Airline crew scheduling automatic system

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Abstract

Crew scheduling is one of the most common tasks in air transportation. There is a list of specific requirements for crew planning. Crew should be balanced between load and rest periods during flight duty period and duration of recovery time. Human action is limited by its performance. Increased load of a person without a required period of recovery will increase multiple risks associated with human factor in civil aviation. Therefore, after each flight which is associated with flight duty period, crew have to spend some time for recovery (which includes acclimatization and rest periods). International aviation community developed a list of specific requirements for the duration of flight duty period and required time for crew recovery. Airlines have to follow all these requirements to provide safe air transportation services. In the paper, we propose an algorithm for an automatic crew scheduling system based on effective time distribution. A history of flight duty periods assigned to a particular crew member has been accumulated and used as input data. The algorithm provides effective crew planning of airlines based on normative regulations provided in different countries. Specific software has been developed to verify proposed model of airline crew planning tasks.

Keywords

flight duty period, civil aviation, air transportation, data processing, software, big data, human factor

1. Introduction

Globalization is a fundamental aspect of today's world, and aviation has played a crucial role in facilitating it. Air transportation makes passengers travel and cargo delivery across long distances. Civil aviation connects continents with the speediest transportation means, making distance no longer a barrier. Civil aviation has created a global transport network that spans the entire planet, enabling people to travel vast distances quickly and comfortably [1]. According to the International Air Transport Association, about 37.7 million flights were made in 2023, which is 17% more than in 2022 with 32.2 million, and 8.6 billion passengers being transported [2]. However, these figures still do not reach the values of 2019, before the start of the COVID-19 pandemic, when the value of completed flights was 46.8 million and passengers were 9.1 billion [3]. Air transportation is served by 28674 aircraft operating globally by 2022 [4].

Despite all the latest achievements in artificial intelligence and electronic systems, the presence of the crew on board the aircraft is a mandatory factor. During a normal flight, many different factors could act on an airplane [5, 6]. Only humans can make adequate feedback in case of dangerous factor action [7, 8]. Algorithms of Flight Management System and Automatic control are capable of supporting nominal airplane flight in fully automatic mode [9, 10]. Moreover, crew uses manual flight control during the take-off and landing phases of flight. Most modern airplanes are in fully automatic control mode during the en-route phase when airplane is on cruise altitude and weather action is minimal. Crew should control main parameters of flight only [11, 12]. Crew and air traffic controllers are important components of successful air transportation. The importance of crew caused appearance of human factor which affect the safety of aviation [13, 14].

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Human factor action could be controlled by specific rules based on human responsibility in the air transportation system [15, 16]. To perform main tasks crew should have normal human needs for sleep and rest. Commonly, airlines have a special department responsible for organizing crews for a flight ("Crew Planning"). Crew planning grounds on multiple normative documents which minimized human factor action and ensured required level of flight safety [17, 18]. Minimization of human factor action on the crew is achieved by multiple inspections and training [19, 20].

The crew selection process requires processing a large volume of data, including full flight history and results of last training by each personnel (pilot, flight attendant, engineer) [21, 22]. Crew selection process has to identify the most effective crew composition, which could be the most suitable based on the conditions of the specific flight under consideration and the flight schedule as an operational scale, from today to a week ahead (or in strategic from a week to a year). Selection process requires exchange of official data between a wide range of departments and includes a lot of nuances and bureaucracy for the crew planning manager [23, 24]. Modern information technologies have greatly facilitated this issue due to the high performance of storing data from various departments in one unified database and then using software to reproduce and represent data in a given format for one or another user [25].

Also, there are several specific software, that could automatically analyze changes to the flight schedule made by the flight planning manager of the flight planning department, the airline's current boards and crews [26, 27]. Result of data processing could be effective crew scheduling to serve particular flights. Also, such software supports simultaneous data sharing with all users, which has been involved in the process.

Specific software makes possible to specify different types of actions that can be assigned to the crew. For example, a train transfer or a scheduled air safety briefing is convenient, but the downside is that even though there is a function that shows the crew suitable for the selected flight, only takes into account the fact that they do not have other tasks during the selected flight. In the case if user puts such an action as a transfer for a certain crew member, the function will select him for the flight, although according to the rules, he cannot perform it due to a violation of the pre-flight rest.

In this paper, we develop an algorithm of passive decision support systems for implementation in specific crew planning software. Proposed algorithm uses input data from airline historical flight database to select crew members who are suitable for the flight according to multiple criteria and provides effective decisions based on the ranking system.

The paper is structured as follows: the second section includes detailed information about the organization and selection of the crew for the corresponding flight, as well as specific of flight planning department; the third section describes a mathematical and functional model of software, as well as the list of criteria for initial selection and ranking; fourth section escribe results regarding performance and quality of proposed software.

2. Crew scheduling in air transportation

Air transportation grounds on aviation law and regulation of all activities, like any other business or human activity. Specific of air transportation grounds on airspace usage. Airspace is provided by different administrative bodies to airspace users based on criteria of safety of air transportation. Most flights use multiple airspaces to perform flight connections [28, 29].

Basic principles of air transportation and flight rules were approved at "Chicago Convention". The International Civil Aviation Organization (ICAO) regulates all activities of civil aviation [30]. ICAO issues Standards and Recommended Practices (SARPs) in the field of civil aviation, based on which ICAO members provide legislation regulating all aviation activities. SARPs are not mandatory and any country can notify a difference in its legislation and SARPs. However, since the uniformity of the application of these standards improves the state of aviation safety, more and more countries apply them. In addition, various international and regional organizations (Eurocontrol, IATA, and EASA) also issue rules for their participants.

In this study, we follow ICAO regulation on fatigue risk management, system requirements [17], and the European Union document on the regulation of air operations [31]. Normative documents define specific terms: Duty, Duty period, Flight duty period, and On-call to identify actions and duties of crew. When the flight planning manager assigns a crew member to a flight on a certain day, he assigns him a Duty period, within which he will perform the duties assigned to him. At the same time, the Duty period (DP) is not a Flight duty period (FDP), but the second may be included in the first. It could be, that when a crew member leaves home and expects to be taken to the airport, his Duty period continues, and when the airplane on which crew member takes off, his Flight duty period begins and ends when the plane lands and stops the engines. But his duty period ends when he leaves the airport and is taken home.

In addition, a crew member can be assigned On-call or standby as it is called otherwise, that is, he does not fly on that day, but at the same time remains in full readiness to arrive at the designated place and start performing duty. Of course, it is impossible to work 24/7 without a break, so there is a rest period when a crew member rests and cannot be called to perform duty.

Duration of all of these periods is described in normative documents. The maximum duty period is 14 hours per day, but the number of hours can be up to 16 with a reinforced crew and up to 18 with a doubled crew. Also, the maximum number of hours should not exceed 60 for 7 days, 110 for 14 days, and 190 for 28 days. The daily maximum flight duty period is determined based on time start, whether the crew has acclimatized, and the duration of the planned flight (the crew can perform several flights during the Flight duty period if it meets the standards) in accordance with Table 1 [19]. The number of sectors indicates the number of joint flights for one crew team.

Table 1
Duration of flight duty period

Start of flight duty period	Sectors								
	1–2	3	4	5	6	7	8	9	10
06:00–13:29	13:00	12:30	12:00	11:30	11:00	10:30	10:00	09:30	09:00
13:30–13:59	12:45	12:15	11:45	11:15	10:45	10:15	09:45	09:15	09:00
14:00–14:29	12:30	12:00	11:30	11:00	10:30	10:00	09:30	09:00	09:00
14:30–14:59	12:15	11:45	11:15	10:45	10:15	09:45	09:15	09:00	09:00
15:00–15:29	12:00	11:30	11:00	10:30	10:00	09:30	09:00	09:00	09:00
15:30–15:59	11:45	11:15	10:45	10:15	09:45	09:15	09:00	09:00	09:00
16:00–16:29	11:30	11:00	10:30	10:00	09:30	09:00	09:00	09:00	09:00
16:30-16:59	11:15	10:45	10:15	09:45	09:15	09:00	09:00	09:00	09:00
17:00-04:59	11:00	10:30	10:00	09:30	09:00	09:00	09:00	09:00	09:00
05:00-05:14	12:00	11:30	11:00	10:30	09:00	09:30	09:00	09:00	09:00
05:15-05:29	12:15	11:45	11:15	10:45	10:15	09:45	09:15	09:00	09:00
05:30-05:44	12:30	12:00	11:30	11:00	10:30	10:00	09:30	09:00	09:00
05:45-05:59	12:45	12:15	11:45	11:15	10:45	10:15	09:45	09:15	09:00

Maximum flight duty time is 100 hours for 28 calendar days, 900 hours for 1 calendar year, and 1000 hours for 12 consecutive calendar months.

Acclimatization is another important element of human factor. Human require some time to adapt to new time zone. In case, after the flight, a crew member is not at the airport from where his flight started, the difference D_{TZ} in the time zones between the point of departure and landing has to be calculated for getting a particular time for rest and recovery:

- If $2 \leq D_{TZ} \leq 4$, then crew requires from 48 to 72 hours for acclimatization;
- If $4 < D_{TZ} \leq 6$, then from 72 to 96 hours of rest are required;
- If $6 < D_{TZ} \leq 9$, then from 96 to 120 hours of rest could be required;
- If $9 < D_{TZ} \leq 12$, then 120 hours of rest for acclimatization could be provided.

If a crew member was not given enough hours of rest before the next flight duty period, crew should be considered in an uncertain state of acclimatization. That could be a reason for the increased risk of human factor action.

Duration of the rest period should be not less than the previous flight duty period or 12 hours, whichever is longer (in case if crew is still at the departure airport). There are also recurrent extended recovery rest periods, which are at least 36 hours of rest for 7 consecutive calendar days, while this time must include 2 local nights, and no more than 168 hours must pass from the end of one recurrent extended recovery rest period to the beginning of another. There are also mandatory pre-flight and post-flight 12-hour rest periods when the crew cannot perform additional flights.

3. Crew selection process

Crew selection is an important element of risk minimization in civil aviation. Each crew member has a specific identification code. All historical data associated with the crew are archived in the specific database. Selection process should search for the most efficient set of crew members that meet the requirements of DP, FDP, rest, and acclimatization.

Input data for selection algorithm includes airplane crew schedules during particular periods which are provided by specific software. Proposed algorithm analysis of input data and provides a ranked list of crew for upcoming flights for a specified duration of flight planning. User (or flight planning manager) of software should choose a crew load for the upcoming period. Following the selected parameters, the input array of data is sorted.

Let's denote the input associative array of data as A, which consists of keys that represent unique records of the number of crew members a_i. Value is assigned in the form of tuples of data N_i concerning the tasks assigned to particular crew members for a selected period.

The structural scheme of proposed algorithm is shown in Figure 1. Input data obtained from the database includes crew members' identification and their schedules. Also, input data includes information from flight planning manager about the list of events that must be taken into account when calculating the FDP. Selection is an iterative process of removing the worst crew which is continued until the required crew set is obtained.

Each task has a specific duration which includes the datetime of its begin and finish. After initial screening of input data by identification code of crew member, a ranked list of crew members could be obtained. That restriction for FDP, rest, and acclimatization should be checked for each line of the sorted list. In case, if requirements are met and the selected crew member can perform the flight, he remains in the array. If not, crew member is removed from the array. Flight planning manager could assign other actions which could be other than boarding the flight, but these actions do not affect the increase of the corresponding employee's flight time. It is also possible to assign the following types of actions to particular array D and then calculate for each person his raid (FDP_i) for the selected period:

$$FDP_i = \sum_{j=1}^{N_i} f(T_{ij}, d_{ij}), \tag{1}$$

$$f(T_{ij}, d_{ij}) = \begin{cases} 0, if\ d_{ij} \exists D \\ Tij. if\ d_{ij} \nexists D' \end{cases} \tag{2}$$

$$T_{ij} = t1_{ij} - t2_{ij}, \tag{3}$$

where $t1_{ij}$ is a time of flight finish; $t2_{ij}$ is a time of flight begin; T_{ij} is event execution duration; d_{ij} is event type; N_i is a data tuple with tasks for i crew member.

Value of FDP is calculated by (1), but only in case parameter T_{ij} is already taken into account (which means that crew began performing duties). Calculated FDP by each crew member should be compared with maximum values, for example, 100 hours for 28 calendar days. Persons whose FDP, when adding the flight time of the selected flight, exceed these norms, should be excluded from the list of potential candidates for future flights. Also, it is necessary to check the availability of recurrent extended recovery rest period in the last 7 calendar days. In addition, it is necessary to assess the position of crew member so that the flight is performed where he will be on the day of the flight, and if this place is not the base airport, then according to Table 1, determine whether he is suitable for the degree of acclimatization. Then, based on some criteria (minimum FDP, some parameters of social work as team building could be used based on previous data) ranked list of available crew could be generated.

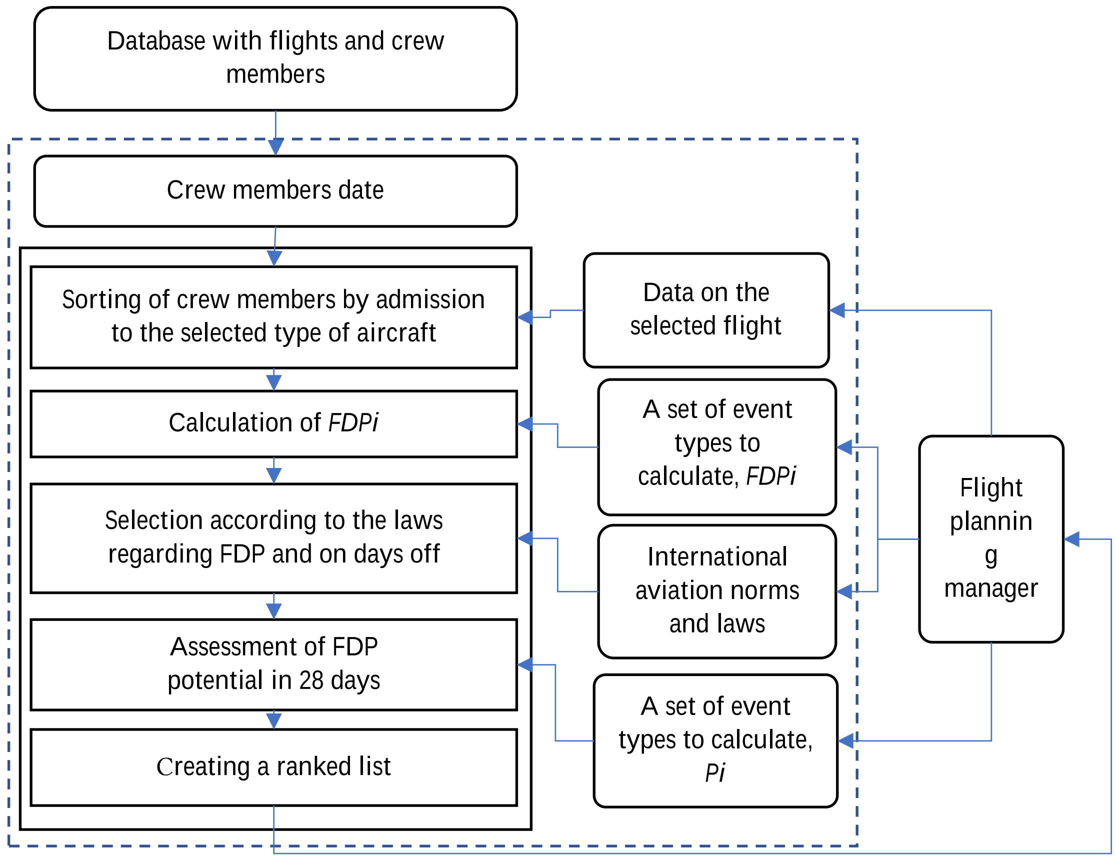

Figure 1: Structure scheme of crew scheduling algorithm.

An important point is the availability of vacations for the crew members in the selected period (28 days). Also, it is necessary to estimate the volume of Flight duty of the i-th crew member to his potentially possible volume for the selected period. For example, in the selected period of 28 calendar days, a given crew member spent 14 days on vacation, so his Flight duty volume will be less than the same volume of a crew member who worked for 28 days. Accordingly, the flight planning manager can create an array of data *B* with event types where the execution period will reduce the potential volume of Flight duty for 28 days:

$$P_i = \frac{FDP_i}{28*24-\sum_{j=1}^{N_i} f2(T_{ij},d_{ij})}, \tag{4}$$

$$f2(T_{ij},d_{ij}) = \begin{cases} 0, if\ d_{ij}\exists B \\ Tij.if\ d_{ij}\nexists B \end{cases}, \tag{5}$$

where P_i is the ratio of Flight duty of the i-th crew member to the difference between all the time in 28 calendar days and the time when he could not perform Flight duty due to other events.

Finally, value P_i could be used as a weight coefficient for crew members' ranking. Based on the obtained results flight planning manager could choose an appropriate crew team for a particular flight. Complete algorithm of crew scheduling could be represented in form of pseudo code as a sequence of following steps:

```
import DB, D, B, Norms // config parameter of connection to DB, diction of norms for FDP , rest and
DP, A set of event types to calculate FDPi and Pi
flight=input('Flight parameter:'     // input flight planning manager information of flight
        'Time of start:'
        'Time of end:'
        'Airport of start:'
        'Airport of end:'
        'Type of aircraft:')
A=connect(DB).request(f'Select crew From BD where type_aircraft={flight["type"]} and airport of
start={flight["start_airport"]} '
                  f'and time  between "{flight["time_start"]-datetime.timedelta(days=28)}" and
"{flight["time_start"]}";') // request to the database to obtain suitable crew members
_A_=dict() // initialization of the dictionary where the selected crew members will be recorded
for a in A: // selection of the list of all crew members
    FDPi, P_pre,Rest=0,0,False // initializing changes for the current crew member
    for Ti in a: // list of tasks that were assigned to the crew member a
        if Ti.type not in D:
            FDPi+=Ti.finish-Ti.start  // FDPi calculation
        if Ti.type not in B:
            P_pre +=Ti.finish-Ti.start // calculation of how many employees were unavailable this month
        if flight["time_start"]-Ti.start<datetime.timedelta(days=7):
            if Ti.type =='Rest':
                F_rest(Ti,Rest) // Rest calculation for the last 7 days before the flight
    Pi=FDPi/(28*24-P_pre) // calculation of Pi
    if FDPi +(flight['time_end']-flight['time_start'])>=Norms['FDP'] or not Rest: // Verification of
compliance with norms
    _A_.update({a:[Pi,FDPi]}) // adding the selected user to the dictionary
_A_.sort() // sorting the dictionary from smallest to largest value
print(_A_) // flight planning manager value output
```

Based on proposed algorithm a specific software has been developed in Python. MySQL server is used for data base.

4. Numerical demonstration

Validation of proposed algorithm has been done with developed software in Python. Also, we use real flight planning data of a particular airline. We consider airline staff of 80 persons, 20 of them will be assigned to 6 upcoming flights based on their schedule data for the past 28 days before the date of the selected flights. We consider two cases of the flight planning process: manual mode when flight planning manager analyses all the data manually to prepare a crew list and automatically with proposed software.

The time required for the selection of a crew list has been measured for different numbers of flights (each flight requires a crew list). Performance of developed software in comparison to human performance is given in Figure 2.

The approximate processing time with 80 available crew members per flight, assuming the flight planning manager is not familiar with the situation per day, would be 10 minutes for manual mode. In addition, manual mode requires a lot of paper work, which can significantly increase the processing time. However, when the flight planning manager familiarizes himself with the flight situation on the day of the appointment, as well as reducing the crew list during selection, because if the first flight was selected from 80, the last from 55, the selection time will be reduced. Therefore, the process of selecting crew members for 6 flights of 80 crew members in manual mode will take up to 47 minutes. This value was obtained experimentally as the average value of the task completion time of four different flight planning managers in Table 2.

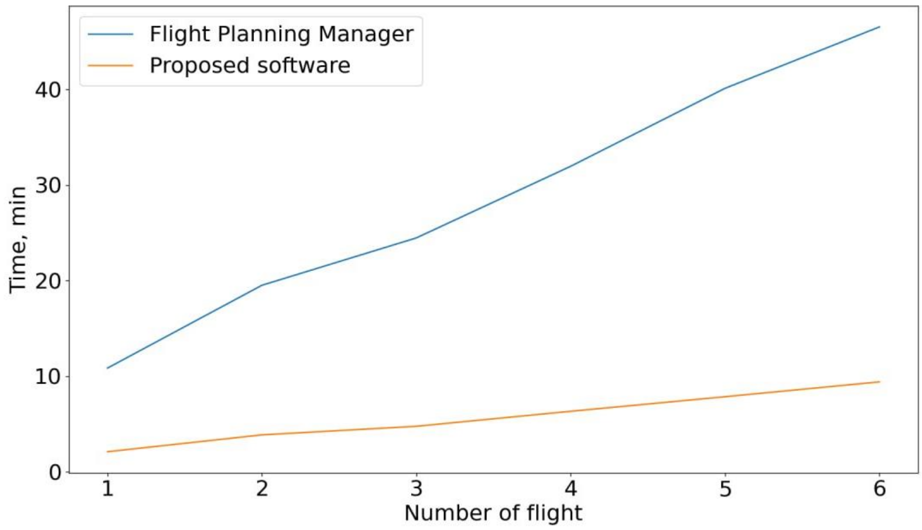

Figure 2: Performance of crew scheduling process.

Table 2
Performance of Flight Planning Manager

Flight Planning Manager	1 flight	6 flights
Person A	8.42 min	55 min
Person B	7.26 min	45 min
Person C	8 min	48 min
Person D	7 min	42 min
Mean	*7.67 min*	*47.5 min*

Developed software required at least 1 min 30 s to process crew list for one flight, and for 6 flights performance reached 10 min. Time of computation is a result of number of cycles performed by software when screening unsuitable crew members and calculating their FDPi. Increase in the number of crew members, computation performance decreases significantly. Also, obtained result shows that performance of software selection process is 5 times better than the manual one. In total flight planning manager selects a crew for 1 day in almost 50 minutes and for a week in 350 minutes or almost 6 hours of work, respectively, for 28 days, it is 1400 minutes or 23 hours, and for 20 minutes, it is 4 eight-hour working days. Software requires only 4 hours and 40 minutes to perform the same task. Flight planning manager has only to control the selection process and verify obtained results. Correlation of obtained results from humans and software is given in Tables 3 and 4.

Table 3
The crew and their percentage P_i are selected by humans and proposed software for one flight

Software		Manually by flight planning manager	
Crew member	P_i	Crew member	P_i
1	62	1	73
2	65	2	62
3	65	3	65
4	70	4	65
5	73	5	75
6	75	6	70

Table 4
The match between the crew members assigned by humans and proposed software

Flight number	Crew members match	Number of non-matches
1	100 %	0
2	85 %	1
3	100 %	0
4	60 %	2
5	85 %	1
6	100 %	0

Based on the above data, crew selection process by software mostly corresponded to results indicated by the flight planning manager. Three times out of 6 flights results of crew selection list are identical. Analysis of selection logic helps to identify three cases when crew lists were different:

- Computation of 2 flight includes several flight attendants with the same P_i. In the case of software, results have been obtained based on position in the array. In the case of human selection process, a choice for crew in this case has been given randomly.
- A fourth flight considers a case when the training of the flight attendant should be carried out and, accordingly, one member of the crew will be an instructor who will perform the check and the other will be a flight attendant who will pass the check.
- In flight 5 a co-pilot will be involved in another flight for which he will have to make a transfer to another airport and, accordingly, he cannot be involved in flight 5.

Results of verification give an 88% correlation between software results and human activity. However, time saved by software is significant. Also, final validation of results should be provided by humans at the end.

5. Conclusions

Crew planning process is an important element of civil aviation safety. Following all requirements of normative documents is mandatory for each crew member. Modern computerized systems mostly focus on only flight duty period calculation, but not the overall duty period associated with involved crew members. Proposed algorithm takes into account both flight duty and duty periods for scheduling crew members. Results of practical evaluation of proposed algorithm in Python indicate at least five times speedy than manual flight crew scheduling. Software provides efficient crew scheduling, however, obtained results need to be validated by flight planning managers to avoid mis selection. In the case when provided by software crew rank is identical to another crew member, flight planning manager could take into account the personal properties of each crew member (or preference for teamwork) to make an effective crew set for the particular flight.

In case the number of crew is less than 50 manual mode is possible, however for airlines with much bigger staff automatic crew scheduling is an important tool. The main advantage is the ability to quickly calculate additional parameters such as duty period, and flight duty period, which, with a large number of flights, allows for removal from the crew list, persons who are close to exceeding the norm, and with a small number of flights.

Automated crew scheduling can improve the results of the crew planning department due to faster selection of eligible persons for the flights to be performed by the airline. Proposed algorithm could be useful for both strategic and operational crew planners.

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