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METAHEURISTIC ALGORITHMS APPLICATION IN THE AVIATION INDUSTRY: A SHORT REVIEW

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ABSTRACT

This paper is a short review of metaheuristic algorithm applications in the airline industry. The purpose of these applications is to optimize the flight operation, especially during flight delay situation. Big data in the flight industry play an important role in predictive as well as prescriptive analysis. Usage of historical flight data enable model building using a metaheuristic algorithm to find a better solution in dealing with flight delay. Optimization on flight route, airlines recovery problem, crew rescheduling and passenger centric strategy will be further discussed in this paper as well. Previous related works on each aspect are reviewed to have a better understanding of the available solutions. Some recommendations are also suggested for future improvement, based on the review.

Keywords: *Metaheuristic Algorithm, Airlines Recovery Problem, Big Data, Optimization, Flight Scheduling, Flight Delay.*

1 | INTRODUCTION

The aviation industry produces vast amount of data daily, which could provide insight to optimize profits. Every year, 35 million flight departures were recorded globally, and IATA forecasts passenger demands will be doubled in the following 20 years [1]. In fact, the aviation industry is a fast-growing industry, and business is predicted to have an expansion of USD 4.20 by the year 2021. According to the Aviation Analytics Market, this expansion is mainly due to advancement in Information Technology, increasing data volume and rising usage on cloud service [2].

Big data are termed as a large and complex data set consisting of structured and unstructured data. Currently, traditional data processing applications face difficulty to cope with the underlying big data concept, 5Vs model which consists of volume, variety, velocity, veracity and value [3, 4].

In order to strive in a competitive environment, it is crucial for the airline company to leverage on the data to identify methods for minimizing cost and improve profitability. Generally, there are several problems face by airline companies such as flight delay and cancellation that may incur extra cost.

Metaheuristic algorithm is a process to explore and exploit a search space, followed by the construction of a strategy using learning strategy to obtain near-optimal solutions [5]. This algorithm has two distinct characteristics which are intensification and diversification. Intensification means utilization of information to search in a specific region, while diversification implies creation of various solutions by efficient searching in a wide search space [6, 7]. Examples of metaheuristic algorithm are genetic algorithm, neural networks and natured inspired metaheuristic algorithm [7].

This paper will identify the application of metaheuristic algorithm in the airline industry. In this paper, a short review of the main applications will be conducted. This includes optimization of the flight route, air recovery problem, crew rescheduling and reorganization of passenger itineraries. The summary of related works on each subtopic are discussed to gain more insight of the technique and purpose of various mathematical model used. Furthermore, improvements or new ideas regarding the optimization in flight delay using metaheuristic algorithm are also discussed.

2 | AVIATION DATA

There is only a small portion of archive and current aviation data being analysed, and airline companies have yet to fully understand their business well [8]. Structured and unstructured data are generated in large scale, including those of data from aircraft engine. These data seem to have less impact as compared to the primary data source consisting of passenger seat bookings, weather and airline route. However, identifying different parameters might give insight in reduction of fuel consumption [9]. As a good example from Akerkar [8], the data available in the cockpit will allow pilots to adjust their flight pattern to avoid flight delay and emergency. The primary data source can be exploited and personalized to improve the passenger's experience and to understand the passenger behaviour for marketing purposes.

3 | ON ROUTE OPTIMIZATION

Optimization is basically minimization or maximization of a problem. In improving airlines decision-making, one of the methods is to propose new flight route and ways in utilizing aircraft. In research done by Kasturi et al. [9], few metaheuristic algorithms, including firefly algorithm, bat algorithm and cuckoo algorithm were studied to optimize flight routes for profit increment. Parameters used were distance, fuel usage, income, expenditure, profit and loss. The output revealed that the bat algorithm generates the most optimum route with the least fuel consumption as compared to others. The bat algorithm is based on the mechanism of bat echolocation. In this case study, the nearest available sources and options were collected, stored and ranked. The highest ranked was considered the best option available. This paper emphasizes on the fuel saving aspect, reduction in flight distance, overflight cost and extra payload. Thus, airline company is not restricted in terms of scheduling and services. Aside from that, this paper also shows that big data analytics can assist in diversifying flight route, relocation of passenger and the formulation of an effective flight plan. In their proposed future work, they wish to consider several other variables such as operating cost, traffic forecasting, and airport capacity for obtaining the optimum result. Apart from that, the authors also suggested on hybridization of algorithm focusing mainly on the performance aspect of it.

In one of the researches done on the uninhabited combat air vehicle (UCAV), bat algorithm was used to solve the complex flight route in the battlefield. The model enables the UCAV to find a safe path while avoiding risky area. The model also considers the minimum fuel usage during that flight. This bat algorithm was modified with mutation. Hence, the UCAV can work by joining the selected nodes of the coordinates, at the same time avoiding risky area and perform costing of minimum fuel required. The traditional bat algorithm and the mutated bat algorithm were used for comparison and the result showed that the mutated bat algorithm is more effective. The authors suggested that a more detailed study of the efficient route planning method should be done, especially in the environment of the combat field. Besides, real time data should also be used on the adaptive route planning to test the usability of the plan. Although this paper focuses on the battlefield area, the method and strategy can be applied on commercial airlines to avoid dangerous flight route, finding out safer paths and further minimizing the risk of flight accident [10].

4 | AIRLINES RECOVERY PROBLEM (ARP)

One of the biggest challenges in the airline industry is the unpredictable flight delay which may be due to extreme weather, technical problem of aircraft and absentees or lateness of crew members. Subsequently leading to flight cancellation and airport closure. This issue has a negative impact in terms of profit and reputation of an airline company. Thus, having a contingency plan is important to minimize the impact of flight delay [11].

ARP functions to form new flight departure times and handle affected aircraft by cancelling or rerouting. While reaching the end of the recovery process, the flight should be under original scheduled operation [12].

There are three types of cost involved in ARP which are operating cost, passenger inconvenience cost and inconsistency cost. In order to implement any solution, operational and functional constrain of each flight need to be considered [13]. Generally, there are three main options available in the case of flight disruption which include aircraft swapping, delay and cancellation. Using empty or spare aircraft will remain the last resort to handle the problem [14].

Figure 1 shows the general procedure during flight delay by the Airline Operational Control (AOC).

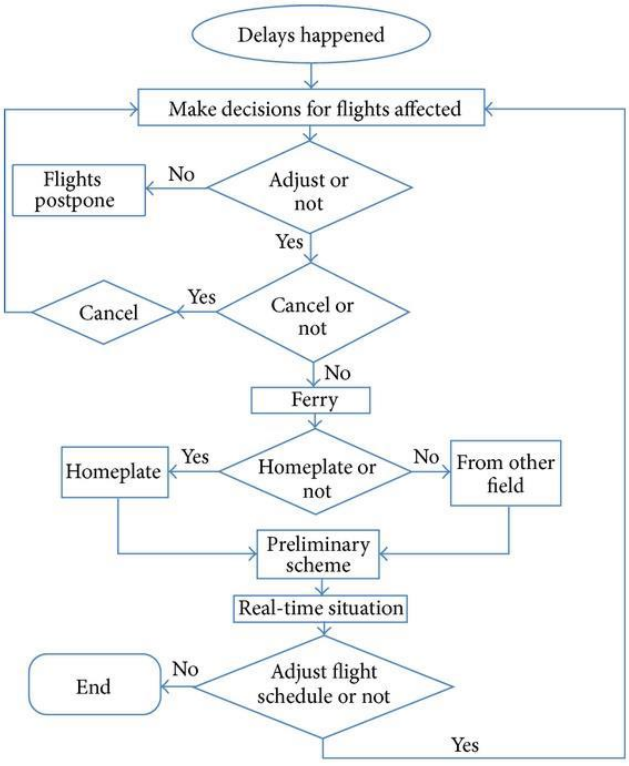

Figure 1: Flow chart of flight delay procedure by Airline Operational Control (AOC) [15].

Each airline company has their own ways to overcome flight delay situations and most airline companies follow the procedure in Figure 1. Once a flight delay occurs, the Maintenance Control Centre (MCC) will send a report to the AOC. Next, AOC will obtain relevant information from related departments. Based on the information gathered, the AOC will provide expected minutes of flight delay. AOC will then decide on the cancellation or delay of the flight. Following step would be to decide for the next flight. AOC is responsible to monitor the real-time situations and to make appropriate decisions.

Based on the procedure in Fig. 1, it is rather difficult to form a comprehensive schedule. Mou and Zhou [15] had used the Hungarian algorithm in solving model that has the application of uncertainty theory. Hence, total delay minutes will be minimized based on a certain amount of cost. Whenever an irregular flight takes place, the data are used to predict the total flight delay time. In the meantime, airline company can move one step further by deciding whether to cancel, postpone or reassign a new flight. From the result of the research, it is proven that the total delay time for passengers has significantly decreased and shows that the Hungarian algorithm is feasible for irregular flights. The authors suggested that their framework needs extra tuning. They also proposed that a future research on fleet reassignment, crew schedule recovery, integral uncertain and stochastic model. These proposed ideas aim to make the approach for flight delay more comprehensive and systematic [15]. By detecting the irregular flight at the very beginning certainly allow more time to predict possible flight delay and mitigation step can be undertaken by the airline company to handle such situation systematically. The combination of predictive and preventive analysis in this research is comprehensive and should be explored in depth.

The Ant Colony (ACO) algorithm is one of the metaheuristic algorithms implemented in ARP. Initial research was done by Zegordi et al. [16] with the approach of returning original flight schedule in the most minimum time after a flight delay. One of the strong points of this solution is the ability for flight to return to its original flight operation in the fastest time. Besides, the subsequent disrupted flight will be handled diligently, further ceasing the flight delay propagation effect. The ACO algorithm is proved effective in handling flight delay problem. However, the author suggested that this model should be tested on other similar recovery problem to fine tune the model. This study concerns more towards time management in cases of flight delay. It is indeed crucial for airline company to have a systematic and fast recovery system so that the trustworthy image of the company would convince more people. Thus, attracting more business opportunity either from the local nor global market.

Sousa et al. [17] had also used Ant Colony Optimization technique to solve the problem of Aircraft Assignment Problem (AAP) and Aircraft Recovery Problem (ARP). This study had incorporated sliding window to reschedule delayed flight. The theory behind this nature-inspired algorithm describe the tendency of ant to combine action with the main goal to minimize cost and prevent propagated disruptions. Such approach is heading towards the direction in automating AOCC due to its adaptive and flexible features. This system will also help to cut down operational cost and help reduce employees involve in the flight delay. The authors also realized that this approach is currently not feasible in a real flight management because the frequent changing of flight schedule will threaten the security protocol as well as long term flight planning. Improvement suggested includes consideration of the aggregates of flights originated from the similar route. The system will only need to generate a few nodes to obtain a solution. Besides, the authors also recommended integration of crew rescheduling problem with the Ant Colony Optimization technique. The dynamic and adaptive features of this approach would be a step closer to automate the AOCC operation with a more accurate solution. Hence, reducing the risk of making decisions based on a traditional method.

A Large Neighbourhood Search (LNS) Heuristic method processes in three level, construction, repair followed by improvement. The first two phases produce a solution aligned to the operational and functional constraint. The third phase functions to improve the solution with large changes on scheduling. Bisaillon et al. [13] had used this method in the integration of airline recovery problem with fleet assignment, on route optimization and passenger recovery. An aspect of randomization has been incorporated in this study with the aim to diversify search. This solution is capable of handling a high number of simple moves and its high feasibility allows efficient performance. However, this approach is not sensitive to characteristic of a particular variable because a prior to airline's knowledge is not necessary. The authors also explained that the algorithm is able to handle real-time data in a large scale. The robustness of this approach is suitable for Big Data application where the ability of handling complex and large amount of data is present.

In the other research done by Guimarans et al. [18], the same algorithm was used on the Stochastic Aircraft Recovery problem (SARP). They had used Constrain Programming formulation, which is fast, economical and efficient to solve combinatorial problem. They have modified the LNS through performing a SimLoop at the end of the method for robustness checking. The second modification would be the integration of SimLNS at the very beginning of the search stage. In short, the unwanted attributes will be filtered out at the early stage of the process. Yet, the computational time to run the SimLNS may be slightly longer due to the presence of simulated scenarios. The authors recommended that more study to be put into the development of tools for decision making purposes. Apart from that, they had also mentioned search efficiency improvements and increasing the neighbourhood's size in order to improve constraint propagation. Furthermore, a good suggestion was proposed for integrating simulation in the CP search tree so that during the search process, the most likely value of the variables can be propagated.

5 | CREW SCHEDULE RECOVERY

The flight delay and rescheduling will affect the crew scheduling. In that case, normal and reserve crew will be coordinated to cover the open flight followed by a formation of a new crew schedule. The new crew pairing is subjected to the rules and regulation and is usually viewed as a bottleneck phase in the whole recovery process [19]. The crew cost is considered a major cost after the fuel cost. Rules have to be taken into consideration during the planning and it is difficult to coordinate the crew with sudden rescheduling [20].

Muter et al. [20] describes a robust solution in crew pairing by using the column generation model. One of the challenges in column generation model was to solve the pricing sub problem and multi-label shortest path problem (MLSP) while searching for a negative reduced cost pairing. This had resulted in the inability to accurately calculate the reduced cost in the new column. The authors had overcome the complexity of real-life cases in crew recovery with the column generation model by using 2 pruning strategies which are exact and approximate. The context of robustness in this research is the management of extra flight, which is initially not on the flight schedule but will be added during operation. An important point of this paper is the incorporation of disruptions and recovery options during the planning stage. Thus, the crew recovery would be more effective. In order to handle the simultaneous increase in rows and columns number in column generation stage, modifications on the multi-label shortest path problem was required. Modification includes forming of new columns through pairing and building new mechanism. In future work, they proposed to improve their current algorithm, especially on the data storage aspect. Furthermore, parallel programming can be utilized to improve current performance.

Zhang et al. [19] has come out with a two-stage algorithm to solve the problem between airline and crew recovery. The first stage focusses on the flight schedule recovery with partial crew consideration to minimize the disruption of the original crew connection. The latter stage was to solve crew rescheduling with partial aircraft consideration. Furthermore, the authors compared their algorithm with two benchmark algorithms and found out their algorithm is capable of generating high quality solutions consistently. This study had shown that by integrating flight-scheduling and aircraft consideration, the solution will be in a more efficient manner. The authors may consider the integration of passenger's schedule recovery with the current algorithm in near future. With such integrated model, a more accurate solution with consideration of delayed flight details and crew schedule can be produced as compared to only consideration on one aspect which is ARP.

6 | PASSENGER CENTRIC STRATEGIES

Delayed flight will subsequently affect the passenger itineraries. A new schedule needed to be recovered and a few available options are reassigning to available flights in the same airlines, second, seek assistance from other airline company to allow transferring of flights to the same destinations. Thirdly, is to reschedule another flight on the next day with compensation of an overnight accommodation [14].

The majority of literature approach the passenger recovery issue using the hub and spoke network. The number of itineraries that must be reconstructed following a flight delay may be higher than a flight network because passenger itineraries may contain one or more flight leg. This complex system has made it difficult to be handled [21].

There are a few types of cost incurred, including flight delay cost which refers to overtime payment and cost of meals. The transition cost, referred to dissatisfaction cost of the customer as well as the costs of baggage transfer and rebooking [14]. Passenger recovery is usually the last stage of a flight recovery [21].

In the research by Hu et al. [14], a new method using an integer programming model was proposed in combining aircraft and passenger recovery. This model is based on approximate reduced time-band network and passenger transiting relationship. The main goal of this study is to reduce. This study had shown that the optimum method is to ground few aircrafts followed by passengers rescheduling. At the initial stage, a feasibility analysis was conducted to identify specific conditions to perform aircraft and passenger recovery. IBM ILOG CPLEX Optimization Studio (CPLEX) produced the solution followed by adjustment to obtain a more accurate cost. In future, the authors stated that they consider looking into the aspect of aircraft maintenance. Secondly, they also have the intention to integrate aircraft, passenger and crew recovery in an expanded model where a more improved solution will be produced followed by the integration.

On the other hand, Sinclair et al. [22] had proposed a post-optimization column generation heuristic which can be modified solely for passenger variables. It had also proven to yield the best solution after execution with Large Neighbourhood Search (LNS) heuristic. This model can be further modified to solve large instances based on the passenger variables. The model is already able to considerably reduce the operating costs of solving the Mixed Integer Programming (MIP) in a small number of flight delay. This implies that solving all instances may show significant improvements. The authors recommend developing a method which has the capability to solve MIP with many flight delays. Apart from that, future study should place crew recovery component in the solution methodology rather than solving it in a sequential method.

A paper written by Maher [21] focussed on passenger recovery process using column and row generation which can reduce operational costs and increase passenger flow. This approach proposed alternative arrangement for passenger through cancellation variables modelling. In the case of flight disruption, a knapsack variable represented by cancellations variable produces possible passenger relocation options. Column-row-generations solution can be applied on the model for an integrated recovery problem with passenger reallocation (IRP-PR) to obtain a faster runtime for the process. A comparison was made between column generation and column-and-row generation solutions in term of runtime. The latter proves to have a faster runtime and a few enhancements was also made on the solution approach which further improve the runtime. Although this approach is simple and effective, the average delay experienced per passenger down not have any significant improvement. Future works proposed by the authors are to enhance the passenger reallocation approach to a broader recovery scheme. Other than that, more focus should be on the passenger flows in order to reduce recovery cost and improve passenger satisfaction.

7 | CONCLUSION

There are several researches on meta-heuristic algorithm in the airline industry where this family of algorithm is capable of handling complex and large changes in a network. In fact, there are multiple types of algorithm within the meta-heuristic approaches, each being implemented according to the type of case and needs. However, testing of these algorithms requires a large, quality data for an accurate result. In this literature review, I would like to focus on the perspective of incorporating big data analytics with meta-heuristic algorithm to achieve better and enhanced outcome either to optimize flight route or dealing issues with flight delay. Furthermore, many possible variables can be added into the algorithm to solve more issues. As for example, variable such as traffic forecasting and airport capacity restriction variables can be added to optimize better flight route. Apart from that, by integrating three cascading recovery phases, which are flight, crew and passenger recovery will produce a holistic framework of airline service recovery.

Integration of both predictive and prescriptive analysis in the area of flight delay would make the handling of this issue more efficient and cost-effective. Flight delay can be predicted based on the suitable model and real time data, followed by the prescriptive analysis discussed above will certainly help the airline company to plan ahead and make accurate decisions.

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