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MASTER THESIS



A DECISION SUPPORT SYSTEM FOR CREW PLANNING

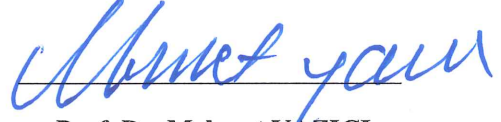
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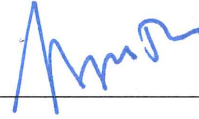
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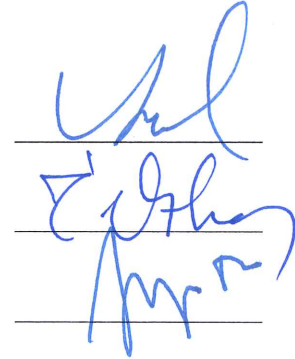
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STATEMENT OF NON PLAGIARISM

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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ABSTRACT
DECISION SUPPORT SYSTEMS FOR CREW PLANNING

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In this research, I aim to address rostering planning problem of an air taxi company. In order to streamline the operations and reduce personnel costs involved, efficient planning has to be carried out.

Planning of crew is a highly complex decision problem involving many factors such as crew specialization, industry regulations, demand and available means of the company.

The aim of the thesis may be to summarize the effective use of Flight Personnel with minimizing fatigue and fulfilling the task at the highest efficiency level. To serve this purpose; an operational research approach will be taken to address the problem and a mathematical programming model will be developed to generate the optimal crew rosters.

Keywords: Air Taxi, General Aviation, Crew Planning, Scheduling, Rostering, Decision Support Systems, Mixed Integer Programming, Modeling

ÖZET
EKİP PLANLAMADA KARAR DESTEK SİSTEMLERİ

TÜRKSEVEN, Mehmet Tankut
İşletme Anabilim Dalı Yüksek Lisans
Tez Danışmanı: Prof. Dr. Ş. Armağan TARIM
Haziran 2018, 49 sayfa

Bu araştırmada, bir hava taksi şirketinin ekip planlama problemi ele alınmıştır. Hava Taksi şirketlerinde, operasyonları düzene koymak ve ilgili personel maliyetlerini azaltmak için efektif planlama yapılmalıdır.

Mürettebatın planlanması, birçok faktörü içeren oldukça karmaşık bir karar problemdir örneğin; mürettebat uzmanlığı, endüstri düzenlemeleri, talep ve şirketin mevcut hava araçları gibi.

Tezin amacı, uçuş personelinin yorgunluğunu en aza indirerek görevi en yüksek verimlilik seviyesinde yerine getirmek ve ilgili personelin etkin kullanımını sağlamaktır. Bu amaca hizmet etmek için; bir yöneylem araştırması yaklaşımı ele alınmış ve optimal ekip kadrolarını oluşturmak için karar destek sistemlerini içeren bir matematiksel programlama modeli geliştirilerek test edilmiştir.

Anahtar kelimeler: Hava Taksi, Genel Havacılık, Mürettebat Planlama, Çizelgeleme, Karar Destek Sistemleri, Karışık Tamsayılı Programlama, Modelleme

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LIST OF ABBREVIATIONS

Aircraft; Any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface.

Air Operator; A person, organization or enterprise engaged in an aircraft operation.

Block time (airplane); The total time from the movement that an aircraft first moves under its own or external power for the purpose of taking off until the movement it comes to rest at the end of the flight.

Block time (helicopter); The total time from the first movement of the rotor blades until the rotor blades come to rest at the end of the flight.

Cockpit crew; Minimum number of pilots and if there is a flight engineer who is licensed by civil aviation authority.

Commander; The pilot designated by the operator to be in command of the aircraft.

Crew planning specialist; Who is responsible to plan, publish, distribute and notify the latest changes of the flight operation plan to the flight crew with the coordination of flight operations managers.

Duty; Any task that a crew member is required to carry out.

Duty time (DT); It is the elapsed time between the preparations briefing of the flight operation and start of the first flight time of entering the aircraft of a single flight or a series of flights.

DGCA; Turkish General Directorate of Civil Aviation

EASA; European Aviation Safety Agency

Flight crew; Flight crew comprise of pilots responsible for navigation and management of the air vehicle, cabin crew responsible for cabin safety and other services and loading crew.

ICAO; International Civil Aviation Organization

Pilot; It is the captain pilot or other pilot or pilots who are certificated and authorized by Turkish DGCA, responsible for navigation and management of an aircraft.

Rest time; It is the time that starts from the end of a flight duty and ends at the beginning of a new flight duty. The flight crew will be exempted from all kinds of duties.

SHT 6A-50; Turkish DGCA flight crew time limitations direction (old legislation).

SHT FTL-HG; New draft crew time limitations legislation which is shared by Turkish DGCA.

Time definitions:

One day; It is the time which starts 00:01 UTC ends 24:00 UTC.

One week; 7 consecutive days.

One month; One calendar month

3 months; Consecutive three calendar months

One year; A calendar year.

UTC; Universal Time Coordinated

CHAPTER ONE

1. INTRODUCTION

Personnel scheduling shows shifting on timelines for employees in a defined period. Crew scheduling can be used for different areas such as hospital personnel, train personnel, drivers, security department personnel and customer care service rostering etc. The rostering process is for assigning a good schedule for each personnel with a good balance. For crew planning, important topics are generally based around saving the most money, but the quality of life of the personnel is also taken into account.

In the aviation sector, companies need effective crew planning for increasing effective use of flight personnel with minimizing fatigue and fulfilling the task at the highest efficiency level. Other sectors can accept flexible crew planning but this can not be accepted by authorities because of the strict safety rules in the aviation sector. There are some differences between the locations but the common need is the same which is assigning duty or off day to each flight personnel for a period according to legislations and firms and personal needs. A flight crew member should not operate an aircraft if she/he knows that she/he is suffering from or is likely to suffer from fatigue or feels unfit, to the extent that the flight may be endangered. Flight crew members should make optimum use of the opportunities and facilities provided to rest and plan and use their rest periods properly. The paramount objective of a flight duty period and flight time limitations, as well as establishing rest periods is that of raising flight safety levels.

Every air taxi and general aviation companies have operation manuals which are approved by the civil aviation authorities. In Turkey, Turkish Directorate General Of Civil Aviation is authorized to confirm airline and air taxi companies operation manuals according to laws, regulations, and rules of Ministry of Transport, Maritime affairs and communications.

In order to do correct crew planning, I need to detect the actual status of aviation companies. For this reason, I will compare airlines' with general aviation and air taxi companies' actual status in this section. While airline companies fly on scheduled flights, air taxi and general aviation companies usually carry out flights according to requested flights. Air taxi and general aviation companies generally plan their flights as not scheduled flights which creates hard crew planning conditions. Air taxi firms do not know when flight request will come for them and they do not want to reject those requests. They should have pilots who are ready to fly for 24 hours and 7 days to not reject flight requests. This situation creates fatigue for flight crews as a result of waiting every day.

The diversity of airlines' aircrafts are less than air taxi companies. This situation only makes it easy crew pairing for airlines but also creates a hard process and lack of economical resource for air taxi companies. Air taxi and general aviation firms' assets and financial facilities are limited, if we compare with airline companies. Developing economic policies and strategies are crucial for companies with insufficient financial resources. The important section of planning is to plan with minimizing cost factor as possible according to the legislations' constraints. The big portion of costs are coming from flight personnel expenses for air taxi firms after the fuel and aircraft costs. The air taxi companies wish to sign contracts with fuel suppliers to decrease their expenses but fuel suppliers do not sell the fuel below standard costs. Because of this reason, air taxi companies wish to increase their profitability by managing staff costs. When we look from this point of view, the right team planning is to provide the best team management for air taxi companies.

In the following section, I will briefly introduce how air taxi companies can effectively plan their crew. They should do their crew planning as using the limits specified by the constraints in the most optimal way. Air taxi companies can increase flight crew efficiency with decision support systems. In detail, crew planning department should plan true schedules for true flight personnel via decision support systems easily with saving time and money. Air taxi companies should do correct crew planning for flight efficiency and safety via decision support system for their different needs. DSS become meaningful because of difficult planning problems which includes human factor. There are complex constraints, variables and needs in air taxi scheduling. For example, each air

taxi company has different workload according to their flight crew number in different fleets and this creates hard conditions to balance their pilots' working conditions. Because of this situation, DSS become meaningful for air taxi and general aviation companies.

In order to have more detailed information about our study, I briefly share the content of the study. In this study, I summarized the personnel scheduling and crew plannings. After that I detected the aviation industry's actual status by comparing airline, air taxi and general aviation companies. I examined crew planning in terms of aviation sector, how legislation and DSS could help team planning. In literature review section, crew planning studies and modelings that have been done so far have been examined in detail. I have witnessed how theoretical work can find effective solutions to real life problems.

Furthermore, in problem description and legislation part, I understood the general terms of aviation and I examined aviation legislations according to location as Turkey and Europe. In more detail, the crew planning legislation in practice with the draft legislation to be passed to new applications and changes in Turkey were examined according to the firms' operation manuals. I defined problems for air taxi companies and evaluated the possible solution alternatives. After this section, valuable inferences about mathematical programming were shared with readers to create a brief review of mathematical programming on readers' mind. In the MIP model chapter, I remembered what is mixed integer programming. I created and optimized our problem's mixed integer problem method via IBM CPLEX optimization studio application according to our decision variables and constraints. I interpreted model that I have optimized for the compatibility of constraints and tested the validity of the solution. After analyzing the validity and efficiency of the optimization process with different numerical examples, I sought to provide guidance on how DSS could be used in future research in different sections.

Air taxi companies need easy solutions for crew scheduling because of their fiscal status and high workload cases. I will try to find a new approach via mixed integer programming by examining global academic reviews and legislations. I wish to model the needed fundamental crew planning and scheduling with mixed integer programming techniques via Decision Support Systems for an air taxi firm. The aim of this study is to examine air taxi companies' crew scheduling problems and support the companies via decision support system for effective scheduling. I hope, this study can create an image

which is to help creating true crew planning for each air taxi and general aviation company according to their needs.



CHAPTER TWO

2. LITERATURE REVIEW

There are different approaches to crew planning problems modelling. Each modelling helps to solve different problems. Table 1 shows the papers that make use categorical modelling approaches. Linear programming used by (Suyabatmaz, A. Ç., & Şahin, G. ,2015), binary non-linear multi-objective optimization examined from (Mesquita, M., Moz, M., Paias, A., Paixão, J., Pato, M., & Respício, A., 2011). One of the studies compared bi-criteria model and the stochastic programming model (Tam, B., Ehrgott, M., Ryan, D., & Zakeri, G.,2011).

Some of the studies used integer programming to solve different rostering problems. (Marsten, R. E., Muller, M. R., & Killion, C. L.,1979) (Desrosiers, J., Lasry, A., McInnis, D., Solomon, M. M., & Soumis, F., 2000) (Sohoni, M. G., Bailey, T. G., Martin, K. G., Carter, H., & Johnson, E. L.,2003) (Yu, G., Pachon, J., Thengvall, B., Chandler, D., & Wilson, A., 2004). (Zeren, B. ,2015). Mixed integer programming will be used in this study according to air taxi companies' needs and constraints.

| <i>Modeling Approaches</i> | <i>Literatures</i> |
|--------------------------------------|---|
| <i>Linear Programming</i> | (Suyabatmaz, A. Ç., & Şahin, G. ,2015) (Mesquita, M., Moz, M., Paias, A., Paixão, J., Pato, M., & Respício, A., 2011) |
| <i>Stochastic Programming</i> | (Tam, B., Ehrgott, M., Ryan, D., & Zakeri, G.,2011) |
| <i>Integer Programming</i> | (Marsten, R. E., Muller, M. R., & Killion, C. L.,1979) (Desrosiers, J., Lasry, A., McInnis, D., Solomon, M. M., & Soumis, F., 2000) (Sohoni, M. G., Bailey, T. G., Martin, K. G., Carter, H., & Johnson, E. L.,2003) (Yu, G., Pachon, J., Thengvall, B., Chandler, D., & Wilson, A., 2004). (Zeren, B. ,2015) |

Table 1: 1 Shows important modeling approaches of literature according to programming types

Personnel scheduling is a general process which can be used in different locations and sectors. If we minimize our scale as crew planning problems, we could focus on the background of the academic studies. There are many companies in different sectors which are using crew planning tools for effective scheduling. While the tool programs are creating, many academic studies and literature emerged in different sectors.

One of the striking study was about crew capacity planning problem in railways improved path based formulation and solution method which is related with linear programming. From their point of view, “We study a tactical level crew capacity planning problem in railways which determines the minimum required crew size in a region while both feasibility and connectivity of schedules are maintained. We present alternative mathematical formulations which depend on network representations of the problem. A path-based formulation in the form of a set-covering problem along with a column-and-

row generation algorithm is proposed. An arc-based formulation of the problem is solved with a commercial linear programming solver. The computational study illustrates the effect of schedule connectivity on crew capacity decisions and shows that arc-based formulation is a viable approach. (...) Our numerical experiments show that the arc-based formulation is capable of solving all real-life cases to optimality within reasonable computational time. On the other hand, CRG algorithm fails to solve even the LP relaxation within reasonable computational time due to convergence problems. Both solution methods are capable of generating integer feasible solutions but arc-based formulation outweighs not only by solution quality but also with respect to computational time. In essence, these two approaches can be considered as competitors or at least alternatives to each other while the literature has given more attention to the path-based formulation for its advantages due to scalability. In this battle for a new version of the problem with schedule connectivity, arc-based formulation seems better off despite lack of attention in earlier studies. From the decision-maker's point of view, the results clearly show that the decisions on regional crew capacities ignoring the connectivity of the schedules might significantly differ from those where connectivity of schedules are integrated into the problem at the planning/pairing phase." (Suyabatmaz, A. Ç., & Şahin, G. ,2015) Also, integrated vehicle-crew rostering problem was studied as linear programming optimization problem. They clarify their study as, "Operational planning within public transit companies has been extensively tackled but still remains a challenging area for operations research models and techniques. This phase of the planning process comprises vehicle scheduling, crew-scheduling and rostering problems. In this paper, a new integer mathematical formulation to describe the integrated vehicle-crew-rostering problem is presented. The method proposed to obtain feasible solutions for this binary non-linear multi-objective optimization problem is a sequential algorithm considered within a preemptive goal programming framework that gives a higher priority to the integrated vehicle-crew-scheduling goal and a lower priority to the driver rostering goals. A heuristic approach is developed where the decision maker can choose from different vehicle-crew schedules and rosters, while respecting as much as possible management's interests and drivers' preferences. An application to real data of a Portuguese bus company shows the influence of vehicle-crew-scheduling optimization on

rostering solutions.” (Mesquita, M., Moz, M., Paias, A., Paixão, J., Pato, M., & Respício, A., 2011). Those studies are important to understand the literature for examining different programming methods in different sectors.

In the aviation sector, crew planning problem studies are started to examine with a successful study which provides a successful application of basic integer programming to the scheduling of flight crews for a cargo airline. With their cue, “This paper presents a successful application of integer programming to the scheduling of flight crews for a cargo airline. The crew planning process is discussed, the role of the set partitioning model is explained, and representative computational experience is reported. The success of this application is shown to rest upon improved problem conceptualization and decomposition rather than on any advances in solution techniques.” (Marsten, R. E., Muller, M. R., & Killion, C. L., 1979).

One of the model related study was telling a story about a charter airline company becoming the biggest charter company in Canada. The study was focused on the aircraft-routing problems, the crew-pairing problems according to bases. The goal of the objective linear function was to minimize costs. We can understand how does the study become effective for real problem optimizing according to their view. “The system helped the airline to streamline planning and scheduling and to focus on its core business and expansion rather than internal operational problems. By reducing the planning cycle, increasing operational flexibility, and supporting marketing, the system helped the company to become the largest charter operator in Canada. ALTITUDE ensures cost-effective solutions by optimizing planning and scheduling problems and allowing easy interfacing among them. It saved the company an estimated eight to 12 percent of total costs during the first year and over a million dollars during the second year in operation.” (Desrosiers, J., Lasry, A., McInnis, D., Solomon, M. M., & Soumis, F., 2000)

In the Beginning of 2000’s Delta Airlines wished to decrease training cost for cockpit crew members and this need created a way to find a solution for training planning of flight crew. “The downturn in airline business after September 11, 2001, forced Delta to reduce its workforce and to modify its requirements for scheduling pilot training. To mitigate Delta’s exposure to costs and to automate the scheduling process under a rigid planning time line, we developed and deployed an automated optimization system,

CQOPT, that builds and assigns training schedules based on individual pilot's requirements. The primary objectives of CQOPT are to minimize overall operating costs and maximize training assignments. Shortly after CQOPT's deployment in May 2002, the planning cycle dropped from several days to a few hours. Delta expects to save \$7.5 million in annual operating costs by using CQOPT to schedule continuing qualification (CQ) training for its pilots." (Sohoni, M. G., Bailey, T. G., Martin, K. G., Carter, H., & Johnson, E. L.,2003)

In United States of America's aviation industry, where high-level competitions are held, airlines started to produce rational solutions to compete with competitors. Continental Airlines have begun to reduce their expenditures and increase their profits by switching to mixed integer modeling systems for scheduling process because the planning stages are composed of processes that most need time and material resources. "Airlines need The Crew Resource Solver decision-support system employs advanced optimization modeling and solution techniques to solve complex, large-scale pilot staffing and training problems at Continental Airlines. The system determines optimal pilot transitions and efficiently allocates and schedules training resources. The results are improved staffing levels and substantial cost savings through reduced staffing, hiring, and training costs. Continental has estimated savings of over \$10 million per year using the system." (Yu, G., Pachon, J., Thengvall, B., Chandler, D., & Wilson, A., 2004).

Another important study compared two different approaches which were bi-criteria model and the stochastic programming model to solve tour of duty planning Problem. In this comparison, they used real crew scheduling and delay datas from Air New Zealand. According to their study, "We improve the algorithm of Yen and Birge (Transp Sci 40:3–14, 2006) and implement both methods with a commercial crew scheduling software. The results of both methods are compared with respect to characteristics of robust solutions, such as the number of aircraft changes for crew. We also conduct experiments to simulate the performance of the obtained solutions. All experiments are performed using actual schedule data from Air New Zealand." (Tam, B., Ehrgott, M., Ryan, D., & Zakeri, G.,2011)

The one of important study separates crew planning as crew pairing and crew rostering. My study and the below study are almost having the same rules for crew

planning because of the same rulemaking authority which is Turkish DGCA. This study is one of the first examples of crew rostering phase. “(...) The crew pairing optimization problem is the main cost-determining phase in the scheduling process. In this phase, optimum sets of crew pairings which are beginning and ending at the home base for the crew are generated to cover all flights in the airline’s timetable. In crew rostering phase, necessary crew assignments are done for optimum crew pairing set which is generated before. In this study, some studies about crew pairing optimization were examined, some existing methods were improved to obtain faster convergence rate and the existence of multiple crew base was simulated for the solution of the problem using genetic algorithms. As it can be seen from the results, convergence rate was increased and more robust results were obtained through the perturbation operator we used. This study is also an initial study for the crew rostering phase which is the second phase of the crew scheduling. Because the success of the crew rostering phase completely depends on the quality of results of crew pairing phase.” (Zeren, B. ,2015)

As we can understand from literature review section, there are many examples about crew planning in different sectors. Modeling processes are completed with different modelling types such as linear programming, stochastic programming and integer programming. Crew planning studies and modelings that have been done so far have been examined in detail. We have witnessed how theoretical work can find effective solutions to real life problems. Airlines and air cargo companies solved their problems via mathematical programming and the same firms make profits as millions of dollars from their losses by not continuing to spend on wrong crew planning.

In order to streamline the operations and reduce personnel costs involved, efficient planning has to be carried out. As you know, crew scheduling is a highly complex decision problem involving many factors such as crew specialization, industry regulations, demand and available means of the company. I wish to direct air taxi and general aviation companies to the right crew planning by similar methods as literature review section examples. How is it? I created and optimized problem’s mixed integer problem method via IBM CPLEX optimization studio application according to our decision variables and constraints.

CHAPTER THREE

3. PROBLEM DESCRIPTION & LEGISLATION

3.1. General Terms and Definitions

The paramount objective of a flight duty period and flight time limitations, as well as establishing rest periods is that of raising flight safety levels. Air taxi and general aviation companies adhere the rules of civil aviation authorities which is stated in their country. There are many different legislations in the civil aviation sector, the EASA (European Aviation Safety Agency) is the leader of the world due to applicable rules and standards. Flight and duty time limitations and rest requirements document specifies the requirements to be met by an operator and its crew members with regard to flight and duty time limitations and rest requirements for crew members by EASA. We should check the definitions as below to have a clear idea about crew planning for an air taxi business.

3.2. Legislations

In Turkey, Turkish Directorate General Of Civil Aviation wishes to comply with the EASA and ICAO rules on flight and duty time limitations and rest requirements in accordance with the European Union's compliance requirements. Because of this situation, SHT 6A.50 regulation is removed by Turkish DGCA for general aviation and air taxi companies.

The companies will transition gradually to the SHT FTL HG regulation after the draft work is finished. For now, general aviation and air taxi companies should follow their operation manuals' flight crew composition sections which are approved by Turkish DGCA. After 2019, companies will transition gradually to the SHT FTL HG regulation

according to Turkish DGCA revision updates. I will examine to Turkish regulations to understand crew planning rules and details.

3.2.1. Sht.6a.50 (Removed from enforcement by Turkish DGCA)

I will briefly examine Sht.6a.50 regulation's the main limitations.

Maximum flight time limitations:

| Limitations | One Day | One Week | One Month | 3 Months | One Year |
|-------------------------------------|---------|----------|-----------|----------|----------|
| Airplane Limitations (Single Pilot) | 8 hrs | N/A | 110 hrs | 300 hrs | 1000 hrs |
| Airplane Limitations (Multi Pilot) | 10 hrs | N/A | 110 hrs | 300 hrs | 1000 hrs |
| Helicopter Limitations | 6 hrs | N/A | 110 hrs | 300 hrs | 1000 hrs |

Table 2: 1 Maximum flight time limitations

Flight time means the time period of between take-off and landing time for flight personnel. The tables of 2, 3, 4 are given in the SHT instruction as follows [1].

Maximum duty time limitations:

Duty time means the time period of between block times (engine starting and switch off time) plus briefing and debriefing time. If i wish to calculate duty time, I should calculate differences between $DT = (ON\ BLOCK - OFF\ BLOCK) + \text{briefing and debriefing time}$.

| Limitations | One Day | One Week | One Month | 3 Months | One Year |
|---|----------------|-----------------|------------------|-----------------|-----------------|
| Airplane Limitations (Single Pilot) | 10 hrs | 60 hrs | N/A | N/A | N/A |
| Airplane Limitations (Multi Pilot) | 12 hrs | 60 hrs | N/A | N/A | N/A |
| Helicopter Limitations | 10 hrs | 60 hrs | N/A | N/A | N/A |

Table 3: 1 Maximum duty time limitations

Flight crew rostering / Off days limitations:

Crew resting time and free time other than rest time cannot be accumulated shown on this table. There should be a balance between crew rest time and duty time. Weekly 1 Day crew rest time can be added to monthly rest time. This period includes the day after the end of the duty time. Every last day of the months as the latest, all air taxi companies should share their crew planning roster about next month with their flight crews according to legislations which is shared by Turkish Civil Aviation Authority.

| Period | One week | One Month | 3 Months | One Year |
|-----------------|-----------------|-----------------------|-----------------|-----------------|
| Duration | 1 Day | 7 Days (2+2+1+1+1) | 21 Days | 96 Days |

Table 4: 1 Flight crew rostering / Off days limitations

A crew member shall not operate an aircraft if he/she knows that he/she is suffering from or is likely to suffer from fatigue or feels unfit, to the extent that the flight may be endangered.

Crew members should make optimum use of the opportunities and facilities to rest provided and plan and use their rest periods properly. Crew members should make

optimum use of the opportunities and facilities to rest provided and plan and use their rest periods. The rest period of a crew member immediately after a flight duty period will not start before finishing all the duties assigned by the operator. The minimum daily rest period for airplane crew is 8 hours for 8 hours of flight, 10 hours for 9 hours of flight and 11 hours for 10 hours of flight. The minimum daily rest period for helicopter crew is 8 hours and it shall not be less than two times of flight time in any case. Minimum rest periods may be extended to 11 hours for the emergency medical operations on multi-pilot airplanes according to the crew planning and duties are given.

3.2.2. Sht fl hg (draft instruction by Turkish DGCA)

The purpose of this instruction is to establish the principles and procedures for restricting flight and mission limits and resting requirements for flight crews and air taxi companies in order to ensure flight safety and to regulate activities in this respect.

The Instruction has been prepared based on the Turkish Civil Aviation Law No. 2920, Law No. 5431 on the Organization and Duties of the General Directorate of Civil Aviation, and the Regulation on Commercial Air Transportation Operations (SHY6A). In addition, while this introduction was being drafted, the international regulation 83/2014 published by the European Commission was based on the requirements laid down in the guidance documents issued by the European Aviation Safety Agency (EASA).

In general addition, air taxi companies must use softwares and crew planning tools that meet the requirements of this directive. The necessary measures will be taken to ensure that the Turkish DGCA will access all reports and details about crew plannings and rosters via the software. Flight time, duty time and rest limitations are generally same with SHT.6A.50 regulation but new regulation is more complicated and detailed. The most important change that comes with the new instruction is the “acclimatised” definition. Duty time calculation has new constraints as time differences between take-off and landing aerodromes.

This Instruction is effective as of 01.01.2017 following its publication and the transition period is planned to be completed by 01.01.2019. Air taxi and general aviation

firms will transition gradually to the SHT FTL HG regulation according to Turkish DGCA revision updates.

| Time Differences (hours) | Time period since reference duty starting time | | | | |
|-----------------------------|--|------------|------------|-------------|----------|
| | < 48:00 | 48 - 71:59 | 72 - 95:59 | 96 - 119:59 | ≥ 120:00 |
| 2 < ... < 4 | B | D | D | D | D |
| 4 ≤ ... ≤ 6 | B | X | D | D | D |
| 6 < ... ≤ 9 | B | X | X | D | D |
| 9 < ... ≤ 12 | B | X | X | X | D |

| | |
|---|--|
| B | Acclimatised to the local time of the first departure of airport |
| D | Acclimatised to the local time of the next departure of airport |
| X | Acclimatised to unknown |

Time Differences: First airport between next airport

Example

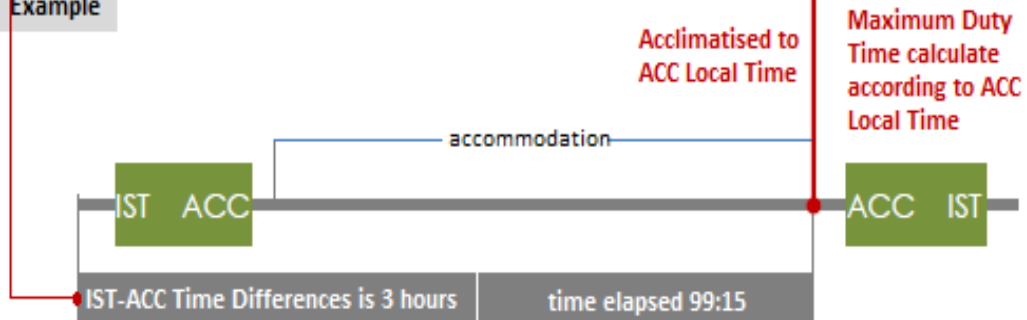


Table 5: 1 Sht Ftl Hg (Draft Instructions) are given in the SHT instruction as follows [2]

Acc is one of Ghana airports where time difference is 3 hours between Istanbul (IST) and Kotoka (ACC) International airports. Pilots' duty time should calculate according to the first row on table 5 because of time differentiation category and time elapsed status. The acclimatization definition, which comes with the new instruction, is used to calculate

the reference “Duty Starting Time” used to determine the “Maximum Duty time limitations”. Safety will increase on intercontinental flights because of acclimatized limitations. The limitations acclimatize the flight crew to reduce their body fatigue which consists of time differentiation as you can see in Table 5. Maximum Duty starting time should be calculated according to time differences.

3.3. Problem Description

In aviation, the rules are written in blood. Aviation organizations have set rules to prevent the above mentioned problems. If the related requirements are not met, companies are punished. As a result of wrong team planning, many accidents have occurred to this day. Civil aviation authorities inspections are carried out to ensure the necessary conditions.

Crew planning is generally done for the future, but this process is difficult for air taxi companies because of not scheduled flights, so it is usually done by revising crew plannings and rosters according to the flights. This situation creates fatigue as a result of waiting for flight crews every day. There is a risk of lowering the level of flight safety in these situations. Air taxi companies should do correct crew planning for flight efficiency and safety.

Each air taxi company has different workload according to their flight crew number in different fleets. Because of this situation, air taxi companies should increase flight crew efficiency with rosters. They should satisfy their needs with setting their own constraints according to legislations. Such as time limitations, flying rules, pilots performance efficiency, age etc. Decision support systems are important for the correct scheduling.

In this section, I will examine problem as detailed. True problem description is half of the solution. In order to define the problem correctly, I made interviews with different air taxi companies crew planning departments. After that, I get one of the air taxi firm's problem as my problem and started to work for my study.

Their general problem was to create the crew planning. As you know, it is a time-consuming task to make crew planning for air taxi and general aviation companies. In scheduling, manual planning is usually done or cheap or free tool programs such as MS

Excel are used by air taxi companies but these tools programs are not effective or useful for air taxi and general aviation firms needs. To create effective and useful scheduling and crew planning tools, they will need mathematical model according to their needs and legislations' constraints. To create a model, I should define the problem as detailed as follows. Firstly, I need to define their pilots actual status, modes and the period which they wish to do crew planning. The air taxi company has 6 pilots for one aircraft in their crew. For the pilots' modes, air taxi companies defined two modes which are ON and OFF. In ON mode, pilots can work at the office, they can fly and they can be in training. In OFF mode, pilots should be in rest.

When I asked the right crew planning period to crew planning department, they expressed they have not got scheduled flight. Weekly crew planning is not varied as much as monthly crew planning. Because of this situation, weekly crew planning can be more efficient for their need. So I decided to do crew planning for weekly. That means our period will be for 7 days. To make the modeling and optimizing easier, I set the minimum time interval to hourly. (it can be changed but optimization take more time.) Finally, our period becomes 7 days multiply 24 hours which will be equal to 168 periods.

| Pilot's Name | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday | Sunday |
|--------------|--------|---------|-----------|----------|--------|----------|--------|
| 1st Pilot | ON | ON | ON | ON | ON | ON | OFF |
| 2nd Pilot | OFF | ON | ON | ON | ON | ON | ON |
| 3rd Pilot | ON | OFF | ON | ON | ON | ON | ON |
| 4th Pilot | ON | ON | OFF | ON | ON | ON | ON |
| 5th Pilot | ON | ON | ON | OFF | ON | ON | ON |
| 6th Pilot | ON | ON | ON | ON | OFF | ON | ON |

Figure 1: 1 Example of weekly crew planning of an air taxi company

As we know, air taxi and general aviation companies do not have scheduled flights and they do not want to miss out on the requested flights because their financial situations are not as good as the airline companies. If a flight requested out of schedule, air taxi companies should decide which pilot can get the duty. So, they should know pilots status for the last 24 hours. That means, I will need to examine pilots' status in the last 24 hours

for each period to decide future planning. Because of this reason, I formulated the situation for each pilot in the previous 24 hours for each period. I should track each pilot for each period. Their crew planning can vary according to flight requesting but they wish to have 2 pilots to be ready to fly to 7/24 for not missing any flight requests.

When I slowly began to form a model in my minds, I needed some detailed information. Secondly, I started to argue their objective function, constraints and decision variables. My objective is to find a feasible solution for the crew planning; so our problem is not an optimization problem but a satisfiability problem, however any convenient objective function can be added to the problem without any complication.

According to the air taxi companies needs, operation manuals and legislations, each pilot must be either defined in every mode and every period. For example, when I asked for 3rd pilot's status in the second day, I should clarify his mode. Pilots can work as 10 hours in a day and they should rest one day in a week according to the legislation.

I defined an air taxi company problem as finding a feasible solution for crew planning for 6 pilots in 168 periods with 2 modes. I started modeling our problem with meaningful limitations. I wish to model the needed fundamental crew planning and scheduling with mixed integer programming techniques via decision support systems. You can examine the modeling details on section 5, The MIP Model

CHAPTER FOUR

4. AN OVERVIEW OF MATHEMATICAL PROGRAMMING

4.1. Mathematical Programming Types

Mathematical programming types divided according to human decision maker functions in modeling process by (Bradley, S., Hax, A., & Magnanti, T., 1977) as operational exercise, gaming, simulation and analytical model.

“The first model type is an operational exercise. This modeling approach operates directly with the real environment in which the decision under study is going to take place. The modeling effort merely involves designing a set of experiments to be conducted in that environment, and measuring and interpreting the results of those experiment.

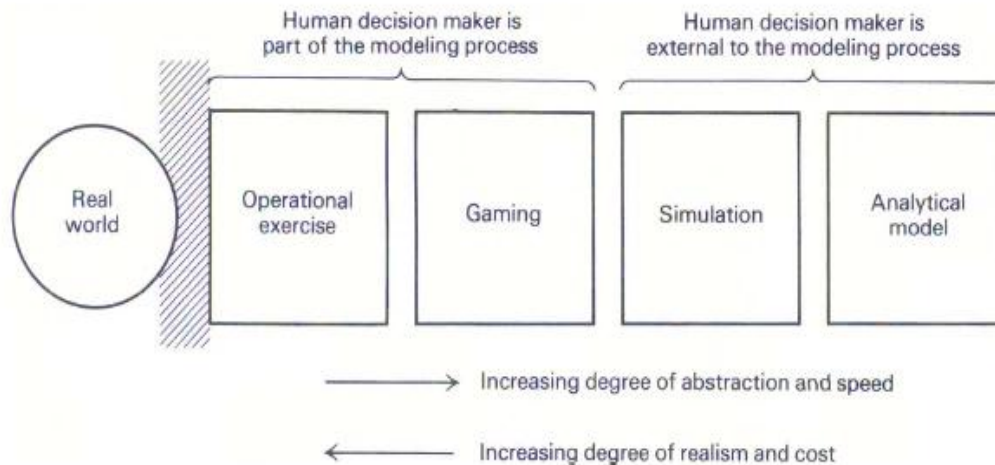


Figure 2: 1 Mathematical Programming Types, It has been quoted from (Bradley, S., Hax, A., & Magnanti, T., 1977)

The second type of model in this classification is gaming. In this case, a model is constructed that is an abstract and simplified representation of the real environment. This model provides a responsive mechanism to evaluate the effectiveness of proposed alternatives, which the decision-maker must supply in an organized and sequential fashion.

The model is simply a device that allows the decision-maker to test the performance of the various alternatives that seem worthwhile to pursue. In addition, in a gaming situation, all the human interactions that affect the decision environment are allowed to participate actively by providing the inputs they usually are responsible for in the actual realization of their activities.

Simulation models are similar to gaming models except that all human decision-makers are removed from the modeling process. The model provides the means to evaluate the performance of a number of alternatives, supplied externally to the model by the decision-maker, without allowing for human interactions at intermediate stages of the model computation. Like operational exercises and gaming, simulation models neither generate alternatives nor produce an optimum answer to the decision under study.

These types of models are inductive and empirical in nature; they are useful only to assess the performance of alternatives identified previously by the decision-maker.

Finally, the fourth model category proposed in this framework is the analytical model. In this type of model, the problem is represented completely in mathematical terms, normally by means of a criterion or objective, which we seek to maximize or minimize, subject to a set of mathematical constraints that portray the conditions under which the decisions have to be made.

The model computes an optimal solution, that is, one that satisfies all the constraints and gives the best possible value of the objective function. Analytical models are normally the least expensive and easiest models to develop. However, they introduce the highest degree of simplification in the model representation.” (Bradley, S., Hax, A., & Magnanti, T., 1977)

4.2. The Main Features of Mathematical Programming

In analytical modeling, the main features of mathematical programming are problem defining, modeling and optimum solution. There are some essential steps between the features. In this section, I will examine not only the big picture but also details.

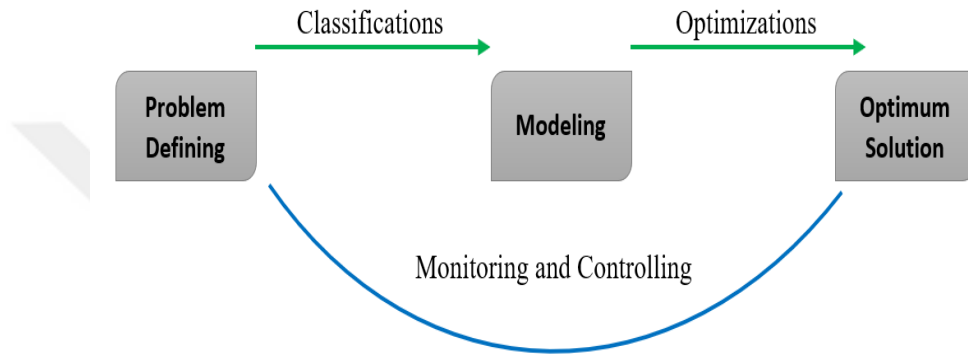


Figure 3: 1 The main features of the Mathematical Programming

I must define our problem as close as possible to real life clearly. I should classify the problem steps to have detailed and effective modeling. In modeling section, I must clarify the objective function(s), decision variables and constraints. There are some important steps to build effective models. Those indispensable model steps are defined as seven step model building procedure as below: “When operations research is used to solve an organization’s problem, the following seven step model-building procedure should be followed:

Step 1: Formulate the Problem, The operations researcher first defines the organization’s problem. Defining the problem includes specifying the organization’s objectives and the parts of the organization that must be studied before the problem can be solved.

Step 2: Observe the System Next, the operations researcher collects data to estimate the value of parameters that affect the organization’s problem. These estimates are used to develop (in step 3) and evaluate (in step 4) a mathematical model of the organization’s problem.

Step 3: Formulate a Mathematical Model of the Problem, In this step, the operations researcher develops a mathematical model of the problem.

Step 4: Verify the Model and Use the Model for Prediction, The operations researcher now tries to determine if the mathematical model developed in step 3 is an accurate representation of reality.

Step 5: Select a Suitable Alternative, Given a model and a set of alternatives, the operations researcher now chooses the alternative that best meets the organization's objectives.

Step 6: Present the Results and Conclusion of the Study to the Organization In this step, the operations researcher presents the model and recommendation from step 5 to the decision making individual or group. In some situations, one might present several alternatives and let the organization choose the one that best meets its needs. After presenting the results of the operations research study, the analyst may find that the organization does not approve of the recommendation. This may result from incorrect definition of the organization's problems or from failure to involve the decision maker from the start of the project. In this case, the operations researcher should return to step 1, 2, or 3.

Step 7: Implement and Evaluate Recommendations, If the organization has accepted the study, then the analyst aids in implementing the recommendations. The system must be constantly monitored (and updated dynamically as the environment changes) to ensure that the recommendations enable the organization to meet its objectives.” (Winston, W. L., & Goldberg, J. B., 2004)

After model building process completed, we should optimize (minimize or maximize) our model and try to reach optimal solution for our modeling via optimizer tools such as CPLEX. Monitoring and controlling process is an opportunity to develop or refine the model. If we did not satisfy from optimal solution, we can start from the beginning and improve effectiveness of mathematical programming.

4.3. The Species of Models

Species of models are shown as four different topics in operations research as static and dynamic models, linear and nonlinear models, integer and noninteger models, deterministic and stochastic models. “A static model is one in which the decision variables do not involve sequences of decisions over multiple periods. A dynamic model is a model in which the decision variables do involve sequences of decisions over multiple periods. Basically, in a static model we solve a “one-shot” problem whose solutions prescribe optimal values of decision variables at all points in time. Suppose that whenever decision variables appear in the objective function and in the constraints of an optimization model, the decision variables are always multiplied by constants and added together. Such a model is a linear model. If an optimization model is not linear, then it is a nonlinear model. If one or more decision variables must be integer, then we say that an optimization model is an integer model. If all the decision variables are free to assume fractional values, then the optimization model is a noninteger model. Integer models are much harder to solve than nonlinear models. Suppose that for any value of the decision variables, the value of the objective function and whether or not the constraints are satisfied is known with certainty. We then have a deterministic model. If this is not the case, then we have a stochastic model.” (Winston, W. L., & Goldberg, J. B., 2004)

4.4. General Terms of Mathematical Programming

Mathematical programming is the optimization of mathematical models in decision making process. Mathematical programming is one of the operation research techniques and optimizing software is run in order to get the best solution to the models.

“Operations research (often referred to as management science) is simply a scientific approach to decision making that seeks to best design and operate a system, usually under conditions requiring the allocation of scarce resources. The scientific approach to decision making usually involves the use of one or more mathematical models. A mathematical model is a mathematical representation of an actual situation that

may be used to make better decisions or simply to understand the actual situation better. (...) The components of a model should include, objective function, decision variables and constraints. An optimization model seeks to find values of the decision variables that optimize (maximize or minimize) an objective function among the set of all values for the decision variables that satisfy the given constraints. (...)

The objective function

In most models, there will be a function we wish to maximize or minimize. This function is called the model's objective function. (...)

The decision variables

The variables whose values are under our control and influence the performance of the system are called decision variables. (...)

Constraints

In most situations, only certain values of decision variables are possible” (Winston, W. L., & Goldberg, J. B., 2004)

Linear programming

“Linear programming (LP) is a tool for solving optimization problems. In 1947, George Dantzig developed an efficient method, the simplex algorithm, for solving linear programming problems (also called LP). Since the development of the simplex algorithm, LP has been used to solve optimization problems in industries as diverse as banking, education, forestry, petroleum, and trucking. In a survey of Fortune 500 firms, 85% of the respondents said they had used linear programming.

A **linear programming** problem (LP) is an optimization problem for which we do the following:

- 1) We attempt to maximize (or minimize) a linear function of the decision variables. The function that is to be maximized or minimized is called the objective function.
- 2) The values of the decision variables must satisfy a set of constraints. Each constraint must be a linear equation or linear inequality.
- 3) A sign restriction is associated with each variable. For any variable x_i , the sign restriction specifies that x_i must be either nonnegative ($x_1 \geq 0$) or unrestricted in sign (urs).” (Winston, W. L., & Goldberg, J. B., 2004)

“Specifically, the linear programming problem can be described as finding the values of n decision variables, x_1, x_2, \dots, x_n such that they maximize the objective function z where

$$Z = c_1x_1 + c_2x_2 + \dots + c_nx_n,$$

Subject to the following constraints:

$$a_{11}x_1 + a_{12}x_2 + \dots + a_{1n}x_n \leq b_1,$$

$$a_{21}x_1 + a_{22}x_2 + \dots + a_{2n}x_n \leq b_2,$$

$$\vdots \qquad \qquad \qquad \vdots$$

$$a_{m1}x_1 + a_{m2}x_2 + \dots + a_{mn}x_n \leq b_m,$$

and, usually,

$$x_1 \geq 0, x_2 \geq 0, \dots, x_n \geq 0, ”$$

“Where c_j , a_{ij} , and b_i are given constants. It is easy to provide an immediate interpretation to the general linear-programming problem just stated in terms of a production problem. For instance, we could assume that, in a given production facility, there are n possible products we may manufacture; for each of these we want to determine the level of production which we shall designate by x_1, x_2, \dots, x_n .

In addition, these products compete for m limited resources, which could be manpower availability, machine capacities, product demand, working capital, and so forth, and are designated by b_1, b_2, \dots, b_m . Let a_{ij} be the amount of resource i required by product j and let c_j be the unit profit of product j .

Then the linear-programming model seeks to determine the production quantity of each product in such a way as to maximize the total resulting profit z , given that the available resources should not be exceeded, and that we can produce only *positive* or *zero* amounts of each product. Linear programming is not restricted to the structure of the problem presented above. First, it is perfectly possible to minimize, rather than maximize, the objective function.

In addition, “greater than or equal to” or “equal to” constraints can be handled simultaneously with the “less than or equal to” constraints presented in constraints.

Finally, some of the variables may assume both positive and negative values. There is some technical terminology associated with mathematical programming, informally introduced in the previous section, which we will now define in more precise terms. Values of the decision variables x_1, x_2, \dots, x_n that satisfy all the constraints of and simultaneously are said to form a *feasible solution* to the linear programming problem.

The set of *all* values of the decision variables characterized by constraints and form the *feasible region* of the problem under consideration.

The general ***nonlinear programming*** model can be stated as finding the values of the decision variables x_1, x_2, \dots, x_n that maximize the objective function z where

$$z = f_0(x_1, x_2, \dots, x_n)$$

subject to the following constraints:

$$f_1(x_1, x_2, \dots, x_n) \leq b_1,$$

$$f_2(x_1, x_2, \dots, x_n) \leq b_2,$$

⋮

$$f_m(x_1, x_2, \dots, x_n) \leq b_m,$$

and sometimes,

$$x_1 \geq 0, x_2 \geq 0, \dots, x_n \geq 0$$

Often in nonlinear programming, the righthand-side values are included in the definition of the function $f_i(x_1, x_2, \dots, x_n)$, leaving the righthand side zero. In order to solve a nonlinear programming problem, some assumptions must be made about the shape and behavior of the functions involved. We will leave the specifics of these assumptions until later. Suffice it to say that the nonlinear functions must be rather well-behaved in order to have computationally efficient means of finding a solution.” (Bradley, S., Hax, A., & Magnanti, T., 1977)

Mixed integer programming

The basic feature of the mixed integer problem is the name given to model programs that contains both binary variables and integer variables.

“An IP in which all variables are required to be integers is called a **pure integer programming problem**. For example,

$$\begin{aligned} \max z &= 3x_1 + 2x_2 \\ \text{s.t. } x_1 + x_2 &\leq 6 \\ x_1, x_2 &\geq 0, x_1, x_2 \text{ integer} \end{aligned}$$

is a pure integer programming problem.

An IP in which only some of the variables are required to be integers is called a **mixed integer programming problem**. For example,

$$\begin{aligned} \max z &= 3x_1 + 2x_2 \\ \text{s.t. } x_1 + x_2 &\leq 6 \\ x_1, x_2 &\geq 0, x_1 \text{ integer} \end{aligned}$$

is a mixed integer programming problem (x_2 is not required to be an integer). An integer programming problem in which all the variables must equal 0 or 1 is called a 0–1 IP.

The concept of LP relaxation of an integer programming problem plays a key role in the solution of IPs.

The LP obtained by omitting all integer or 0–1 constraints on variables is called the LP relaxation of the IP.” (Winston, W. L., & Goldberg, J. B., 2004)

There are two common methods to solve integer programming models which are branch-and-bound and cutting planes techniques.

The Branch-and-Bound method

“B&B recursively divides the feasible set of a problem into disjoint subsets, organized in a tree structure, where each node represents a subproblem that searches only the subset at that node. If computing bounds on a subproblem does not rule out the possibility that its subset contains the optimal solution, the subset can be further partitioned (“branched”) as needed. A crucial question in B&B is how to specify the order in which nodes are considered. An effective node ordering strategy guides the search to promising areas in the tree and improves the chance of quickly finding a good incumbent solution, which can be used to rule out other nodes. Unfortunately, no theoretically guaranteed general solution for node ordering is currently known.” (He, H., Daume III, H., & Eisner, J. M., 2014).

“In practice, most IPs are solved by using the technique of branch-and-bound. Branch-and-bound methods find the optimal solution to an IP by efficiently enumerating the points in a subproblem’s feasible region. Before explaining how branch-and-bound works, we need to make the following elementary but important observation: If you solve the LP relaxation of a pure IP and obtain a solution in which all variables are integers, then the optimal solution to the LP relaxation is also the optimal solution to the IP. Also, for a solution to a subproblem to be a candidate solution, it need only assign integer values to those variables that are required to be integers.” (Winston, W. L., & Goldberg, J. B., 2004)

Cutting Planes Algorithm method

“Modern branch-and-cut methods for (mixed or pure) Integer Linear Programs are heavily based on general-purpose cutting planes such as Gomory cuts, that are used to reduce the number of branching nodes needed to reach optimality. On the other hand, pure cutting plane methods based on Gomory cuts alone are typically not used in practice, due to their poor convergence properties.” (Zanette, A., Fischetti, M., & Balas, E., 2008)

If we wish to have detailed idea about Cutting Planes Algorithm, we should examine 3 steps of Cutting Planes Algorithm as below.

“Step 1 Find the optimal tableau for the IP’s linear programming relaxation. If all variables in the optimal solution assume integer values, then we have found an optimal solution to the IP; otherwise, proceed to step 2.

Step 2 Pick a constraint in the LP relaxation optimal tableau whose right-hand side has the fractional part closest to $\frac{1}{2}$. This constraint will be used to generate a cut.

Step 2a For the constraint identified in step 2, write its right-hand side and each variables’s coefficient in the form $[x] + f$, where $0 \leq f < 1$.

Step 2b Rewrite the constraint used to generate the cut as

All terms with integer coefficients = all terms with fractional coefficients

Then the cut is

$$\text{All terms with fractional coefficients} \leq 0$$

Step 3 Use the dual simplex to find the optimal solution to the LP relaxation, with the cut as an additional constraint. If all variables assume integer values in the optimal solution, we have found an optimal solution to the IP. Otherwise, pick the constraint with the most fractional right-hand side and use it to generate another cut, which is added to the tableau. We continue this process until we obtain a solution in which all variables are integers. This will be an optimal solution to the IP.” (Winston, W. L., & Goldberg, J. B., 2004)

CHAPTER FIVE

5. THE MIP MODEL

5.1. Problem Definition

The air taxi company needs to create scheduling for their pilots with minimizing fatigue and fulfilling the task at the highest efficiency level. To serve this purpose an operational research approach will be taken to address the problem and a mixed integer programming model will be developed to generate optimal crew rosters with Decision Support System. In this section, I will examine problem as detailed. True problem description is half of the solution. Because of defining the problem correctly, I made interviews with different air taxi companies crew planning departments. After that, I get one of the air taxi firm's problem as our problem and started to work for our study.

Their general problem was to create the crew planning. As you know, it is a time-consuming task to make crew planning in air taxi and general aviation companies. In scheduling, manual planning is usually done with cheap or free tool programs such as MS Excel which are used by air taxi companies but these tools programs are not effective or useful for Air taxi and general aviation firms needs.

To create effective and useful scheduling and crew planning tools, they will need mathematical model according to their needs and legislations' constraints. To create a model, I should define the problem as detailed as follows.

Firstly, I need to define their pilots actual status, modes and the period which they wish to do crew planning.

The air taxi company has 6 pilots for one aircraft in their crew. For the pilots' modes, air taxi company defined two modes which are ON and OFF. In ON mode, pilots can work at the office, they can fly and they can be in training. In OFF mode, pilots should be in rest.

When I asked the right crew planning period to crew planning department, they expressed they have not got scheduled flight. Weekly crew planning is not varied as much as monthly crew planning. Because of this situation, weekly crew planning can be more efficient for their need. So I decided to do crew planning for weekly. That means our period will be for 7 days. To make the modeling easier, I set the minimum time interval to hourly. (it can be change but optimization take more time.) Finally, our period becomes 7 multiply 24 hours which will be equal to 168. As we know, air taxi and general aviation companies do not have scheduled flights and they do not want to miss out on the requested flights because their economic situations are not as good as the airlines. If the not scheduled flight requested, air taxi companies should decide which pilot can get the duty. So, they should know pilots status in last 24 hours. That means, I will need to examine pilots' status in the last 24 hours for each period to decide future planning. Because of this reason, I formulated the situation for each pilot in the previous 24 hours for each period. I should track each pilot for each period. Their crew planning can vary according to flight requesting but they wish to have 2 pilots to ready to fly to 7/24 for not missing to flight requests.

When I slowly began to form a model in our minds, I needed some detailed information. Secondly, I started to argue their objective function, constraints and decision variables. Our objective is to find a feasible solution for the crew planning; so our problem is not an optimization problem but a satisfiability problem, however any convenient objective function can be added to the problem without any complication. According to the air taxi companies needs, operation manuals and legislations, each pilot must be either defined in every mode and every period. For example, when I asked for 3rd pilot's status in the second day, I should clarify his mode. Pilots can work as 10 hours in a day and they should rest one day in a week according to the legislation. I defined an air taxi company problem as finding feasible solution for crew planning for 6 pilots in 168 periods with 2 modes. I started modeling our problem with meaningful limitations.

The air taxi company has one type of pilot. They need to create crew planning as weekly because of not scheduled flights and they have 6 pilots for 1 aircraft type. By setting the optimal rest days, each pilot was given a 1 day holiday, and all pilots were working on the 3rd day. (In this way, because it is 6 pilots in the 7 days working period)

P= Number of pilots, We have 6 pilots for the sample problem.

M= Mode of pilots, There are two modes which are ON and OFF. ON means flight crew are on their duty time. OFF means flight crew are on their rest time.

T= Time period, There are 24 hours in a day. I wish to create crew planning for a week. I decided to choose hourly period for easy calculation process. 168 period (as hourly for a week = 7*24) will be used on the calculations.

X= Shows pilots actual status according to P, T, M

K= Shows pilots actual status for 24 hours before for each period

Max_air= Maximum time on the air, I can call it as duty time for the problem.

Rest= It is the time that starts from the end of a flight duty and ends at the beginning of a new flight duty. The flight crew will be exempted from all kinds of duties in their rest time.

5.2. Decision Variables

Each pilot must be either defined in every mode and every period. For example, when we asked for 5th pilot's status in the second day, we should clarify his mode.

$$\text{minimize } \sum_{k=0}^1 X_{p,m,t}$$

I formulated the situation for each pilot in the previous 24 hours for each period as follows.

$$\text{minimize } \sum_{k=0}^1 K_{p,t}$$

5.3. Objective Function

Our objective is to find a feasible solution; so our problem is not an optimization problem but a satisfiability problem, however any convenient objective function can be added to the problem without any complication. I don't need to minimize or maximize

pilots number at this level. Modeling will be complex enough for the scheduling. Creating feasible solution took 16 minutes for 6 pilots, 2 modes and 168 periods. (may be proportional to processor speed)

5.4. Constraints

A pilot should only be in one mode at a given time.

$$\sum_{m=1}^{M=2} X_{p,m,t} = 1 \quad \forall p \in \{1, \dots, 6\}, \forall t \in \{2, \dots, 168\}$$

If the pilot is in the air in the previous hour and then in the following hour, then $K = 1$

$$X_{p,1,t-1} + X_{p,2,t} \leq K_{p,t} \quad \forall p \in \{1, \dots, 6\}, \forall t \in \{2, \dots, 168\}$$

Keep tracking of how much of each pilot's total time in the previous 24 hours for each hour in 'tot_air'

$$k > 0$$

$$\sum_k^{t-24 \dots t-1} X_{p,1,k} = \text{tot}_{\text{air } p,t}, \quad \forall p \in \{1, \dots, 6\}$$

Pilots must not fly more than 10 hours, I set the max air variable from the data section to 10 hours.

$$\text{max}_{(air)} = 10$$

$$tot_air(p, t) \leq max_air(p, t)$$

Pilots have to rest for 10 hours (rest) if they flew for 10 hours and land at the same time; they can not fly.

$$tot_{air(p,t)} - max_{air(p,t)} + K_{p,t} \leq 1 - X_{p,1,t+r}$$

$$\forall t \in \{1, \dots, 168\}, \forall r \in \{0, \dots, rest - 1\}$$

The formula is set so that as many pilots as possible in a given time zone are set in the air, in our model we have 2 pilots in each period to be in the air.

$$\sum_{p=1}^{P=6} X_{p,1,t} = F_t \quad \forall t \in \{1, \dots, 168\}$$

Each pilot should be rested once a week.

$$\sum_{t=1}^7 Holiday_{p,t} = 1 \quad \forall p \in \{1, \dots, 6\}$$

Pilots must not fly on the day they are on vacation (rest day).

$$\forall t \in \{24 * (d - 1) + 1, \dots, 24 * (d - 1) + 24\} \quad \forall d \in \{1, \dots, 7\}$$

$$X_{p,1,t} \leq 1 - Holiday_{p,d}$$

5.5. Optimizing and Creating Feasible Solution

As an example weekly crew scheduling minimized for 6 pilots for 2 modes in 168 period (as hourly for a week = 7*24) via IBM OPL Cplex Studio according to DSS model. Creating feasible solution took 16 minutes.

Pilots' status tracking is one of the important and hardest processes for air taxi and general aviation companies. We can track pilots' status for each period to decide their future mode in scheduling. According to our problem's constraints, a pilot should only be in one mode at a given time, we can track of how much of each pilot's total time in the previous 24 hours for each hour for all periods. Pilots must not fly more than 10 hours. Pilots have to rest for 10 hours (rest) if they flew for 10 hours and land at the same time; they must not fly. Each pilot should be rested once a week (holiday). Furthermore, pilots must not fly on the day they are on vacation.

I scheduled 6 Pilots' weekly crew plan as two pilots will be ready to fly for 168 periods (24 hours * 7 days). The figures of 4, 5, 6 are taken from our model optimization tool which is IBM ILOG CPLEX Optimization Studio Tool. Examination of the results according to the figures will enable us to have a more detailed idea of the optimization.

I will examine the feasible solution via figures which is taken from optimization tool as follows. We can see pilots' weekly schedule from Figure 4. 'P' means the number of pilots and we have 6 pilots on the left vertical sections. I planned pilots schedule for 7 days as a week on the top there are 7 sections for each day. Values of '1' in the table show pilots are resting for a week. Values of '0' in the table show pilots are ready to work.

| P (büyüklük 6) | 1..7 (büyüklük 7) | | | | | | |
|----------------|-------------------|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 6 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |

Figure 4: 1 Six Pilots weekly schedule

On the third day of the week, we can see that all the pilots are ready to work. According to our sample problem, each pilot need to rest 1 day in a week. I wanted to use the pilots as effectively as possible. If i change pilots number and our period, the planning will change and it will take more time to optimize.

| P (büyükük 6) | M (büyükük 2) | T (büyükük 168) | X Değer |
|---------------|---------------|-----------------|---------|
| 1 | 2 | 1 | 0 |
| 1 | 2 | 2 | 1 |
| 1 | 2 | 3 | 1 |
| 1 | 2 | 4 | 1 |
| 1 | 2 | 5 | 1 |
| 1 | 2 | 6 | 1 |
| 1 | 2 | 7 | 0 |
| 1 | 2 | 8 | 0 |
| 1 | 2 | 9 | 1 |
| 1 | 2 | 10 | 1 |
| 1 | 2 | 11 | 0 |
| 1 | 2 | 12 | 0 |
| 1 | 2 | 13 | 0 |
| 1 | 2 | 14 | 0 |
| 1 | 2 | 15 | 0 |
| 1 | 2 | 16 | 0 |
| 1 | 2 | 17 | 1 |
| 1 | 2 | 18 | 1 |
| 1 | 2 | 19 | 1 |
| 1 | 2 | 20 | 0 |
| 1 | 2 | 21 | 1 |
| 1 | 2 | 22 | 1 |
| 1 | 2 | 23 | 1 |
| 1 | 2 | 24 | 1 |
| 1 | 2 | 25 | 1 |
| 1 | 2 | 26 | 1 |
| 1 | 2 | 27 | 1 |

Figure 5: 1 Pilots' detailed status for each period.

In Figure 5, the columns show:

'P' means the number of pilot

'M' means pilots' mode (1: ON, 2: OFF)

'T' means which period ($24 * 7 = 168$ Periods)

'X' indicates the value of the pilot.

We can understand the detailed status of the first of the pilots, between 1st and 26th periods (each period represents an hour.) from figure 5. We can also check each pilot's detailed status like in figure 5.

| P (büyükük 6) | | | | | | | |
|---------------|----|----|----|----|----|----|----|
| | 37 | 38 | 39 | 40 | 41 | 42 | 43 |
| 1 | 8 | 8 | 8 | 8 | 8 | 9 | 10 |
| 2 | 9 | 9 | 9 | 8 | 7 | 6 | 5 |
| 3 | 7 | 7 | 7 | 7 | 8 | 8 | 9 |
| 4 | 10 | 10 | 10 | 10 | 10 | 9 | 8 |
| 5 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 6 | 4 | 4 | 4 | 5 | 5 | 6 | 6 |

Figure 6: 1 Pilots' detailed total air value for each period

In Figure 6, the columns show periods and rows means the number of pilots. Flight personnels' flight status can easily understand from figure 6. We can follow of how much of each pilot's total time in the previous 24 hours for each hour for all periods. In order to have a clear idea about our modeling and mathematical programming processes, I will give brief information about our optimization tool as below.

5.6. IBM ILOG CPLEX Optimization Studio Coding

I used IBM ILOG CPLEX optimization studio to model and create feasible solution for crew planning. In the application, CPLEX Optimization Studio IDE will use the language used by your operating system, if the language is supported. There are two useful sections in the application which are mode and data. I wrote the modeling at mode section and model took the datas from data section. When I finish the model, I should create configuration section to run our model. Running time for your model can vary according to your operating system and computer specifications. I added the model as below for your examining.

Modeling section

```
int pilot=...;
int mode=...;
int period=...;
int max_air=...;
int rest=...;
```

I defined the *definitions* to be used.

```
range P=1..pilot;
range M=1..mode; // 1:air; 2:off
range T=1..period;
range R=0..rest-1;
```

I clarified *ranges* which will be referred from data section.

```
int flight[T]=...;
```

I described *flight function* which will be taken from data section that includes 2 Pilots for each period.

```
dvar int X[P][M][T] in 0..1;
dvar int K[P][T] in 0..1;
dvar float+ tot_air[P][T];
dvar int holiday[P][1..7] in 0..1;
```

Our *decision variables* are shown as left

Objective function is portrayed.

```
minimize 0;
```

Our objective is to find a feasible solution; so our problem is not an optimization problem but a satisfiability problem however, any convenient objective function can be added to the problem without any complication.

Our *constraints* described as below.

```
subject to {
  forall(p in P, t in T)
    sum(m in M) X[p][m][t] == 1;
  forall(p in P, t in 2..period)
    X[p][1][t-1] + X[p][2][t] <= 1 + K[p][t];
  forall(p in P, t in T)
    sum(k in t-24..t-1: k>0) X[p][1][k] == tot_air[p][t];
  forall(p in P, t in T)
    tot_air[p][t] <= max_air;
  forall(p in P, t in T, r in R: t+r<=period)
    tot_air[p][t] - max_air + K[p][t] <= 1 - X[p][1][t+r];

  forall(t in T)
    sum(p in P) X[p][1][t] == flight[t];

  forall(p in P)
    sum(t in 1..7) holiday[p][t] == 1;
  forall(p in P)
    forall(d in 1..7)
      forall(t in 24*(d-1)+1..24*(d-1)+24)
        X[p][1][t] <= 1 - holiday[p][d];
};
```

Data section

```
pilot=6;  
mode=2;  
period=168; //24*7  
max_air=10;  
rest=10;
```

Those datas will be taken from data section to modeling section. That means i don't need to change our model. So, I can vary datas and model can take them.

```
flight=[  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
];
```

Crew planning of an Air taxi company can vary according to flight requesting but The Air taxi company wish to have 2 Pilots to be ready to fly for 7/24 for not missing any flight requests. Flight

function is planned for 2 Pilots for each period.

In this study, I summarized the personnel scheduling and crew plannings. After that, I detected aviation industry actual status with the comparing airline, air taxi and general aviation companies. I examined about crew planning in terms of the aviation sector, how legislation and DSS could help team planning. In literature review section, crew planning studies and modelings that have been done so far have been examined in detail. I have witnessed how theoretical work can find effective solutions to real life problems. Then, in problem description and legislation part, I understood the general terms of aviation and I examined aviation legislations according to location as Turkey and Europe. I defined problems for air taxi companies and evaluated the possible solution alternatives. In overview of mathematical programming section, valuable inferences about mathematical programming were shared with readers to create a brief review of mathematical programming on readers' mind. In the MIP model chapter, I remembered what is mixed integer programming. I created and optimized our problem's mixed integer problem method via IBM CPLEX Optimization Studio application according to our decision variables and constraints. According to our model and mathematical programming method, I reached a feasible solution for The air taxi company which I take as our

example. I interpreted our model that I have optimized for the compatibility of constraints and tested the validity of the solution.

I can improve the model according to different objective functions, decision variables and constraints. I can use the crew planning model for different air taxi and general aviation companies or different companies in different sectors. In order to have more detailed information, I will test our model with different examples in chapter 6 and compare the results. After that, I can check 7th section for future researches and developments.



CHAPTER SIX
6. A NUMERICAL EXAMPLE

Optimizing and creating feasible solutions are most important factors to have effective scheduling. Modes, number of pilots, periods can change according to our new problem and model. I will examine the model with scale up method as below.

Our numerical example can be explained as: 'If the company purchase a new aircraft, they will need the same crew composition.'

I wish to double the number of flight crew as '12'. The feasible solution will not be effective for The air taxi company because of creating extra personnel cost for a company but I can track optimization running time for an example. I updated our data section as below.

```
pilot=12;  
mode=2;  
period=168; //24*7  
max_air=10;  
rest=10;  
  
flight=[  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
  2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2  
];
```

I doubled the number of pilots in the company. The other rules and datas stayed same as before. We will have 12 pilots for one aircraft. Optimal running time viewed as 22 seconds. In this case, I have more pilots than the air taxi company need as I informed before. The constraints are not restrictive in our model for 12 pilots. The tool produced the feasible solution in 22 seconds.

In mathematical programming, the scale was enlarged but the constraints were not updated according to the new scale, so resources were not used effectively. I decided to update our constraints according to our new number of pilots. Data section updated as

above, I updated our number of pilot as 12 but the constraints were not enough to restrict. Because of that, modeling optimization took 22 seconds but the solution is not feasible for the air taxi company.

I need to update our new numerical example as ‘If the air taxi company purchase a new aircraft, they will need the same crew composition as before because of that, I will need to double number of pilots who will be ready to fly.’

I will have 4 pilots for each period who will be ready to fly while I create a weekly program for 12 pilots in our new example. I decided to update the flight function matrix in the data section as a 4 Pilots for each period.

```
pilot=12;
mode=2;
period=168; //24*7
max_air=10;
rest=10;

flight=[
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4
];
```

Updated areas showed as highlighted with yellow color. Creating feasible solution took 2 hours and 14 minutes. I just doubled the number of pilots and available pilots number who will be ready to fly. As we can see from numerical example our modeling working for different datas. I produced a new feasible solution for air taxi company with new example updating via IBM Cplex tool.

I have analyzed the availability of our model and have seen that it can be developed with different examples. I only changed the number of pilots and the number of available pilots who can fly for each period (flight function), creating feasible solution took a very long time to solve our model.

Computers with much larger capacity and higher processing power will be needed to solve larger scale examples. It is known that different companies in different sectors have purchased computers which have 10,000 cores to optimize models.

CHAPTER SEVEN

7. CONCLUSION & DIRECTIONS FOR FUTURE RESEARCH

Importance of crew scheduling process for air taxi companies was examined via the study. I define the problem, checked the available solutions and created our model according to legislations and the air taxi companies needs. Mixed integer programming method used in modeling and supported with decision support systems for the air taxi company crew planning modeling.

I reached a feasible solution for crew planning problem of an air taxi firm. There is no doubt that flight safety and effectiveness will be enhanced with the work to be done. As we can understand from section 6, we can develop our model with new datas. For example, If air taxi company purchase new aircrafts, we can set new decision variables, we can add new objective function and we can limit our model via constraints. I produced new feasible solution for air taxi company with new example via IBM Cplex tool, so I checked the validity of our model with new numerical example. I hope, this study can be helpful for air taxi and general aviation companies' crew scheduling process.

For future research and developments, I can divide selections and constraints according to limitations from legislations. Because of flexible needs of air taxi companies, I can use decision support systems for crew planning according to combined limitations. Such as ages, experiences, training status of pilots and window of circadian low, civil aviation authorities' regulations.

As we know, after 2019, air taxi companies and general aviation companies which are located in Turkey will be responsible for new legislation which is SHT-FTL [2]. The companies will need updated optimization rules and tools after 2019. Air taxi and general aviation companies can use this study as an example and as part of their crew planning process.

Furthermore, crew planning departments can use our study for airline and defense industry firms. For airlines, I can use crew pairing and experience based crew scheduling functions to increase pilots' performances. The Model can be improved according to the airline firms' needs. Defense industry companies have different aircraft types and different rules. Such as rules of drones, attack test flights, test flights, unscheduled test flights, parts of aircrafts' test rules and etc. The model may be categorized according to defense industry companies needs. New roles can be added to the crew planning such as test engineers. Pilots' test skills can be ranked. New crew planning can be updated according to new roles and rules via new mathematical modelling. This study can be developed and used for different sectors and companies as we can see from above examples. It can be used in big hotels' personnel scheduling for different departments. Such as reception, kitchen, animation team, housekeeping and etc.

As I mentioned before, crew scheduling can be used for different areas such as hospital personnel, train personnel, drivers, security department personnel and customer care service rostering etc. There is no limits about developing mathematical programming and modeling, it will be possible to study for crew planning effectively in every sector. Planning in personnel management takes an important place in cost management. We have seen examples of this in the literature review many times via this study. After a business successfully optimizes their personnel scheduling processes management, they inevitably become more efficient. Crew planning process optimization helps organizations avoid the extra fees and comply with every applicable regulations and obligations. Optimized personnel scheduling practices ensure in place to reduce risks from human error. It is impossible for people to try to solve models that even modern technology computers have difficulty for solving processes. Of course, it is difficult formulating and modeling the problems mathematically. If the companies get help from the experts, they can reach the satisfactory results.

CHAPTER 8
8. REFERENCES

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CHAPTER 9
15. CURRICULUM VITAE

PERSONAL INFORMATION

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EDUCATION

| Degree | Institution | Year of Graduation |
|---------------|---------------------------------------|---------------------------|
| MS | Çankaya Univ. Business Administration | 2018 |
| BS | Çankaya Univ. Management | 2015 |
| High School | M. Akif Ersoy High School | 2007 |

WORK EXPERIENCE

| Year | Company | Enrollment |
|---------------|-------------------|--|
| 2017- Present | TAI Inc. | Specialist |
| 2016-2017 | Skyline Aviation | Flight Ops., Training & Crew Planning Specialist |
| 2015 – 2016 | Mesamak Machinery | International Sales Representative |

FOREIGN LANGUAGES

Advanced English, Beginner Slovenian

HOBBIES

Kick boxing, reading book, watching air shows.