become intractable with respect to this approach.

After conducting the computational tests using the Gurobipy Python library to solve our model, the results show that as the number of health tourists increased, the time required to find an optimal solution also increased. Additionally, the optimal objective value, which represents the generated revenue, generally increased with the number of tourists, but this growth was subject to constraints. Notably, a significant spike in runtime was observed around 27 tourists, indicating that the run time has tendencies of exponential increase, and potentially, there could be intractability with larger problem sizes. These findings emphasize the need for efficient algorithms and computational resources when tackling real-life scenarios involving a substantial number of health tourists.

5. CONCLUSION AND FUTURE RESEARCH DIRECTIONS

Our study has successfully addressed the problem of directing health tourists towards additional tourism activities to maximize profits. By formulating the problem as an integer programming model and leveraging a commercial mathematical programming software, we have successfully solved small-sized instances on generated data. The tackled sizes are sufficient for practical problems that can arise in the context of many real tourism companies.

However, as evidenced by the increase in solution times during computational tests, it is clear that more advanced computational approaches are needed to handle larger instances efficiently. Techniques such as branch and cut and heuristic approaches can be explored to improve tractability and solution times. For example, employing a genetic algorithm can effectively handle the large number of constraints, allowing for the optimization of larger problems with longer planning horizon and more medical tourists.

Furthermore, investigating dynamic pricing strategies that dynamically adjust daily prices for different tour types based on demand and capacity utilization can lead to more adaptable and responsive pricing schemes, potentially resulting in increased revenue.

By pursuing these research directions, we can further enhance the efficiency and effectiveness of directing health tourists towards recreational activities. This, in turn, will contribute to improved patient experiences and yield economic benefits for tourism providers.

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BIOGRAPHY

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