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Airline Crew Hotel Assignment: An Optimization Framework for Fairness and Efficiency

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Abstract

Crew fatigue management is a critical aspect of airline operations, and layover scheduling plays a key role in ensuring the well-being of flight crew members. The increasing complexity of airline networks and availability of multiple hotels at stations necessitates the development of a framework leveraging efficient assignment of crew to the hotels. Besides efficiency, there are pre-defined rules that should be considered such as group-based assignment and maximum quota. In order to efficiently handle the assignment process, this study proposes a novel optimization framework with Mixed Integer Programming (MIP) formulation that ensures compliance with the associated rules. Meanwhile, the proposed optimization model prioritizes fairness among the hotels at the same station. To validate the effectiveness of the proposed approach, an extensive set of experiments are conducted using real-world airline data and the results are analyzed thoroughly. The experiments depict that the proposed optimization model can be solved efficiently within a short time frame, making it suitable for large-scale airline operations.

Keywords: Crew scheduling, optimization, layover planning, fairness

1. Introduction

Airline operations include many activities such as fleet planning, tail assignment, aircraft routing and disruption recovery, all of which are critical for strategic and tactical decisions. A key component of these activities is crew management, which is a complex process that varies in scope depending on the time horizon [1]. For long-term crew planning purposes, based on the number of aircrafts and their flight schedules, both cockpit and cabin crew requirements are forecasted. This allows airlines to plan the resources according to the demand in the long run. Monthly crew scheduling is another core crew planning process which consists of generating duties, trainings and rest periods. As an integral part of the monthly crew scheduling process, layovers play an important role in preventing crew fatigue [2]. Layover durations should exceed a certain threshold to comply regulations. Failing to satisfy these obligations does not only lead to legal sanctions but also result in fatigue which directly affects the flight safety. As flying requires complete attention and is a cognitively dense activity, crew must be fully rested before the flight. Therefore, airlines try to maximize the rest duration between the duties. On the other hand, layovers incur both accommodation cost and transportation cost to the airlines. To avoid additional transportation cost, airlines group the crew according to their departure flight and try to assign them to the same hotel as a group.

The crew can be assigned to the hotels that an airline has an agreement with. To lower the costs and enhance the flexibility of the operations, airlines may negotiate contracts with multiple hotels. These contracts typically specify the number of rooms pre-allocated to the airlines on a daily basis. Hence, it is important to maximize the utilization rate of these rooms as exceeding the given quota or assigning crew to a non-contracted hotel results in additional cost.

In this direction, this paper implements a Mixed Integer Programming (MIP) model assigning crew to the hotels at a station. Within this scope, given a layover schedule, the model executes a group-based assignment based on the hotel properties and contracts. In the case where multiple contracted hotels are available at a station, the proposed solution seeks fairness and tries to minimize the variations of the hotel utilization rates.

The remainder of this paper is structured as follows. Review of the related literature and contributions of this work are given in Section 2. Problem definition and proposed MIP model is presented in Section 3. Experiment settings and performance evaluation of the proposed model is explained in Section 4. Section 5 concludes the paper and provides potential future directions in this domain.

2. Literature Review

There are different applications of assignment problems in different domains, including but not limited to logistics, healthcare, and transportation. Assignment problem has been extensively studied for several decades, with a literature dedicated to developing efficient algorithms and models. While the study made by Nguyen et al. [3] utilizes assignment problem to optimally assign nurses to patients, in another study made by Dolgui et al. [4] applies assignment problem for assigning operations for stations.

Assignment problems are also widely encountered in the aviation domain. For instance, the study conducted by Yan and Chang [5] proposes a solution that assigns flights to gates. In another study, which is made by Khaled et al. [6], an optimization model is introduced that assigns aircrafts to the flights of the given flight schedule.

Fairness concern can be observed in various problems. Depending on the problem characteristics and the need of the decision maker, definition and scope of fairness could vary. In some cases, fairness can be interpreted as maximizing the minimum of the outcomes which is the case in the Rawlsian approach [7]. As discussed by Karsu and Morton [8], there are many inequity indexes that can be used for fairness, such as range of the values, mean deviation, variation and sum of pairwise absolute differences. In the study made by Ulutaş [9], it assumed that the decision maker has equitable rational preference model and if the allocation follows this model it is assumed to be fair.

Although assignment problems and fairness concept are worked thoroughly in the literature, to the best our knowledge, there are not many works directly related to the hotel room assignment. In study made by Wang and Caudillo-Fuentes [10], the similar problem is approached from the perspective of hotel management. The solution approach proposed in this study assign rooms to the reservations such that the duration between consecutive reservations for each room is minimized. To achieve this, the proposed heuristic solution maximizes the number of bookings. Then, an MIP model is implemented, which is fed with the result provided by the heuristic-based solution.

This study proposes an MIP model for the crew layover assignments to hotels with the objective of reducing the costs while ensuring the related rules and maintaining fairness among the hotels. The literature on this specific topic is limited and our proposed approach provides a novel contribution to the field.

3. Design of Optimal Crew Hotel Assignment

In this section, we introduce the MIP formulation for the optimal assignment of airline crew to the hotels for efficient planning of layover. Before providing the mathematical formulation of the proposed model, the problem definition is introduced by covering the related rules that need to be taken into consideration throughout the optimization process, rendering a constrained assignment problem.

3.1. Problem Definition

There are stringent regulations in the airline industry requiring a minimum rest time for crew members between consecutive duties. If duty ends at a non-base station, to ensure compliance, crew members are typically assigned to one of the contracted hotels. Considering this process in an end-to-end manner, it should be handled efficiently to prevent the crew fatigue.

The typical monthly crew scheduling process focuses on creating a feasible and efficient schedule that meets regulatory requirements, crew preferences, and operational constraints. The planned layovers are often represented as a block of time, without specifying the exact hotel assignments, check-in and check-out times. As a result, a separate process is needed to transform the planned schedule into an operational plan.
Especially at hub stations, multiple contracted hotels are often available, presenting an opportunity to enhance crew experience while reducing operational costs. However, the optimal assignment of crew to hotels, as well as the determination of check-in and check-out times, remains a complex challenge. A non-optimal solution might lead to airlines incurring unnecessary transportation costs and compromising crew well-being. This study aims to address this problem by developing a solution to optimize crew-to-hotel assignments. Within this scope, in addition to the typical aviation regulations, there exists a set of business rules that should be considered during this assignment:

- Maximum quota defined for each contracted hotel
- Transportation time
- Fairness among the hotels at a station

- Group assignments
- Assignment of crew with short layover to the hotels closer to the airport

The details of the contract between airlines and hotels might specify a maximum quota for each day, which specifies the maximum number of crew that can be assigned on a daily basis. While determining the check-in and check-out times, the assignment model should take the estimated transportation time into consideration, in order not to shorten the layover duration and violate the regulations. As mentioned before, while meeting these rules, the optimization model is expected to maintain fairness among the hotels and not prioritize one over another, for stations where multiple contracted hotels exist.

In airline operations, a flight crew comprises multiple members, and those assigned to the same departure flight at a station are considered a "group". Crew members within the same group typically travel together to the airport, and therefore, it is logistically efficient to assign them to the same hotel. By doing so, airlines can minimize the need for multiple shuttle services and reduce transportation costs. Lastly, in order to satisfy the minimum rest time regulations, crew with short layover should be assigned to the hotels that are closer to the airport in order to avoid long transport durations.

To satisfy these requirements and achieve optimal assignment of crew to the hotels, this section introduces an MIP model along with the associated objective function and constraints.

3.2. MIP Model

The main objective of the proposed optimization model is to minimize the violation of rules while making assignments. In the proposed solution, some of the rules are defined as hard constraint, such as maximum quota. However, group-based assignment and fairness are integrated into the optimization model as soft constraints. In this direction, the proposed model is formulated as multi-objective optimization.

In this model, the set of a planned layover throughout the planning time frame is denoted as L. The set of hotels are listed in set H. In order to determine the check-in and check-out time, it would be critical to also utilize the set of flights, which is denoted as F, with relevant information during the optimization process. Crew members are grouped based on their departure flight at a station after layover. These groups are represented by set G.

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Lastly, the set of time slots throughout the planning time frame is depicted as T. These sets, indices and their descriptions are summarized in Table 1.

Table 1: Sets and descriptions

Sets and indices	Descriptions
$L = \{0, 1, ..., l\}$	Set of layovers
$H = \{0, 1, ..., h\}$	Set of contracted hotels
$F = \{0, 1, ..., f\}$	Set of flights
$G = \{0, 1, ..., g\}$	Set of crew groups based on departure flights
$T = \{0, 1, ..., t\}$	Set of time slots

Based on these sets and the requirements, the optimization model also incorporates a cluster of parameters, which are depicted in Table 2. In this direction, we define the maximum quota defined for hotel h as v_h. The planned arrival and departure date/time for flight f is specified as b_f and d_f, respectively. In addition to these, there are some operation related parameters. The duration of brief and debrief processes are defined as β and θ, respectively. Lastly, since the main objective is to minimize the violation of assignment rules and maximize the degree of fairness, corresponding penalty values are introduced. For each violation of group-based assignment (e.g., assigning the members of same group to different hotels), penalty of ω is added. Furthermore, penalty μ is added for the following scenarios:

- If the duration of layover is higher than e, assignment of crew to airport hotel should be penalized.
- If the duration of layover is shorter than e, assignment of crew to city hotel should be penalized.

This preference of hotel types based on the layover duration is represented as j_{lh}. To map each time slot to the exact date/time format, the optimization model utilizes parameter α_t. Lastly, the distance between hotel h and associated airport, in terms of transport duration, is defined through c_h.

Based on the problem characteristics and requirements, three different type of decision variables are defined. In this direction, x_{lht}, which is a binary decision variable, becomes 1 if layover l is assigned to hotel h and check-in is at time slot t. Another related binary decision variable is z_{lht}, which is 1 if layover l is assigned to hotel h and check-out is at time slot t. These decision variables are the main representation of assignments.

Table 2: Optimization model parameters

Parameters	Descriptions
v_h	Maximum quota defined for hotel h
b_l	Planned arrival date/time for layover l
d_l	Planned departure date/time for layover l
ψ_{gl}	Whether layover l is a member of group g
β	Duration of brief process
θ	Duration of debrief process
ω	Violation of group-based assignment penalty
μ	Violation of airport/city hotel assignment penalty
e	Threshold of airport/city hotel assignment
j_{lh}	If hotel h is the preferred type (i.e., city or airport hotel) according to the duration of layover l
α_t	Day-time of time slot t
c_{h}	Distance (in terms of duration) of hotel h to associated airport

There is another set of decision variables that plays a critical role in the objective function for penalizing rule violations. While y_{gh} represents whether at least 1 crew member in group g is assigned to hotel h, it is mainly used in penalizing the cases where group-based assignment is violated. To calculate the fairness, the optimization model utilizes r_h, which represents the total number of assignments to hotel h throughout the planning period. Based on this, the standard deviation of hotel h, which is represented as σ_h, based on the average number of assignments made to the hotels at the same station is calculated.

Table 3: Decision Variables

Decision Variable	Descriptions
x_{lht}	Whether layover l is assigned to hotel h and check-in is at time slot t
y_{gh}	Whether at least 1 crew member in group g is assigned to hotel h
z_{lht}	Whether layover l is assigned to hotel h and check-out is at time slot t
σ_h	Standard deviation of hotel h based on the average number of assignments made to each hotel at the corresponding station
r_h	Total number of layover assignments to hotel h throughout the planning period

Based on the sets, parameters and decision variables introduced in this section, the following mathematical formulation of the MIP model is proposed. It should be noted that the optimization model is intended to be executed separately for each station.

Objective Function:

$$min \sum_{l,h,t} x_{lht}(1 - j_{lh})\mu \; + \omega \sum_{g} \left(\sum_{h} y_{gh} - 1 \right) + \frac{\sum_h \sigma_h}{|H|} \quad (1)$$

Constraints:

$$\sum_{t} \sum_{h} x_{lht} = 1, \qquad \forall l \in L \quad (2)$$

$$\sum_{t} x_{lht}\psi_{gl} \leq y_{gh}, \qquad \forall g \in G, h \in H, l \in L \quad (3)$$

$$\sum_{t} \sum_{l} x_{lht}\psi_{gl} \geq y_{gh}, \qquad \forall g \in G, h \in H \quad (4)$$

$$\sum_{t} x_{lht} = \sum_{t} z_{lht}, \qquad \forall l \in L, h \in H \quad (5)$$

$$\sum_{t} \sum_{h} x_{lht}\alpha_t \geq \sum_{t} \sum_{h} x_{lht}(\theta + c_h + b_l), \forall l \in L \quad (6)$$

$$\sum_{t} \sum_{h} z_{lht}\alpha_t = \sum_{t} \sum_{h} z_{lht}(d_l - \beta - c_h), \forall l \in L \quad (7)$$

$$\sum_{t \in day} \sum_{l} x_{lht} \leq v_h, \qquad \forall h \in H, day \quad (8)$$

$$\sigma_h \geq r_h - \frac{\sum_h r_h}{|H|}, \qquad \forall h \in H \quad (9)$$

$$\sigma_h \geq \frac{\sum_h r_h}{|H|} - r_h, \qquad \forall h \in H \quad (10)$$

$$r_h = \sum_{t} \sum_{l} x_{lht}, \qquad \forall h \in H \quad (11)$$

$$x_{lht} = \{0,1\}, \qquad \forall(l,h,t) \tag{12}$$

$$z_{lht} = \{0,1\}, \qquad \forall(l,h,t) \tag{13}$$

$$y_{gh} = \{0,1\}, \qquad \forall(g,h) \tag{14}$$

Equation 1 represents the objective function in which a set of assignments are penalized. The first part of the objective function tries to assign layovers based on the duration. If the duration of layover is short, an airport hotel should be prioritized, if available, to maximize the rest time. However, if the layover duration is long enough, then the model should prioritize the city hotel. If the layover is assigned to a non-prioritized type of hotel, the objective function adds a penalty. The second part of the objective function penalizes if crew in the same group are assigned to different hotels. Lastly, the third part of the objective function tries to minimize the deviation between hotels. In other words, it tries to maximize the fairness among hotels at a station.

In Constraints 2, it enforces each layover to be assigned to a hotel. Constraints 3 and 4 defines the group assignment rules. In the former one, group assignment variable should be set to 1, if any layover instance (i.e., crew) part of that group is assigned to the corresponding hotel. The latter one states that the group assignment variable should be set to 0, if none of the associated layover instances are assigned to the corresponding hotel. Constraints 5 states that check-in and check-out operations should be handled at the same hotel. Constraints 6 and Constraints 7 specifies the earliest check-in and latest check-out times, respectively. In Constraints 8, the maximum quota rule is defined. The total assignment for a particular day cannot exceed the maximum quota defined for that corresponding hotel. Constraints 9, Constraints 10 and Constraints 11 are associated with the fairness rule. Constraints 9 and Constraints 10 defines the lower bound of deviation from the average assignments, while Constraints 11 introduces an intermediate variable for calculating the total number of layovers assigned to a hotel during the planning horizon. Lastly, Constraints 12, Constraints 13 and Constraints 14 defines the value set of the binary variables used in the model.

4. Performance Evaluation of the MIP Model

The proposed MIP model is evaluated based on a set of test cases and experiments. The MIP model is implemented with Python interface of Gurobi 12.0.1, which runs on a machine with 8-core CPU and 64 GB main memory. For hotel, layover and other related information, this paper benefits from data provided by Turkish Airlines. The performance of the model is assessed according to its scalability, solution quality and solution time. For this purpose, we parameterized different settings in the experiments and the results are presented as well as discussed in this section. The parameters that are utilized throughout the performance evaluation phase is summarized in Table 4.

Table 4: Experiment Settings

Parameter	Values
Number of hotels	[2, 3, 5, 7, 9]
Number of layover instances during the planning horizon	[100, 300, 600]
Runtime	5 minutes
Planning period	5 days
Daily quota of hotels	50

Based on the experimental settings, the proposed optimization model is executed and the results are analyzed thoroughly. The results provide insights into the efficiency of the proposed approach and highlights how it scales to larger problem instances.

The results are presented in Table 5. It should be noted that the proposed optimization model implementation leverages the hierarchical multiple objectives feature of Gurobi to effectively manage the complex objective function presented in the previous section. In particular, the objective function is categorized into a bi-level hierarchy, where the top-level objective prioritizes group assignment and city/airport hotel assignment costs based on duration. The secondary layer of the hierarchy focuses on minimizing the cost of violating fairness. Across all problem instances and settings, MIP model is able to achieve optimality for the top-level objectives. Consequently, this section reports the optimality gap of only the fairness part of the objective.

The results indicate that the fairness optimality gap is 0% for most instances and except for a few cases where the number of layover instances and hotels is larger. Specifically, when the number of layover instances is 600 and the number of hotels is 7 or 9, the fairness optimality gap is 18.4% and 100%, respectively. It should be noted that the optimality gap 100% refers to a case where a feasible solution is found but lower bound is set to 0 until the runtime expires. These results suggest that the proposed MIP model is still successful in achieving fairness among hotels as the problem size increases.

Table 5: Results obtained through various settings

Number of layover instances	Number of hotels	Fairness optimality gap	Runtime (with fairness)	Runtime (without fairness)
100	2	0%	1 sec	1 sec
	3	0%	2 sec	1 sec
	5	0%	8 sec	1 sec
	7	0%	20 sec	1 sec
	9	0%	80 sec	1 sec
300	2	0%	3 sec	1 sec
	3	0%	3 sec	1 sec
	5	0%	14 sec	1 sec
	7	0%	25 sec	1 sec
	9	0%	140 sec	2 sec
600	2	0%	7 sec	4 sec
	3	0%	11 sec	3 sec
	5	0%	148 sec	3 sec
	7	18.4%	300 sec	1 sec
	9	100%	300 sec	4 sec

As stated, maximum runtime for all cases is set to 5 minutes. In order to assess the complexity brought by fairness, the experiments are also conducted by disabling the fairness aspects of the model. The related results depict that the proposed model with fairness consideration has a longer runtime compared to the model without fairness. When inspected in detail, it is seen that as the number of hotels increases, the runtime with fairness grows significantly. However, the runtime without fairness remains relatively stable. The main reason is that the fairness constraints and related variables add a significant complexity to the optimization model. However, it is observed that the runtime increase is reasonable, especially for the smaller problem instances. For example, when the number of layover instances is 100, the proposed solution is able to find optimal solution in at most 80 seconds. Except the largest problem instance (i.e., 600 layover instances with 9 hotels), the proposed solution is capable of providing optimal or near optimal solution. In fact, the model was able to find a good solution but it fails to report the optimality gap.

It is also observed that the number of layover instances has relatively lower impact on the optimality gap and runtime than the number of hotels. As expected, the increase in the number of layover instances leads to a longer solution time, for a fixed number of hotels. However, with the increased number of hotels, the solution space of fairness expands as well. For this reason, when fairness aspects are added to the model, solution runtime is mostly impacted by the number of hotels.

Overall, the experimental results demonstrate that the proposed optimization model is efficient and scalable, especially for small and medium sized problems. While the fairness optimality gap increases for larger problem instances, the results indicate that the model can still achieve good solutions within a reasonable runtime. The ability of the proposed solution in achieving fairness and optimality for assignment rules makes it a valuable tool for practical applications.

5. Conclusion

Efficient layover planning is a significant process for airlines to manage crew fatigue under stringent rules. In cases where airlines have business relationship with multiple hotels at a particular station, it might become challenging to handle the operations of assigning crew to the hotel as there are specific business rules. To implement an efficient and scalable solution while addressing the fairness requirements, this study proposes an MIP model providing optimal assignment of airline crew to the hotels. Based on an extensive set of experiments, it is shown that the proposed optimization model is capable of providing optimal or near optimal solutions for even larger problem instances. While it efficiently assigns crew to the hotels meeting group assignment, quota and other related business constraints, it is also able to maintain fairness among multiple hotels during the planning period. As a future work in this domain, a pre-processing module utilizing machine learning (ML) algorithms could be a promising approach to eliminate a subset of the hotels based on the previous assignments. Besides, further investigation of the scalability for larger instances and development of a heuristic for such cases where exact solution methodologies might fail to provide a good solution is important.

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