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A STUDY ON APPLICATION OF OPERATIONS RESEARCH IN AVIATION INDUSTRY

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Abstract: **The air transport industry, a vital global economic component, has evolved significantly over the past century. Operational Research (OR) has played a pivotal role in driving aviation growth, particularly since the advent of the jet era. This paper explores OR's substantial contributions to air transport, with a focus on scheduling, fleet allocation, hub planning, and queuing theory.**

In Section 2, we delve into classic scheduling challenges, including crew assignments and routing. OR's large-scale optimization methods have propelled this field forward. Section 3 further investigates Hub Planning and Queuing Theory, optimizing flight schedules through both point-to-point and hub-and-spoke systems.

The paper meticulously examines Schedule Planning and Cost Minimization, exploring feasible solutions for crew and plane assignments. Fleet Allocation and Cost Reduction are addressed using network flow problems. Despite its drawbacks, Hub Planning proves advantageous due to efficiency, passenger convenience, and network growth. Additionally, Behavioral Operations Research integrates human behaviour into operational scheduling, especially in seasonality analysis.

The final section introduces Queuing Theory as a powerful tool for analysing airport runway systems amidst the ever-growing air traffic. We discuss key components such as arrival characteristics, waiting line dynamics, and service facility characteristics. Queuing equations are presented to estimate the expected number of units in the system and the queue.

In conclusion, this research paper provides a comprehensive overview of OR's historical impact on the air transport industry. By highlighting its evolution, challenges, and contributions to scheduling, fleet allocation, hub planning, and queuing theory, we recognize the critical role OR continues to play in shaping the future of aviation.

Keywords: **air transport industry, vital global economic component, driving aviation growth, future of aviation.**

SECTION - 1

Introduction:

During the hundred years since the first flight of Orville and Wilbur Wright, the air transport industry has become an important sector of the world economy. More importantly, it has become essential for the development and maintenance of cultural and economic ties between countries and peoples.

After spending the first 40 years trying to take off, sometimes literally, the air transport industry has been growing giant in the last 60 years, especially since the advent of the jet era at the end of the 1950s. Operational Research (OR) has played a key role in helping the aviation industry and its infrastructures maintain high growth rates and move from a news that has served an elite clientele to a mass service industry.

One of the reasons is that air operations and more generally the air transport environment provide natural contexts for the application of OR techniques and models. A second is that the aviation industry has always been a leader in the use of information technology and is heavily entrusted with the intensive use of computers over the years.

The aim of this document is to present a historical perspective of the contributions of operational research to the air transport industry. The scope of work will be limited to a selected subset of issues relating to air transport, where operational research has made some of its most significant contributions to date.

Section 2 of the document deals with the classic scheduling, routing and assignment problems of the crew in the airline industry. This is a context that fits perfectly with the use of discrete large-scale optimization approaches and in fact has motivated several methodological and computational developments in this vibrant OR zone over the years. Section 3 covers HUB planning and Queuing theory.

SECTION - 2

Schedule planning and cost minimization:

Scheduling planning involves planning future planes and crew plans to maximize airline profitability. This problem presents discouraging challenges, as they are characterized by a number of complexities, including a flight network, different types of aircraft, ports, limitations to air traffic control, air traffic control restrictions, curfew noise, maintenance requirements, passenger needs are uncertain and pricing strategies are complex. It is no surprise that no optimization model has been solved or even formulated to address this complex task of designing in a comprehensive way. The uncontrollable dimension and the complexity of the problem led to the decomposition of the global problem in a set of subproblems, often defined as follows:

(1) Schedule design: Define the markets it serves and how often and how to plan flights to meet these frequencies.

(2) Fleet assignment: Specify the size of the aircraft to be assigned to each flight.

(3) Aircraft Routing: Determine how to pilot aircraft to ensure compliance with maintenance requirements.

(4) Crew Scheduling: Selecting crews to be assigned to each flight to minimize crew costs.

Sub-optimal but feasible planes and crews have been designed, solving secondary problems, limiting solutions to subsequent problem-based solutions to the previous problems. Even if they are smaller and more simple than the general problem, these subproblems remain large and rich in complexity. In fact, practitioners and practitioners are developing models and algorithms to solve them for decades and thus have had important successes and impacts. In the late 1960s and early 1970s, United Airlines, American Airlines, British Airways and Air France, recognizing the competitive advantage that decision-making technologies could provide, form OR groups.

Fleet Allocation and Cost Reduction

With the given flight plan, the problem of fleet allocation is to allocate cost reduction from aircraft types to the leg in the flight network. The prolonged costs consist of:

(1) Operating Costs: Specific for each pair of aircraft types - aircraft type, which represent the cost of flying that flight lever with that type of aircraft.

(2) Spill Costs: Measurement of lost revenue when passenger demand for a flight segment exceeds the assigned aircraft capacity.

Abara (1989) and Hane et al. (1995) has formulated the problem of fleet allocation as a multichomain network flow problem with lateral restraints. The underlying network (shown in Figure 1) has: (1) Nodes: Represent flight and flight paths and positions. (2) Flight arches and ground arches: Each flight arch corresponds to a flight leg with the appropriate arrival time to include the minimum time needed to land and board passengers, download and load baggage and stock up. Ground bows represent inactive ground planes between flights. The goal is to flow the goods, that is, the types of aircraft, through the network in a feasible and at a minimal cost. Side restrictions impose the following requirements and restrictions:

(1) Platform: Each flight stage is assigned exactly to one type of aircraft.

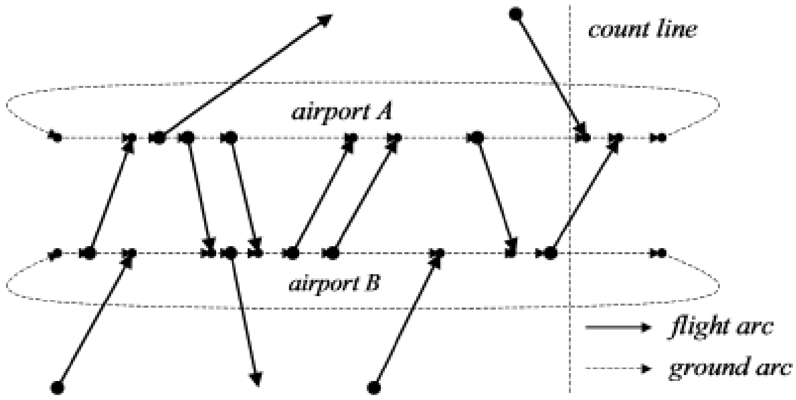

Figure 1 A Timeline Network Involving Two Airports

(2) Airline: Only available aircraft are assigned to the network.

(3) Balance: Each type of aircraft is assigned the same number of flight feet as arriving at a station departing from that station.

Each possible assignment of an aircraft type to a flight segment is represented by a binary variable, with a value of 1 if the aircraft type is assigned to that flight section and 0 otherwise. The resulting wording for the problem of allocating a main airline fleet contains about 20,000 rows and 30,000 columns and can typically be resolved in just a few minutes.

SECTION - 3

Hub planning:

Hub Planning is a multi year strategic planning activity which uses operational research to discover optimal flight schedules for meeting air transportation demand from a market of origin to a market of destination. The two methods under this procedure are point to point and hub and spoke systems which are used by airline carriers all around the world with a view to maximize profits and minimize costs.

In a pure ***point to point system***, all passengers board the planes at the origin of the flight and get off at the arrival destination. In the ***hub and spoke system***, all passengers except those whose origin or arrival destination is the hub, transfer at the hub for a second flight to their destination, or in other words take a connecting flight to reach their destination. The words "hub" and "spoke" create a pretty vivid image of how this system works. A hub is a central airport that flights are routed through, and spokes are the routes that planes take out of the hub airport. Under the point-to-point system, airlines have to fly directly between two cities, irrespective of them being large or small markets for the airlines. This results in many flights that are almost half empty, which results in airlines losing money. Most major airlines have multiple hubs as that allows them to offer more flights for passengers. From that hub, the spoke flights take passengers to select destinations. The Hub and spoke system serves network destinations with the fewest routes of any alternative design. For example, five destinations require only four routes with one hub and four spoke cities but ten routes are required if the same destinations are connected with a point-to-point system.

The basic purpose of the hub-and-spoke system is to save the airline carrier's money. Airplanes are an airline's most valuable commodity and every flight has certain fixed costs which gets broken down on per seat basis. And for every seat that gets filled by a passenger, the airline's break even point goes down. The economic advantages increase with passenger volume and flight destination network growth, positively affecting both supply and demand. Also, passengers prefer to use a single airline for their entire journey, so the ability to serve many cities of varying markets gives a competitive advantage. Passengers taking connecting flights benefit from closely timed flights, single check-in, more convenient gate and facility locations, and reduced risk of lost baggage. Familiarity with the airline's product lessens uncertainties and increases loyalty. Increases in the number of destinations also provides a bigger base to spread over advertising and promotional expenses. A single advertisement promotes 50 destinations instead of just a few.

On the supply side, seat kilometer costs benefit from economies of scale. Larger aircraft can be utilized as the number of passengers per route increase and because seating capacity increases at a higher proportion than operating and fundamental capital costs with aircraft size, seat kilometer costs decline. These savings also allow for network growth as adding a city to the network requires only one additional route by using many of the existing hub facilities. With more destinations, smaller, lower demand cities can be added that a network with fewer destinations would not support.

Although the advantages of the Hub and spoke system in gathering and dispersing passengers are many, the costs of operating the system are high. Typically about 40% of all network carrier passengers have the hub as their origin or destination. The remainder only passes through the hubs to make outbound connections. Extensive facilities and significant personnel are needed solely to accommodate these connecting passengers which is on top of the additional takeoff and landing fees and facility charges.

Finally, H&S systems are highly susceptible to delays. A delay on one or a few inbound flights can spread as outbound flights are held for connecting passengers. Flight delays increase as the airport nears full capacity as arrivals and departures are limited by available runways and so terminals and gates become more and more crowded. The hub carrier creates its own traffic congestion by scheduling ever more flights into each complex which ends up in more and more decline in asset utilization of the airlines.

On the other hand, point-to-point flights reduce total travel time, primarily by eliminating the intermediate stop, but also by avoiding roundabout routings. Passengers value the reduction in travel time. Without the schedule constraint of connecting complexes, aircraft can be utilized more fully and give rise to revenues. Gates can accommodate more operations per day and airport personnel can be utilized fully throughout the day. This system however only works in major cities or the airlines can start incurring losses. The inability to integrate passengers bound for many destinations on one single flight limits the number of origin-destination pairs in which non-stop flights can be economically operated and most small and mid-sized cities have insufficient demand to support non-stop flights to more than a few destinations.

Finally, demand varies significantly by time of day, week, season and even festivals which makes it difficult for an airline to match supply with demand. And without connecting traffic, the point-to-point carrier has no ability to balance route-specific demand, rather, it is left with scope for changes only in frequency of flights, airplane size, and the best origin and destination city pairs.

Due to the various advantages and disadvantages of both the systems, airline carriers rely on combinations consisting of both the systems to schedule their flights domestically and internationally. Companies arrive at these combinations by the means of ***Network Analysis***. Airline carriers use their data series that provide links between airports and true time origin and destination of the passenger flows ***(DB1B)***. All companies use own algorithms and for coding and optimizing hubs along with data collected for target segmentation under ***Behavioral Operations Research.***

Operations research provides a wide range of problem-solving skills to increase efficiency of individuals and organizations, however, it assumes that people always make fully rational decisions which are not affected by their emotions as well as their surroundings and that they are able to react and distinguish between different types of information. In reality, however, this is not always true and this led to the foundation of a new branch Behavioral operations research. It is defined as the study of impacts that human behavior has on operations, design and business interactions in different organizations. BOR in airlines is a major factor as it helps make the best operating schedule to meet the air transportation demand and maximizing profits while doing so. It uses social psychology and organizational behavior to investigate the seasonality of demand in air transportation.

Queuing theory:

Waiting lines and queues are a very common phenomenon. Long lines are for the most part found before railroad booking workplaces, post workplaces and bank counters especially in vast urban areas. Similarly, we also find automobiles waiting at service stations, ships waiting for berths, airplanes waiting for landing and patients waiting for doctors, Queues are, thus a very common phenomenon of modern civilized life.

Queuing models are those where a facility performs a service A queueing issue emerges when the present service rate of an office is less than the mark concerning the present flow rate of customers. If the service facility is capable of servicing the customer when he arrives, no bottlenecks will occur. But if it takes fifteen minutes to service a customer and one customer arrives every twelve minutes, then a queue will build up and it'll continue to build up up to infinite length if the same arrival and service rates continue. In such a situation the bottleneck is eliminated only if either arrival rate decreases or service rate increases or there takes place an increase in the number of service facilities. The queuing theory is concerned with the decision-making process which confronts with queue questions and makes decisions relative to the numbers of service facilities which are operating.

In the event that there are lines then the customers need to sit tight for quite a while before the service. The time lost in holding up is frequently costly regarding cash, equipments, and so forth. In that capacity there are costs related with holding up in line, usually known as waiting time cost. Cost related with facility are known as service cost. The protest of the queuing hypothesis is to accomplish a decent financial harmony between these two sorts of cost and the ideal arrangement is touched base at a point where the whole of the waiting cost and service cost is least. In brief, the question of any queuing issue is to limit the aggregate waiting and service costs.

The queuing hypothesis does not specifically take care of the issue of limiting the aggregate waiting and service costs, however it gives the administration data important to take relevant choices for the reason. It does this job by estimating different characteristics of the waiting line such as the average arrival rate, the average service rate, the average length of the queue, the average waiting time and the average time spent in the system.

Air traffic, worldwide, keeps on growing creating critical capacity situations and traffic congestion. airlines, passengers and airport authorities suffer when there are large delays. When we need a rough estimate, queuing theory can be used to analyze airport runway systems.

The three parts of a queuing system are the arrival or inputs to the system (sometimes referred to as the calling population), the queue* or the waiting line itself and the service facility.

The characteristics of these components are:

Arrival Characteristics: The input source that generates arrivals for the service system has three characteristics. Those are the size of the calling population, the pattern of arrivals and how the arrivals behave.

Size of the calling population: Population sizes are considered to be either unlimited (essentially infinite) or limited (finite). Example- The unlimited passengers arriving to check-in for traveller at airport (an independent relationship between the length of the queue and the arrival rate moreover the arrival rate of passengers lower). Most queuing models assume such an infinite calling population.

Pattern of arrivals at the System: Passengers arrive at a service facility as per some known schedule or else they will arrive in some random order. Arrivals are considered to be random when they are independent of one another and their sequence cannot be predicted exactly. Frequency in a queuing problem i.e. the number of arrivals per unit of time can be estimated using a probability distribution known as the Poisson distribution.

Behavior of the arrival: Usually queuing models assume that the passenger who arrives is a patient traveller. Patient arrive is a person or who will wait in the queue until they are served and do not change the queues. Unfortunately, life and quantitative analysis are complicated by the fact that people have been known to balk or renege. Balking refers to passengers who refuse to join the waiting lines because it is to suit their needs or interests. Reneging arrivals are those who enter the queue but they get impatient and leave the queue. Lot of times we have seen a shopper simply abandoning the shopping cart before checking out because the line was too long.

Waiting Line Characteristics: The waiting line is the second component of a queuing system. The length of a queue can either be limited or unlimited. A queue is said to be limited when it cannot increase to an infinite length. Analytic queuing models are treated in this article under an assumption of unlimited queue length.

A second waiting line characteristic deals with queue discipline. This refers to the rule by which passengers in the line are to receive service. Most systems use a queue discipline known as the first-in, first-out rule (FIFO).This is obviously not appropriate in all service systems, especially those dealing with emergencies. Usually in companies, when computer-produces pay checks and they are due out on a specific date, the payroll program has highest priority over others.

Service Facility Characteristics

The third part of this system is the service facility. It is important to examine two basic properties that is the configuration of the service system and the pattern of service times.

D.G. Kendall has developed a notation that is accepted worldwide for specifying the pattern of arrivals, the service time distribution, and the number of channels in a queuing model. This notation is usually seen in software used for queuing model. The basic three-symbol Kendall notation is in the form of the arrival distribution/service time distribution/number of service channels open. We have various equations to find the same.

Queuing Equations μ = mean number of arrivals per time period (for example, per hour) μ = mean number of people or items served per time period When determining the arrival rate (λ) and the service rate (μ), the same time period must be Used.

1. Expected no. of units or customers in the waiting line or being serviced (i.e. the expected no. of customer in the system) is:

$$\mathbf{E(n) = \lambda/(\mu-\lambda)}$$

2. Expected number of units (or customers) in the queue is:

$$\mathbf{E(nq) = \lambda\text{^}2/(\mu-\lambda)\mu}$$

The element of uncertainty is there in all queuing situations. The element of uncertainty hovers around viz-

i) we may not know the form of theoretical probability distribution which applies

ii) we might not know the parameters of the process even when we know that a particular distribution applies

iii) finally, we would simply be knowing only the probability distribution of the outcomes and not the distribution of actual outcomes even when i) and ii) are known to us.

All this complicates the queuing theory analysis. If the assumptions of ***FIRST COME FIRST SERVED*** is not a true one queuing analysis becomes more complex.

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