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Application of the Hungarian Assignment Method in the Aviation Industry

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Abstract:- The Aviation industry comprises of all aspects of air travel, activities and facilities that keep the aviation industry going. it. India is coming up as one of the fastest growing Aviation sectors in the world. The sector was adversely impacted during the outbreak of the Covid-19 pandemic and hasn't recovered since then. Thus, the importance of using Operational Research to minimize the cost and increase profits signifies even more. Operational Research has been significantly used in multiple areas of aviation such as Crew Pairing, Scheduling, In Flight Crew Job assignments, Yield Management and Revenue Management, Departure Control, On Ground Cargo Handling and Flight Scheduling. In this research the problem of air crew scheduling is discussed using Hungarian Assignment. Air Crew Scheduling is a very complex problem especially in larger airlines which have multiple hubs, spokes and feeder location. The problem gets complicated with long duration flights exceeding 12 hours of travel time spanning multiple time zones which requires in-flight crew rest planning to be included while solving for the crew scheduling problem. In this research a point-to-point transit has been selected along with stipulated crew rest hours on ground for simplicity and the Hungarian Assignment technique has been used to solve the problem.

Keywords:- *Air Crew Assignment Problem; Hungarian Method; Crew Scheduling; Layover Time; Optimal Crew Assignment.*

I. INTRODUCTION

According to a recent analysis provided by the Air Transport Action Group (ATAG), the worldwide air transport sector supports 65.5 million employment and $2.7 trillion in global economic activity. The aviation business has grown steadily over the last decade, indicating the likelihood of sustained expansion in the years ahead. For instance, between 2009 and 2019, revenue in the worldwide aviation business expanded at a compounded annual growth rate (CAGR) of roughly 5.3 percent, reaching $838 billion in 2019.Operations research (OR) has been crucial in the growth of the aviation industry and its infrastructure since the 1950s. The airline industry's spectacular rise into a highly competitive global transportation network over the last thirty years has been accompanied by considerable application of operations research and management science techniques in all aspects of airline operations. All airlines invest heavily in advanced aircrafts and employ highly trained and competent personnel. The efficient use of such significant and costly resources is unquestionably a key goal in the functioning of a profitable airline. The purpose of this report is to solve the air Crew Assignment Problem (CAP) using an operations research technique called, the Hungarian assignment method. Harold Kuhn created and published the "Hungarian technique" in 1955 and named it so because the algorithm was largely based on the earlier work of two Hungarian mathematicians, Denes Knig and Jen Egervary. It's a combinatorial optimization algorithm that solves the assignment problem in polynomial time. The Hungarian technique is quick and easy to use, and it works for any problem that can be represented as integer programming. It has been frequently employed in many assignment and matching issues, since the early twentieth century. This approach was created specifically to solve assignment problems with ease and efficiency. The concept of opportunity cost underpins HAM. It is of widespread use in common balanced assignment problems with a set number of persons and an equal number of jobs (or even an unbalanced matrix) and a minimization-type objective function. This is exactly what the Crew Assignment Problems are about as well. Thus, this specific OR technique is of great importance for solving the aforesaid problem.

A. Crew Schedule Planning

To maximize airline profitability, schedule planning entails creating future aircraft and staff routines. This problem is exacerbated by a network of flights, various aircraft types, gate, airport slot, and air traffic control restrictions, noise curfews, maintenance requirements, crew work rules, and competitive, dynamic environments in which passenger demands are uncertain and pricing strategies are complex. Unsurprisingly, no one optimization approach has been solved, or even developed, to adequately address this multifaceted design problem. Air crew assignment, alongside schedule design, fleet assignment and aircraft maintenance routing, is a subproblem under the wide umbrella of crew scheduling.

In its true sense crew members represent the airlines and crew is the second highest cost incurred by airlines after fuel, therefore any reduction in these costs can translate into significant savings. During 1960's heuristic methods were employed to find improved crew solutions because of large problem size and lack of advanced techniques.

Crew scheduling problem is broken into 2 types ever since it has been studied. One of its components is crew pairing problem and the other one is crew assignment problem, as differentiated below.

Crew pairing problem- The problem generates pairings. The pairings have certain work limit restrictions like maximum number of hours worked in a day by the crew, minimum hours of rest amongst several others. Even with these limitations there are millions of pairings possible among members of the airline staff. The large size of pairings inevitably acts as a drawback in the method and process of the same.

Crew scheduling- This problem converts pairings into crew schedules called "bidlines" or "rosters" which are assigned to individual crew members. The assignment of schedule to employees is primarily based on their levels of seniority. However, the problem faced while doing this is that there are billions of crew pairings which results in billions of crew connections that can be possibly formed. Moreover, there are thousands of constraints and equally large number of variables while making these decisions.

Therefore, heuristic methods were widely used. The increasing need to generate optimal solutions even with countless variables, quite a few researchers had also moved to "branch-and-price" which solved large LP's via column generation. However, even the rules of this method had its own set of drawbacks. Here, the branching decisions needed to justify optimality, were immoderate for crew scheduling problems.

Nonetheless, with the recent advances being made, crew pairing solvers became imperative and came for the save. There are airlines that have achieved significant savings and cost reductions due to various heuristic techniques.

II. LITERATURE REVIEW

The airline industry over the last 50 years has seen significant application of technology to conduct its business. The aviation industry as it stands today caters to multiple segments namely:

Retail and Corporate Travel
Cargo
Charter Flights
Specialized Courier Flight

Irrespective of the type of segment being serviced, the aviation industry is described as one of the most technologically advanced industries in existence. Most of the renowned carriers and primary players like Lufthansa, Emirates and Singapore Airlines rely on a variety of Information systems to carry out their operations on a day-to-day basis. The entire industry relies a lot on Operations Research concepts and Artificial Intelligence to run its Management Information Systems, Decision Support Systems and Online Real Time Transaction systems like the Reservation, Check-in Control System, Departure Control, Yield / Revenue Management, Crew Scheduling, Flight Scheduling and Flight Load Planning among a slew of other systems. (IATA, n.d.)

(Barnhart, Belobaba, & Odoni, 2003) & (Etschmaier & Rothstein, 1974) Both the papers discussed the various segments and departments of the aviation industry, where the methodologies of OR have been successfully applied for cost minimization and revenue maximization for the airline firms. The applications of OR in crew and flight schedule planning, fleet assignment, operations recovery, airline revenue management, overbooking models and nested booking. The challenge presented for future researchers is for developing quick-decision supportive tools to maximize safety and efficiency of airline operations via real-time data flows. (Koksalmis, 2019) A data collected by ICAO in 2006 shows that there are more than 900 commercial airline companies, 22,000 airline fleets, 1,670 airports with millions of kilometers of network, 2 billion passengers per year, 2.1 million employees. From this we can get a fair idea as to how big the aviation sector has become in the recent years. This paper talks about some of the OR techniques used in air transportation sector, the applications used in order to solve these problems are- demand forecasting, fleet assignment, aircraft routing, crew scheduling, runway scheduling problem and gate assignment.

(Rothstein, 1985) This paper discusses the problem of overbooking in the aviation sector and the application of OR to deal with the same. The paper describes various models found by researchers over the years. However, none of them proved to be effective. The problem wasn't very noticed until 1972, when Ralph Nader (a famous consumer advocate) was denied boarding by an oversold Allegheny Airlines flight. The case was taken to the supreme court, where even the judge couldn't ascertain whether the overbooking situation was "carefully controlled" or not. A major gap discussed in the paper is that the bumped customers are still not fully refunded but are only given a small amount. In most cases the customers were being given free flights instead of being issued a full refund. Lastly, there was no real study was being performed on the fundamental nature of reservation process. Overbooking leads to some serious problems. The passengers can be denied booking causing harm to the reputation of the airline. The paper used historical data and interviews to analyze the variable effect on the number of no-show passengers (Sveinsdottir, 2019). There is need develop a model in the future by doing a study on the fundamental nature of reservation process by considering historical data. There should be new laws made by CAB which forces the airlines to issue a full refund to the bumped passengers, also give them additional perks (like not deducting the mileage points) in order to maintain good public relations. The T&Cs should be written in a better form and the details regarding overbooking should be told to the passengers at the time of booking, so that they are mentally prepared. The papers helped in deciphering other areas where Hungarian method could be used to solve the problems.

(Barnhart, Belobaba, & Odoni, 2003) Operations Research helps airlines to make decisions related to differential pay structure. Some important aspects to be considered while scheduling crew includes crew pairing, rostering and rest period. After fuel costs, crew costs are the second highest cost for airlines. Crew pairing is a challenge for most airlines to decide which crew will be based off which base and how they operate legs between their Homebase and outbound base. Many airlines also have the challenge of serving diverse set of passengers so they need to cater to variety of crew which can speak multiple languages and serve customers. OR helps schedulers with Crew management to get the optimum balance between crew flying hours and utilization resulting in wage reduction by up to 50% based on actual flying hours. Linear Programming approach can be used to solve the crew pairing and scheduling problem.

(Arguello, Bard, & Yu, 1997) Provides a greedy randomized adaptive search procedure (GRASP) to reroute aircrafts in reaction to groundings and delays that occur throughout the day. The GRASP's ability to rapidly investigate a wide range of possibilities and, in most circumstances, create an optimal or near-optimal solution is demonstrated by empirical results. The goal is to reduce the expenses of flight cancellations and delays caused by recovery aircraft routing in the event of groundings and delays. The paper gives results for data associated with Continental Airlines' 757 fleet. Our analysis of the work unmasked how the optimality could be achieved by a simpler method to plummet the costs. (Koksalmis, 2019) A major gap found in the models used in the paper was that the Gate Assignment Problem (GAP), which is used to minimize the unallocated aircraft to a specific gate, and minimize the walking distance for passengers fails if the flights are delayed or cancelled.

(Agrawal, 2020) The article describes the effect of Covid 19 on the airline industry in India. Aviation is unfortunately the worst hit sector amongst all. As per CRISIL Infrastructure Advisory report, the expected revenue loss to the Indian aviation sector due to lockdown amounts to 240 billion. The airlines have greater opportunity to spread their operating cost when the distance flown is higher. In this backdrop, improving Passenger Load by offering lucrative offers is prevalent trend in the industry. Some of them are operating costs, thin profit margin, restricted movements, fear psychosis, declined tourism and reduced commercial activities. However, concrete research is required to show as to how Airlines can get back on track with the help of optimal scheduling of flight to achieve maximum revenue.

(Mittal, Diwan, Baid, & Dua, 2017) Operations Research has helped the aviation industry continually transform itself to compete effectively in the marketplace to match the complex consumer demands. The article highlights the use of Hungarian Assignment problem for assignments of crews at Air India and Indigo flights. It also discusses the application of Critical Path Method to analyze the maintenance of activities at the Lufthansa Airport. The aircraft maintenance scheduling is one of the major decisions an airline has to make during its operation. (Atli & Kahraman, 2012) Along with air crew management, maintenance scheduling is also an important aspect to be considered for an airline's functioning. The article discusses the need of regular airline maintenance check and when and where to undergo these checks based on the airline schedule. This is done using the Critical Analysis Method with the objective to minimize the aircraft maintenance planning time. The successful application of both models could be used to save a lot of time, manpower and maximize profits. A lacking area we felt was the use of techniques to minimize costs. In case of Airlines, its more about reduction in costs as that directly lifts up the profits.

Our aim for writing this research paper is to give the readers considerable and significant insights into the segment of the aviation industry which successfully uses the methodologies of Operations Research to minimize costs, maximize profits and build up the efficiency of the airline sector. We will throw light on a few hiccups faced by the industry and subsequently provide and quote the solution that is often used to capitalize on these opportunistic challenges.

We also desire to widen the horizon of your knowledge by discussing a real world, practical problem, the Air Crew Assignment Problem through the simple solution algorithm called the Hungarian Method to minimize time and costs and maximize profits. This would enable logical and factual comprehension of this OR technique used in the aviation industry. Moreover, the quantitative analysis of these specific topics will be highlighted, that are reflective of the personal interests of the authors.

As mentioned, the purpose of this study is to provide a historical perspective on the operations research contributions to the aviation sector. However, a true and full examination of this subject will almost certainly take an entire issue of this journal because the number of OR papers published on air transport during the previous 70 years easily exceeds 1200. Consequently, the scope of the study will instead be limited to a subset of air transport-related subjects, where operations research has made some of its most momentous contributions till date, while being mindful of the stringent word-limit.

Other survey articles that provide more details and references are cited whenever possible, in addition to the bibliographic references linked with the aforementioned contributions.

III. ANALYSIS AND FINDINGS

The air crew assignment problem, which is a subproblem of the airline crew scheduling problem, is one of the primary subjects of our research. The goal of the crew assignment issue is to determine the best way to allocate crew members to a given set of crew pairings.

Air crew management is a very crucial task for any airline. Flights should be scheduled in a way that optimizes cost as well as time. We have used the Hungarian Assignment

method developed by Harold Kuhn in 1955 to solve the crew assignment problem for Indigo Airlines. The data used for the purpose of analysis is sourced from Go Indigo's official website. (IndiGo, n.d.)

The table shown below contains the to-and-fro schedule for flights between Mumbai to Ahmedabad. We have assumed that a minimum of 6 hours of layover time (rest time) is provided to the crew. Flight numbers have been altered for easier comprehensibility by readers.

Figure 1: Flight Schedule

Flight No	Mumbai (Departure)	Ahemdabad(Arrival)	Flight No	Ahemdabad (Departure)	Mumbai (Arrival)
1	07:30	08:45	101	05:15	06:30
2	18:00	19:15	102	07:15	08:45
3	07:45	09:15	103	18:45	20:15
4	16:30	17:45	104	10:15	11:45
5	19:45	21:15	105	22:15	23:30

Source: Indigo official website

STEP I – Layover time at the Ahmedabad Airport, in hours (Interval between Ahmedabad Arrival and Ahmedabad Departure)

Figure 2: Layover time at Ahmedabad Airport

STEP I	Ahmedabad Arrival to Ahmedabad Departure				
	101	102	103	104	105
1	8.5	10.5	10	25.5	13.5
2	10	12	23.5	15	27
3	20	22	7.5	25	13
4	11.5	13.5	25	16.5	28.5
5	8	10	21.5	13	25

Source: The authors

STEP II – Layover time at the Mumbai Airport, in hours (Interval between Mumbai Arrival and Mumbai Departure)

Figure 3: Layover time at Mumbai Airport

STEP II	Mumbai Arrival to Mumbai Departure				
	101	102	103	104	105
1	25	22.75	23.25	19.75	8
2	11.5	8.25	20.75	6.25	18.5
3	25.25	23	23	20	8.25
4	10	7.75	7.75	28.75	17
5	13.25	11	11	8	20.25

Source: The authors

STEP III – Comparison between the layover time in each cell. The minimum layover time (indicated by the underlined cell) is chosen for the purpose of Problem Formulation.

Figure 4: Minimum Layover Time

STEP III	Problem Formulation				
	101	102	103	104	105
1	8.5	10.5	10	19.75	8
2	10	8.25	20.75	6.25	18.5
3	20	22	7.5	20	8.25
4	10	7.75	7.75	16.5	17
5	8	10	11	8	20.25

Source: The authors

STEP IV – Each cell in the row is subtracted by the least layover time in that row (shown by the underlined numbers in Step III)

Figure 5: Row Minimum

STEP IV	Row Minimum				
	101	102	103	104	105
1	0.5	2.5	2	11.75	0
2	3.75	2	14.5	0	12.25
3	12.5	14.5	0	12.5	0.75
4	2.25	0	0	8.75	9.25
5	0	2	3	0	12.25

Source: The authors

Step V- Each cell in the column is subtracted by the least layover time in that column (shown by the underlined numbers in Step IV). The final and optimal allocations are highlighted by the circles.

Figure 6: Column Minimum

STEP V	Column Minimum				
	101	102	103	104	105
1	0.5	2.5	2	11.75	(0)
2	3.75	2	14.5	(0)	12.25
3	12.5	14.5	(0)	12.5	0.75
4	2.25	(0)	0	8.75	9.25
5	(0)	2	3	0	12.25

Source: The authors

Since, the Number of Allocations = The order of Assignment Problem

The solution is optimal.

Step VI- Final Assignment is shown to depict the best possible order of flights that can optimize time.

Figure 7: Assignment

STEP VI	Assignment		
	Flight Number (For Arrival)	Flight Number (For Departure)	Layover time
	1	105	8
	2	104	6.25
	3	103	7.5
	4	102	7.75
	5	101	8
			37.5 Hours

Source: The authors

Findings: The highest layover time is given to the crew for Flight Number 1 and 5 while the most efficient crew is for the Flight Number 2 (Given, they follow the aforementioned schedule.) As the number of layover hours goes on increasing, it is reflective of the decreasing efficiency of the crew.

IV. CONCLUSION

The purpose of conducting the research was to identify methods that help save time as well as cost for an Airline company. Based on the analysis, it can be inferred that there is a possible way out for the air crew assignment problem. The Airline industry that was the badly hit sector during Covid 19, suffered a blow and received a grave shock with a ban on passenger movements. To overcome and minimize the losses incurred, it is important to focus on optimization of both cost and time. These are the two important factors that affect the industry performance along with uncertain fuel prices that have an impact on the industry. Air crew assignment using Hungarian method is one such technique that can help in achieving optimality and aid the recovery process in the industry during grievous times.

The Hungarian Assignment method is a very significant technique that has been used to solve matching problems over these years. Researches till now have majorly focused on comparison between different assignment methods like the enumeration method vs Hungarian Method. The use of this technique to solve the crew assignment problem has added to the existing pool of knowledge. It gave a solution that required minimum cost and total number of hours while providing sufficient layover time to the crew. The Hungarian Assignment method has widespread uses in a variety of areas where minimization of cost and time and maximization of profits is required. It provides an optimal and accurate solution that can provide huge benefits due to the costs saved. Arrangement and matching problems are made much simpler by this technique.

There are multiple instances in real life situation where efficient scheduling or planning is required. For instance, in a production firm the main factor is production efficiency. Production is dependent on various internal and external factors. Money spent on resources, power, raw materials in a production line has economic and organizational risks. Hungarian method is a simple algorithm to solve a production efficiency problem. Classic application of this method is for personnel assignment for crew scheduling, in flight crew rest planning and cost optimization to save money for the airlines by way of wage reduction.

V. LIMITATIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

A challenge in the crew scheduling is obviously the layover time especially for round trip flights between two destinations as there are hidden costs such as airport handling costs and the crew working hours including on ground hours as well as in air hours which should not exceed the stipulated number of work hours including flying hours. The scheduling also needs to take into consideration turnaround time for flights and how the crew can manage to prepare a flight to complete onward journey and the overall scheduling should still be well within statutory norms. The certainty of finding the optimal solution depends on how the multiple legs of the flight are scheduled and which crew is best positioned to operate the flight.

Optimized solutions are rarely carried out according to plan. Crew sickness, mechanical breakdowns, and inclement weather necessitate plan revisions, which often result in considerable cost increases. Furthermore, by eliminating slack, a finely tuned, optimized solution increases utilization, giving crews less time to connect between flights and aircraft less time on the ground between flights. Less slack time, while theoretically cost-effective, can result in less robustness and higher expenses in actuality.

The benefits of optimization on crew scheduling are important, but the sequential schedule plans limit them. The variety of crew scheduling options is limited once the flight schedule, fleet assignment, and aircraft routing decisions are made. However, some researchers have created enhanced models that integrate crew considerations into some of the other subproblems solved to avoid the limiting consequences of sequential solutions. They modify other assignment models to recognize some of the cascading impacts on crew members. For instance, in the sequential solution process, the fleet assignment model (one which decides the type of aircraft to be assigned) is substituted with one of these modified models, resulting in a higher fleet assignment cost, offset by a lower crew cost.

Moving forward, the task will be to improve current capabilities by taking into account integrated passenger, crew, and airplane recovery decisions while quickly identifying low-cost solutions. Relaxing the limits between the various stages of aircraft and crew schedule planning, so that schedule design, fleet assignment, aircraft maintenance routing, and crew scheduling can all be done at the same time instead of being handled sequentially as separate subproblems. Moreover, developing quick decision-making tools that take advantage of huge, real-time data flows in an increasingly information driven aviation infrastructure to improve the efficiency of air travel systems.

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