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Applications of Operations Research in Airline Industry

Aman Pandey*, Shikha Dangwal**, Karishma Dhawan***, Vidushee Sharma****, Nidhi Jain*****

* Corresponding Author:(Student at School of Commerce, NMIMS University, Bangalore, India
Email:aman.pandey855@nmims.edu.in)

** (Student at School of Commerce, NMIMS University, Bangalore, India
Email: shikha.dangwal570@nmims.edu.in)

*** (Student at School of Commerce, NMIMS University, Bangalore, India
Email: karishma.dhawan055@nmims.edu.in)

**** (Student at School of Commerce, NMIMS University, Bangalore, India
Email: vidushee.sharma795@nmims.edu.in)

***** (Student at School of Commerce, NMIMS University, Bangalore, India
Email: nidhi.jain894@nmims.edu.in)

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Abstract:
Airlines handle a large number of passengers and flights on a daily basis, requiring robust operations strategies. Previous publications and literature have highlighted the importance of scheduling and forecasting for airlines to be able to survive profitably. As a result, there is a need for models based on mathematical and statistical fundamentals to forecast uncertain conditions in this sector and derive the most fruitful alternatives.

This paper examines several critical issues: *Fleet Assignment Problem, Airline Crew Scheduling, Seat Assignment Problem, Airport Gate Assignment Problem, Transportation Problem, Revenue Management, Maintenance Routing, Passenger delay costs,*
The findings and analysis demonstrate the real-world applications of the tools proposed in

Keywords: Operations Research, Airports, Airlines, Airline Crew Scheduling, Airport Gate Assignment Problem, Transportation Problem

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I. INTRODUCTION

The airline industry has grown substantially since the first flight of Orville and Wilbur Wright, and now contributes majorly to the world GDP growth.
Operations Research has helped the whole aviation industry to make a shift from serving only to the upper class customers to serving

the masses, as well by helping them minimise the cost and increase the revenues.

The Airline Industry, in FY21, registered a net loss of $51.8 billion, despite registering a whopping revenue of $472 billion in FY21. The global aviation market, having a CAGR(Compound Annual Growth Rate) of around 5.3% from FY09 to FY19, needs Operations Research for its continual growth and prosperity.

Therefore the objective of writing this research paper is to comprehend the practical use of various Operations Research tools utilised in the Aviation Industry and their real-life applications.

II. LITERATURE REVIEW

Looking at the importance given to efficiency in dynamic industries, the airline industry uses its resources to the greatest extent possible in order to minimise costs.

To achieve this objective, the Airline Industry uses Operations Research techniques to conduct vast amounts of research and looks over the data to find the most feasible optimal solution.

Airlines are faced by many demanding issues. The issues are closely interlinked and are typically solved chronologically.

It usually starts by determining the flights that are to be flown in a given time period, called the *Schedule Design Problem*. Then an aircraft is to be assigned to each flight, called the *Fleet Assignment Problem*. Then the assigned aircraft are to be made sure to have spent adequate time at the airports for maintenance checks, known as the *Maintenance Routing Problem.* Then having concluded all these problems, the airlines go on to the *Crew Scheduling Problem*. (Cynthia Barnhart et al., 2003)

Covid completely changed the way we live our lives. To avoid further spreading it, physical distancing had to be maintained. The seating assignment problem hence had to be revamped. A **MIP model** and a **heuristic formulation** were brought to the picture which takes into account ordering and grouping(if they're family members) of passengers. (Jane F. Moore et al., 2021)

In China, when no solid research and focus was on civil aviation management and planning, profits were meagre and costs were high. Having an **improved Grover's algorithm**, and **a branch-and-price algorithm to the cost optimization model**, helped the Chinese aviation market. (Yaohua Li et al., 2013)

Countries located in Africa, especially in Nigeria never focused on extensive research for FAP optimisation. As the competition grew, the importance of such research became visible. The **MC(Monte Carlo)-GA(Genetic Algorithm)** technique then acted as a lifeline. (Okafor et al., 2019)

The Crew Scheduling Problem has always been the main focus of research in the Aviation Industry. More focus is on cockpit crew as their salaries are greater. **Local Improvement Heuristics for Crew Pairing**, **Carmen Crew Pairing**, **The Column Generation Algorithm**, **Primal Dual Algorithm**, **Steepest Edge Pricing Rule**, **Pricing by Enumeration**, **Time Line Branching**. (Cynthia Barnhart et al., 2003)

The Transportation Problem takes into consideration supply, demand and the cost of each route in order to determine the most profitable. (Vedika Dixit, 2022).

Moreover, t**he Airport Gate Assignment Problem** assigns each gate to a specific aircraft taking into consideration the distance walked by the passengers. (Abdelghani Bouras et al, 2014)

However, aeroplanes transport passengers,cargos from one destination to another. It will be more efficient for the flight to have several stops and travel in one big route rather than several multiple. Here **Dijkstra's Algorithm** provides the shortest route from the first destination to the last ensuring that the route chosen is cost effective. (Alaa Wagih et al, 2022)

The airline industry faced a problem in determining the optimal ownership levels of spares in the engine shop and this problem was solved using the **simulation and approximate analytical methods** of operations research which aims at providing an idea of system performance, in different conditions. One of the methods used is the **Markov-type model.** (Maximilian M. Etschmaier et al, 1974)

Due to the increasing competition in the airline industry, the airlines have to have a fleet assignment in a manner that the costs are minimised and profits are maximised , which was done using the **heuristics and metaheuristics algorithm** (Vildan Özkır et al 2021)

Increased traffic results in delays and hence possessing a problem in the air traffic flow management which was solved using **stochastic optimization.** (Cynthia Barnhart et al, 2003)

There is always a possibility that the flight flies with half of the seats unoccupied making it difficult to earn revenue or passengers travelling through different distances and yet paying the same amount.This problem was solved through **Network Revenue Management or Origin-Destination Control** (Cynthia Barnhart et al., ND).

The cost incurred per route per flight could also hamper the profit that could be earned by the airline company. Using **meta-heuristics algorithms** we can find out the optimal route profitability (Kasturi E et al., 2016).

Over years, the traditional method of revenue management was challenged with the **Dynamic Programming Model**. (Sarvee Diwan et al., 2010).

We have also focussed on the problem of dealing with daily flight delays at a hub airport using operational tools such as **Integer Linear Model** and the **Receding Horizon Control Technique** . (Bruno F. Santos et al.,2014)

Research on network models of air transportation is classified based on the quantity of interest, scope of the network and temporal behaviour. Operational tools used are the following: **Markov Jump Linear Model**, **Airport Delay Dynamics Model** and **Topology-dependent model**. (Karthik Gopalakrishnan et al., 2021)

Airlines' main target is to increase efficiency and satisfaction for passengers whilst increasing their profitability as well. In order to do so the airlines decrease boarding time. Operational tool used is the New **mixed integer model** (Majid Soolaki et al., 2012).

III. ANALYSIS AND FINDINGS

When we mention the Crew Scheduling Problem, we have in mind the cockpit crew (the pilots) and the cabin crew(those who attend to the passengers). Crew Scheduling problems have always been majorly focused on the cockpit crews since they're the ones that earn the greater salary and hence optimising the resources of the cockpit crew is crucial for any airline.

Crew Scheduling Problem is one of the most noted problems in the Aviation Industry and hence a lot of research has been done to optimise this problem. Tools like Local Improvement Heuristics, Carmen Crew Pairing, Column Generation Algorithm, Primal Dual Algorithm, etc., have been proposed for the objective of optimising the Crew Scheduling Problem.

All of the aforementioned tools have had different methods of achieving efficiency, hence every tool has had a different number of iterations on every problem it had to solve.

There are many variations as well in the Crew Scheduling Problem hence the use of multiple tools takes place, and the most commonly used tool is the Carmen Crew Pairing Tool.

The seats of every aeroplane is its product. The airlines have to make sure that the seats are properly distanced, hence ensuring enough comfort for every passenger and also having an adequate amount of seats to generate enough profits and revenue from every scheduled flight.

Seat Assignment Problem isn't a problem that continuously requires new tools for optimality. Hence, not many OR tools were applied in the seat assignment problem. Once the seats are installed not much can be done for the optimality, only the grouping of the passengers can be handled.

Not many variations exist for the seat assignment problem. Only when a policy/law comes into picture, like that of physical distancing in the pandemic, only then can there exist variations in this problem. Tools like MIP and the heuristic formulation have real-life applications in this problem.

Another aviation problem having deep rooted connection with Operations Research is the Fleet Assignment Problem. This means assigning an aircraft for every scheduled flight. The FAP exists along with many variations. Over the years the importance of assigning the appropriate flight to every scheduled flight has come into light. The MC-GA tool is the most widely used tool in this problem along with the improved Grover's algorithm.

The FAP has now gained importance in the Aviation Industry since the cost of assigning an aircraft should always supersede the revenues generated from each generated flight.

AGAP is one of the tools the airline heavily depends upon as it speeds up the process of assigning each flight to a gate. In big airports where there are several gates, flights get delayed or get cancelled on a regular basis, and thus the gates have to be changed. Though there are many ways to solve such as LPP, heuristics, metaheuristics and more, most airlines solve AGAP through a genetic algorithm to speed up the process of assignment.

One of the benefits of using AGAP is that it considers several variables such as the aircraft type, gates, gate types, crews and many more.

Transportation Problem (TP) is a tool, which is a type of LPP that provides optimal routes from one designation to another while also obtaining the least possible cost. Even though TP is widely used in many industries for transporting, we were unable to find real-life application of TP in the Airline Industry. TP heavily depends on three factors, that includes cost, demand and supply. Through the past data, an airline will be able to find cost per unit of a route, it is harder to find actual data for demand and supply. There are also many points TP doesn't take into consideration. It doesn't consider the availability of the resources at a specific time.

TP also assumes that the profit per unit is known and certain, but due to demand and supply the cost per unit for a route fluctuates very often. The airline can increase the cost for last minute purchase of a seat or reduce it due to low demand. The profit per unit is never certain.

Since arranging intercity flights at a cheaper cost is one of the main issues an airline faces, many employ Dijkstra's Algorithm to discover the shortest path possible using several nodes. No matter how many nodes are used, Dijksta's method saves time since it finds the shortest route in a couple of seconds.

quality towards optimality.

A Stochastic Linear Programme is a specific instance of the classical two-stage stochastic program. A stochastic LP is built from a collection of multi-period linear programs (LPs), each having the same structure but somewhat different data.With a finite number of scenarios, two-stage stochastic linear programs can be modelled as large linear programming problems. This is called the deterministic equivalent linear program.

Another challenge is to make efficient 'Wait-depart decisions'. Primary focus has been given to the capacitated version of Delay Management Problems (DMP).

Its objective is to minimise passengers' delay costs and related fuel costs.The factors influencing decision-making process include changing airplane arrival and departure time, using airport capacity over time and rebooking passengers who missed connections.The soft costs are added to the price for passengers' delay compensation that are established by the airline (aka hard costs). This problem is solved optimally using the Receding Control Horizon technique.The acquired solution has been applied to Kenya Airways and its hub airport at Nairobi. Results show a significant reduction in delay costs of 29% with a reduction of 90% of missed connections. However there is a slight increase in fuel costs of about 2 thousand USD per day but is considered meagre in comparison to savings in terms of passengers' delay costs. This method is considered to be efficient and provides effective results as well. However, with advancements in the airline industry, more variables can be assumed under this approach such as the integration of the CADMP with crew and aircraft schedule disruption tools which will enhance the use of OR in this field.

The research paper on Control and Optimisation of Air Traffic Networks illustrates the application of data-driven modelling, optimization, and control algorithms in ensuring the efficiency and robustness of a large-scale infrastructure.We showed that the dynamics of air traffic delays are well-represented by positive Markov Jump Linear System models. The research presented in this paper also shows comprehensive analysis of system resilience, the extension of these results to multilayer networks, the development of optimal recovery algorithms for networked systems, and its practical implementation to enable safe and efficient air traffic operations. Bridging the gap between theory and practice in the control of complex and dynamic networks, the true potential of the proposed techniques can be achieved through real-world implementation.In order to assess the robustness of systems with time-varying network topologies, more OR-driven tools must be used.

Airlines decrease boarding time by minimising the number of interferences between passengers which is one of the challenges of our research. We have used the New Mixed Integer Model whose objective function is formulated to minimise the total expected number of seat and aisle interferences. Genetic Algorithm (GA) , a method applied under the existing OR tool, searches the feasibility space by setting of feasibility solutions simultaneously in order to find optimal or near-optimal solutions. The performance of the proposed GA worked out to be much faster than its alternatives and showed effective results in reasonable computing time. This model was then applied to Airbus 320 - Aircraft and showed effective results because of the use of boarding strategies like efficient solutions and reverse pyramid strategies. OR has been used extensively in this arena but however with some realistic assumptions and more development in its early stages this method will turn out to be more suitable and practical.

It isn't sufficient to have optimum management of crew, seat and fleet assignment and providing excellent on-air experience to passengers for any airline company to run successfully, it is also necessary that they have maximum revenue generated from the cost incurred. There are many OR tools used in the aviation industry over years for revenue management of the companies . These tools focused on same the objective i.e. to maximise profits through different methods, for example, 'Network Revenue Management or Origin/Destination Control' tool focused on managing seat inventory based on revenue value of passengers' origin-destination choice, whereas the 'Meta-Heuristics Algorithms' emphasised mainly on cutting down cost per route per flight and 'Dynamic Programming Model' was introduced to challenge the already existing traditional methods of revenue management. Results show that with help of Network Revenue Management the potential for revenue gains is approximately 1%–2%.The potential to generate even 1% more income through network RM is significant enough as the company already must be having their annual revenue in millions or billions. There are many airlines in the world that have already implemented it or are in the process of doing so. Also with proper implementation of meta-heuristics algorithms we can reduce the usage of millions of gallons of fuel without compromising on the flight schedules.According to the experiments and researches done, DP causes more passengers to sell-up to higher fare classes which results in increase in revenues.

IV. CONCLUSION

Based on the research we can say that there is an extensive use of OR tools in the aviation industry and many tools were introduced overtime and put into use. Operations Research techniques try to help the airline industry optimally utilise their meagre resources. The Aviation Industry has a deep rooted history with Operations Research. From assigning specific aircrafts to assigning the crew to managing the network and the finances, Operations Research is used pretty much in every aspect and every problem of the airline industry. The tools used to solve the aforementioned problems have real-life applications and tend to almost every variation present in the problem. This research has helped us understand the depth at which OR is used in the airline industry. The extensive use of OR tools resulted in optimal usage of all the resources which reduced the costs, and now this transportation facility is used to serve the masses instead of just the elite clientele.

V. LIMITATIONS AND RECOMMENDATIONS

The major limitation that could be seen in all of the research papers was that many constraints were not taken into consideration. For example, cost and revenue per unit was mostly considered linear, while in reality, it doesn't follow any set pattern, ie., it can be cubic, quadratic, etc.

Economies of scale also comes into the picture. When the airlines grow, the flights keep running more frequently, hence the airline grows, and the revenue and cost doesn't stay the same, which is yet another limitation.

Yet another very commonly ignored matter in this area, is that of differential pricing, costs and revenue of different classes of seats, i.e., economy class, business class, first class, etc.

As our research is based on secondary sources, we have no recommendations to provide.

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