A Robust Optimization Scheduling for Carrier Aircraft Support Operation Based on Critical Chain Method

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Abstract. The maintenance and service support of carrier aircraft (MSSCA) is a complex process involving many types of resources and activities that require optimisation which can be considered as a multi-resource constrained multi-project scheduling problem (MRCMPSP). It is of great significance to optimize the makespan and obtain a proactive robust schedule to be adaptive to the changes in the dynamic flight deck environment. This paper develops a critical chain method (CCM) for carrier aircraft support robust scheduling in a time-critical and resource-constrained operation environment. The CCM consists of developing a desirable deterministic schedule under multi-resource constraints and time-critical issues, and adding a project buffer (PB) to the end of the schedule is used to get a robust proactive scheduling and deal with uncertainty. The triangular fuzzy number (TFN) is applied to describe the durations of each activity and calculate the PB size and obtain an appropriate proportionality between the activity duration and the buffer size. In the numerical research, different size simulations are designed to calculate the robust optimization scheduling. The computational results show that the CCM for carrier aircraft support robust scheduling can make a better decision in the robust proactive optimization scheduling about the resource allocation.

1. Introduction

Scheduling is essential for a wide range of engineering applications such as project management, job shop scheduling and system operations, it is about a process to creating an optimal schedule, which consists of a list of times at which possible tasks, events, or activities are intended to be operated. A poor schedule of a large-scale project may result in huge economic loss to its host company. The presented work was motivated by the need of support operation scheduling general assembly of aircrafts on the aircraft carrier flight deck. Nowadays, aircraft carrier is the largest vehicle sailing on the sea, it is a symbol of the general strength of a military power. The combat capacity of the aircraft carrier is closely correlated with the sortie and recovery abilities of the carrier aircraft on the flight deck, while the sortie and recovery performances of the carrier aircraft depend largely on the scheduling strategies carried out during the deck support operations. The maintenance and service support of carrier aircraft (MSSCA) is the main operation process before the carrier aircraft takes off. On the flight deck, each carrier aircraft requires a series of certain supporting operations in a certain order, such as inspection, oiling, gas supply, weapon mount, and inertial alignment, etc, which are required to be performed within one deck cycle to keep high-intensities sortie rates. Therefore, a proactive baseline schedule for the MSSCA is very necessary before the flight deck operation. On the
other hand, the MSSCA problem is a kind of typical dynamic scheduling with many strong constraints, such as time urgency, space restraint and resources restraint. Meanwhile, there exist many uncertainties and disturbances during the scheduling process. It is imperative to make a robust optimization schedule and resource allocation plan for flight deck operations with uncertainty which satisfy the constraints of space, resource, timing and personnel as the efficiency and robustness of flight deck operations are always the bottleneck of improving the sortie generation capacity and operational management level of aircraft carrier.

The keys about the MSSCA are to achieve the aircraft scheduling through different facilities or positions with set limitations in time, space and resource and make the robust proactive schedule be adaptive to the uncertain environment. The research about aircraft carrier deck scheduling for the operations and maintains with limited resources can be considered as resource-constrained project scheduling problems (RCPSP). RCPSP has gained widespread attention for the last few years due to its practical importance and computational challenge. The operation scheduling of MSSCA in the uncertain flight environments, may face many uncertain factors during the flight deck operations, such as stochastic service time of each operation, the resource unavailability, machine breakdowns, operator variation, and even the uncertain change of mission. Moreover, precedence constraints and multiple resource constraints are more complicated in the flight deck operations of carrier, and various kinds of aircraft make the process of flight deck operations diverse. The dynamic scheduling research for MSSCA process can be described as multi-resource constrained multi-project scheduling problem (MRCMPSP) under uncertain environment. Uncertainty in the aircraft carrier usually leads to unscheduled delays, cost overruns, cause the delay and disputes between the operating parties. Managers in the flight deck strongly need an effective method that considers resource constraints and uncertainty for the MSSCA problem, and provides a systematic mechanism for managing schedule during the MSSCA project execution. Therefore, it is imperative to make a time-saving and robust schedule and resource allocation plan for flight deck operations with uncertainty which satisfy the constraints of space, resource, timing and personnel.

Critical chain method (CCM) is a better choice for planning and managing MSSCA that emphasises the resources required to execute project tasks, it is introduced by Goldratt [1] based on the probability theory. CCM has been widely used for project scheduling [2-5]. It uses a deterministic schedule integrated by a buffer mechanism to deal with both resource constraints and uncertainty, and help managers to guarantee the in time and on budget completion of the project. This paper illustrates a robust makespan-based, reliability-based and resource-constraints optimization model for the proactive scheduling of the MSSCA problem based on CCM. In this paper, a project buffer for the MSSCA is placed at the end of the critical chain to protect against exceeding the project deadline, and feeding buffers are placed at the intersections between any non-critical chains and the critical chain to protect it against disturbances. The structure of the paper is as follows. Section 2 presents a literature review of related work about MSSCA and CCM. In the section 3, the MSSCA problems which are consider as MRCMPSP are described in detail. The mathematical programming model for the MSSCA is established. In section 4, the CCM are proposed to deal with the uncertain environment and a buffer is placed to get a robust proactive. In the section 5 demonstrates the model with an example by a proactive robust scheduling optimization algorithm. Finally, we provide overall conclusions in section 6.

2. Literature review
An actual aircraft carrier flight deck environment is one of the most dangerous work environments in the word. a series of researches were conducted, and some research papers have been published about the carrier aircraft scheduling. In the early years, Ouija Board [7] -an aircraft carrier deck simulation platform, was employed by US Navy to monitor the arrangement and sought an optimized schedule by artificial expertise. Ryan [6-7] developed a deck operations course of action planner (DCAP) which was based on human-computer interaction concept and utilizes a conventional integer linear program-based planning algorithm. Then some other research had been published such as the markov decision
process model solved by inverse reinforcement learning technique [8], agent based model [9] which was compared with that of the expert user heuristics over a set of experimental scenarios, and queuing network-based policy [10] generator to generate action plan for deck operation. Yu et al [11] established an extended flexible job shop scheduling model for the MSSCA considering the serial and parallel precedence relations between operations and designed an improved differential evolution algorithm (IDE) to improve the computational efficiency. Feng Qiang [12] proposed a multi-agent based fleet maintenance personnel configuration method to solve the mission-oriented aircraft fleet maintenance personnel configuration problem. Wu et al. [13] designed a GERT-based global sensitive method to analyse the uncertainty of flight deck operations. Ryan et al. designed the deck operations course of action planner include the interactive local and global decision support system, expert user heuristics and agent-based model [14-16].
Zhi Zhang [17] designed a human-computer cooperation decision planning system (aircraft carrier deck operation planner (ACDOP) system). Some other research papers are published using the Markov decision process (MDP) to solve the multi-stage decision course under uncertainty on flight deck, the Markov decision process (MDP) based on the reverse reinforcement learning [18-20]. For the uncertain environment in the flight deck, Chao [21] designed a dynamic hierarchical task network (HTN) planning process for the dynamic aircraft carrier flight deck tasting planning. But the two fold network structure is simple and still have some limitations. Jürgen Kuster [22] presented a real time scheduling method in the disruption management of aircraft turnaround, but it is only a partial research. Feng et al. [23] built an improved direct graph to model and designed an improved ant colony optimization algorithm to optimize the carrier aircraft scheduling.
In the MSSCA scheduling which is consider MRCMPSP, some uncertainties and dynamic disruptions exist in carrier aircraft scheduling, such as resource disruptions (resource station breakdown, the operators reduce) and time disruptions (the operational time for the equipment maintenance, which may become longer). The keys to achieving the carrier aircrafts’ scheduling include different facilities, operational crews, and positions with set limitations in time, space, and resources. In order to address the uncertainty in MSSCA, CCM which is based on the probability theory is attracted considerable attention. CCM is a proactive robust scheduling method which uses a deterministic schedule integrated by a buffer mechanism to deal with both resource constraints and uncertainty [24]. The CCM can help the flight deck commander deal with both resource constraints and uncertain dynamic disruption in time by a buffer mechanism. It overcomes the deficiency of traditional project methods based on the assumption that there are unlimited resources for the execution of the activities. In the reality project resources are not unlimited. Thus, scheduling without considering resource constraints gives unreliable schedules. Due to the uniqueness of some activities in the MSSCA scheduling, and uncertain dynamic perturbations about activity durations, the project manager in the flight deck may not correctly characterize these random variables. The concept of buffer was adopted which is a more reliable alternative in this situation and can absorb the uncertainty in the MSSCA. The CCM with project buffer provides useful information for the MSSCA scheduling and against unpredictable failures, accidents and delays in the flight deck. Some research and literature had been published to research the types of buffer [25]. The CCM has been researched in some problems but not involved in the MSSCA scheduling. On the other hand, the MSSCA scheduling considered as MRCMPSP can not been adequately solved in the dynamic environment. The feeding buffers in the traditional CCM may fail to act as a real robust proactive protection mechanism in the MSSCA scheduling, so the robust optimization scheduling research for MSSCA based on CCM is very necessary and meaningful.

3. Problem description

3.1. Description of MSSCA scheduling problem
The carrier aircraft fleet executes missions in a cyclic way in the flight deck, each aircraft waiting to take off in the flight deck should go through the processes of sortie preparation, launch, flight mission and landing. Once the aircraft is chained in the flight, it will turn to the pre-flight preparation stage.
called MSSCA. The conduct of MSSCA operations involves the intricate scheduling of aircraft, support equipment and personnel and allocate the supporting resource (renewable resources and non-renewable resources) to complete the operations for preparing the aircraft well before taking off. The resource constrained include the support crew constraint, support equipment constraint, support space constraint, and non-renewable resources constraint. The support crew resource contains different majors (machinery major, ordnance major, avionics major, and special equipment major). The support equipment resource contains different resource stations (oiling station, oxygen and nitrogen station, hydraulic station, power station). The support space resource such as aircraft cockpit make the support activity existing space constraints so that the cockpit inspection of each major cannot be proceed simultaneous. The non-renewable resources include oil, gas, weapon, etc. The set of the four types of resources are denoted as $Kp$, $Ke$, $Ks$ and $Kw$ respectively.

In the flight deck, a single aircraft support operation can be considered as a project, and a team of aircraft (denoted as a set $I=\{1,2,\ldots,N\}$) scheduling problem can be considered as multi project scheduling problem. The MSSCA scheduling problem is considered as MRCMPSP in this paper. For each aircraft $i\in I$, a set of real operation activities (denoted as $J_i$) should be scheduling with serial and parallel constraint relationships. In the flight deck, the supporting operations of each carrier aircraft are about 14 activities, inspections of each part, fuelling, arming, oxygen filling, nitrogen charging, alignment of INS (inertia navigation system), and so on. Besides a virtual start process and a virtual finish process are set to combine the operational activities of each carrier aircraft to a multi-aircraft network flow. The precedence relationships of MSSCA are usually modelled as activity on node network (AON). Figure 1 shows the support operation flow chart of single-aircraft.

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![Figure 1. The support process flow chart of each single carrier aircraft](image)

In the Figure 1, the relationships of the MSSCA scheduling process for a single carrier aircraft are as usually modelled as activity on node network $G (N, P)$. $O_{ij}$ is set to denote the $j$th operation of $i$th aircraft, each activity $O_{ij}$ cannot be started until all the operations in the immediate predecessor operation set $P_{ij}$ are completed. Here $P_{ij}$ represents the serial and parallel constraint relationships activities of the $i$th aircraft $j$th activity. As for each operation activities $O_{ij}$, a set of different kinds of support resources are required to complete the support activities, $Kp$, $Ke$, $Ks$ and $Kw$ represent different kinds of support resource in the Figure 1. Each operation activities $O_{ij}$ has a different support duration $d_{ij}$. The support time has a stochastic value because the dynamic scheduling environment, its expectation is relevant to the mission requirement and uncertain environment. Besides, a stationary resource station can only support some settled carrier aircraft. $L_{Pk}$ is the set of $k$th ($k\in Kr$) supporting resource station. The person in a single major supporting operational crew can support all the aircraft. $L_{P_k}$ is set of $k$th ($k\in Kp$) supporting operational crew.

3.2. Description of MSSCA scheduling problem based on CCM under uncertainty
In addition to the MSSCA scheduling problem, the scheduling activities are subject to considered uncertainty (e.g., resource station breakdown, the operators reduce and time disruptions because of bad weather and so on). The uncertainty in the scheduling process can lead to the schedule delays, and cost overruns, and dispute between the different scheduling parties. It is very important to calculate and analyse MSSCA activities duration under uncertainty and resource constraints, and provide the more reliable robust schedule to reduce the overrun. In the flight deck, the commander needs to measure the difference of the actual MSSCA schedule and the initial planned schedule so that managerial actions can be made. A robust optimization scheduling method for carrier aircraft support operation is very necessary to estimate the (uncertain) durations of delays/interruptions for the scheduling activities, and their effects on the remaining schedule under resource constraints, so that the proposed method can provide a systematic mechanism for managing schedule during MSSCA project execution. In order to deal with the uncertainty, the fuzzy CMM is used to deal with the continuous relationship between time-resource. It is easy and simple to be applied and incorporated with MSSCA management system and software to take advantage of available resource level functions. In this paper, the triangular fuzzy number (TFN) is applied to describe the durations of each activities.

4. Fuzzy critical chain method for MSSCA robust scheduling

4.1. Solution methodology

The CCM method for MSSCA scheduling can be implemented as follow three interactive and iterative stages:

Step 1: In the first stage, the proactive scheduling strategy is used to create a static schedule using the heuristic algorithm with time/resource take off to provide a minimum-makespan deterministic schedule which will generally be a good starting point for project execution. The starting time and ending time of each activities can be predetermined in the proactive schedule.

Step 2: In order to deal with the uncertainty, the proposed method uses fuzzy numbers is designed to model uncertainty in activity durations of MSSCA scheduling based on the deterministic activity durations in the first stage and expert knowledge, a project buffer (PB) is added to deal with uncertainty by a fuzzy set-based schedule. The size of PB is determined by computations with fuzzy numbers.

Step 3: In the third stage for the MSSCA scheduling execution, the proposed CCM is executed to focuses on the penetration level in PB, and then dynamically updates the schedule to provide a more accurate schedule for actual progress in the dynamic scheduling environment. The three above stages are repeated until the MSSCA scheduling project is completed. The main problem in the robust optimization scheduling for MSSCA is to find a deterministic schedule, which has suitable durations and optimal start times of activities, so that project duration under multi resource constraints is minimised. The proposed method uses fuzzy theory to balance the relationship between them.

4.2. Implementation of MSSCA based on fuzzy theory

The uncertainty of project activity duration generally uses an L-R type fuzzy number. The definition of an L-R fuzzy number is as follows: $R$ is the real number field, If $\tilde{A}$ is a normal fuzzy number set of $R$, and the cut set $A_\varphi$ of $\tilde{A}$ is a closed interval for any $0 \leq \varphi \leq 1$, then $\tilde{A}$ is a fuzzy number. In this paper we select to use the triangular fuzzy number $TFN(a, b, c)$ to estimate the uncertainty of MSSCA, as shown in Figure 2. The membership function $\mu$ has values in $[0, 1]$, and it is used to express the degree of activity support duration $d_{ij}$ belonging to a fuzzy set. $\mu$ is often determined by the carrier aircraft scheduling project manager. The membership function will be as follows:
\[
\mu(d_{ij}) = \begin{cases} 
0, & d_{ij} < a \\
d_{ij} - a, & a \leq d_{ij} \leq b \\
b - a, & a \leq d_{ij} \leq b \\
c - d_{ij}, & b \leq d_{ij} \leq c \\
c - b, & b \leq d_{ij} \leq c \\
0, & d_{ij} \geq c
\end{cases}
\] (1)

Here, \( a \) is the minimum duration of activity \( j \) for the \( i \)th carrier aircraft \( d_{ij}(a) \), \( b \) is the average duration of activity \( j \) for the \( i \)th carrier aircraft, \( c \) is the maximum duration of activity \( j \) for the \( i \)th carrier aircraft \( d_{ij}(c) \). The support duration \( d_{ij} \) can't be in range less than \( a \) or greater than \( c \). The support time of each activity is dynamic in the flight deck operation environment. The duration of each activity in different support scenarios is shown in formula (2).

\[
d_{ij} (\delta) = d_{ij}(a) + \delta \left[ \frac{d_{ij}(c) - d_{ij}(a)}{2^\delta - 1} \right]
\] (2)

Here, \( 0 \leq \delta \leq 2^\delta - 1 \), \( d_{ij} (\delta) \) is the support duration of activity \( j \) for the \( i \)th carrier aircraft in the different environment. \( \Delta \) represents different dynamic support environment. The same support activity will cost different duration in different support environment. \( \mu(d_{ij}) \) is membership function of the support duration \( d_{ij} \). Each activity duration is calculated to get the duration matrix.

\[
\begin{bmatrix}
d_{ij}(1) & d_{ij}(1) & \cdots & d_{ij}(1) \\
d_{ij}(2) & d_{ij}(2) & \cdots & d_{ij}(2) \\
\vdots & \vdots & \ddots & \vdots \\
d_{ij}(\Delta) & d_{ij}(\Delta) & \cdots & d_{ij}(\Delta)
\end{bmatrix}
\] (3)

The probability matrix of a random dynamic support operation with the membership \( \mu \) is as follows:

\[
P(d_{ij}(\omega)) = \frac{\mu(d_{ij}(\omega))}{\sum_{j=1}^{n} \mu(d_{ij}(j))}, 1 \leq \omega \leq\Delta
\] (4)

The probability matrix can be obtained according to the duration matrix (3) and the probability formula (4).

\[
\begin{bmatrix}
P_1(1) & P_2(1) & \cdots & P_\Delta(1) \\
P_1(2) & P_2(2) & \cdots & P_\Delta(2) \\
\vdots & \vdots & \ddots & \vdots \\
P_1(\Delta) & P_2(\Delta) & \cdots & P_\Delta(\Delta)
\end{bmatrix}
\] (5)

A duration vector can be form through selecting each activity duration from the duration matrix.

\[
d = (d_{ij}(x_1), d_{ij}(x_2), \ldots, d_{ij}(x_\delta))
\] (6)

Here \( 1 \leq x_1, x_2, \ldots, x_\Delta \leq\Delta \), the probability of duration matrix in the corresponding situation can be calculated according to the probability matrix. By repeating the above process, the scenario set and the probability of different dynamic situation can be obtained.

In this paper, the range of activity duration are settled through referring the experience of MSSCA project participants and the judgment. The personnel behaviour factors still play a role in the scheduling project. Therefore, the application of fuzzy theory in the critical chain technology still follows the above hypothesis.
4.3. Identifying critical chains and project buffer

A chain in the MSSCA is a sequence of support activities under both precedence and resource dependencies. In the robust optimization scheduling for carrier aircraft support operation based on CCM, the critical chain is the longest chain, and it will determine the project duration. In the scheduling project, if there are many critical chains can be selected, a critical chain with greatest uncertainty will be scheduled.

The proposed method deals with the dynamic scheduling environment by adding a project buffer (PB) at the end of the selected critical chain. We selected to add the project buffer to the end of the chain because that the resource conflicts often happen during the transfer of the actual information from activities on the chain to the end of the chain in the dynamic scheduling environment. In dynamic scheduling environment, the support finished completion time is not only depended on the sort order of the scheduling activities, but also depend on the duration of each scheduling activity. The size of PB is determined by computations with fuzzy numbers. The $\sigma_m$ is defined as the variance of an activity duration in the critical chain under different scenarios. The PB is calculated as follows:

$$PB = \sqrt{\sum_{i,j \in C} \sigma_{ij}^2}$$ (7)

5. Robust optimization scheduling model for MSSCA based on CCM

In the MSSCA scheduling model, some other sets, parameters and decision variables are set as follows:

$\text{Rp}_{kl}$ is the set of the carrier aircraft support range by the $k$th $(k \in K_p)$ major $l$th $(l \in L_{p_k})$ operational crew.

$\text{Re}_{kl}$ is the set of the carrier aircraft support range by the $k$th $(k \in K_r)$ type $l$th $(l \in L_{r_{k_l}})$ station.

$S_{ij}$ start time of activity $j$ for the $i$th carrier aircraft

$rp_{ijk}$ demand number of $k$th operational crew for the $i$th carrier aircraft $j$th activity

$rs_{ijk}$ demand number of $k$th space for the $i$th carrier aircraft $j$th activity

$re_{ijk}$ demand number of non-renewable resources for the $i$th carrier aircraft $j$th activity

$C_{max}$ the maximum completion time of the activities

$X_{pijkl}$ 1 if the $k$th station $l$th equipment is allocated to activity $j$ for the $i$th carrier aircraft; 0 otherwise

$X_{eijkl}$ 1 if the $k$th station $l$th equipment is allocated to activity $j$ for the $i$th carrier aircraft; 0 otherwise

$x_{ijk}$ 1 if the activity $j$ for the $i$th carrier aircraft has been finished at the $t$ moment; 0 otherwise

The mathematical description of the problem based on CMM is given as follows:

Objective function.

$$\text{Min } F = \text{min } (C_{\max} + PB)$$ (8)

Constraints.

$$S_{ij} \geq SX_{i}, \forall i \in I$$ (9)

$$E_{ij} = S_{ij} + d_{ij}, \forall i \in I, \forall j \in J_i$$ (10)

$$S_{ij} \geq S_{ih} + d_{ih}, \forall (i,h) \in P_{ij}, \forall i \in I, \forall j \in J_i$$ (11)

$$\sum_{i \in I} rs_{ijk} \leq 1, \forall i \in I, \forall j \in J_i, \forall k \in K_s$$ (12)

$$\sum_{i \in I} \sum_{j \in J_i} rp_{ijk} \leq |L_{p_k}|, \forall k \in K_p, t \in [0,T]$$ (13)
\[
\sum_{i=1}^{n} \sum_{j \in J(t)} r_{ijk} \leq |L_r|, \forall k \in Kr, t \in [0, T] 
\] (14)

\[
\sum_{i=1}^{n} \sum_{j \in J(t)} r_{ijk} \leq |L_w|, \forall k \in Kw, t \in [0, T] 
\] (15)

\[
\sum_{i \in I_r} X_{eijk} = r_{ijk}, \forall i \in I, \forall j \in J, \forall k \in Kr 
\] (16)

\[
\sum_{i \in I_p} X_{pijk} = r_{pjk}, \forall i \in I, \forall j \in J, \forall k \in Kp 
\] (17)

\[
\sum_{i \in I_{r_{ij}, j \in J(t)}} X_{eijkl} + \sum_{i \in I_{r_{ij}, j \in J(t)}} X_{pijkl} = 0, \forall j \in J, \forall k \in Kr, \forall l \in L_r, \forall k' \in Kp, \forall l' \in L_p 
\] (18)

The whole project schedule consists of two parts, the duration and the buffer. For any given schedule, if the buffer size is too big, the activity duration will be very short. In this case, it is difficult to finish the activity on time. However, if the buffer size is too small, it may not be succeed in dynamic scheduling environment. The above objective function with duration and project buffer is designed to balance the optimal of makespan and the robustness, and avoided the occurrence of the situation that the total makespan is very short and the duration volatility is very uncertain. Constraint 9 to 19 describe the MSSCA scheduling model in the flight deck. Constraint (9) ensures that the first support activity must start before the carrier is transported up to the flight deck and parked in a permanent position. Constraint (10) defines the relationship between the finish time of each activity with the start time. Constraints (11) ensures the precedence relationship, which means that any activity cannot be started before the completion of its preceding activity. Constraint (12) ensures that each activity is executed only once from one exact period, \( t \). Constraints (13), (14), and (15) represent the capacity constraints for renewable resources (operational space, operational crews, resource stations), respectively. Constraint (9) represents the capacity constraints for the non-renewable resources in each time period. Constraints (10) and (11) represent the allocation of the operational crews and resource stations, which need to be equal to the demand. Constraint (12) represents the support coverage of the operational crews and resource stations.

6. Numerical example

In order to test the performance of the new model and the proactive robust optimization method for the MSSCA, a set of simulation scenarios are generated to make the experimental research. Double population genetic algorithm (DPGA) is designed to improve the quality and diversity of the population. First, encoding and decoding processes are set to get a population and matching scheduling. The left and right populations are processed simultaneous with crossover and mutation and local search processes. For the left population, right scheduling is made in the encoding and decoding processes. For the right population, left scheduling is made in the encoding and decoding processes. The original coding is corrected by decoding the end time of the scheduling solution and the elite population is reserved. The pseudo code of DPGA with local search strategy can be found in our previous paper.

Through the adoption of proper buffer sizing methods, the uncertainty factors of the project will be effectively taken into consideration and absorbed. The project buffer also protects against uncertain failures, accidents and delays. The proposed method uses MATLAB software to simulate the uncertainty of the project, the project buffer, the actual duration and cost of the project. The experiments were performed using a PC with two Intel(R) Core (TM) i5-4258U CPU @ 2.4 GHz processors and 4 GB RAM (Intel cooperation, Santa Clara, CA, USA. The algorithm has been coded in MATLAB 2017(a) software (The MathWorks, Inc., Natick, MA, USA).
In the numerical research, the numbers of each professional operational crew are respectively |K_{pl}| = 8, |K_{p2}| = 6, |K_{p3}| = 8, and |K_{p4}| = 6. Five kinds of resource stations including the power station (K_{r1}), oiling station (K_{r2}), hydraulic station (K_{r3}), nitrogen station (K_{r4}), and oxygen station (K_{r5}) for the service support operations of non-renewable resources. The numbers of each resource station in the experiment are respectively |K_{r1}| = 8, |K_{r2}| = 6, |K_{r3}| = 5, |K_{r4}| = 5, and |K_{r5}| = 5. Kw represents the upper limit of non-renewable resources for the simultaneous support operation. Kw is set [6, 5, 2, 4, 2]. Table 1 shows the station set of each kind of resource station that covers the waiting support carrier aircraft in the fixed parking position. Four kinds of support operational crews and five types of resource stations make up the flexible and sustained carrier aircraft support activities in the flight deck. The average duration of activity j for the ith carrier aircraft b (in minutes) are shown in the Table 2. The maximum duration (c) of each activity and minimum duration (d) of each activity is depend on the average duration, as is shown in the table 2. a=b+Δab, c=b+Δbc. 

**Table 1.** Coverage relationship between resource station and carrier aircraft.

| NO. | Resource Station Coverage Category |
|-----|-----------------------------------|
|     | K_{r1} | K_{r2} | K_{r3} | K_{r4} | K_{r5} |
| 1   | [1]    | [1]    | [1]    | [1]    | [1]    |
| 2   | [1, 2] | [1]    | [1]    | [1]    | [1]    |
| 3   | [1, 2] | [1, 2] | [1, 2] | [1, 2] | [1, 2] |
| 4   | [2, 3] | [2]    | [1, 2] | [1, 2] | [1, 2] |
| 5   | [3, 4] | [2]    | [2]    | [2]    | [2]    |
| 6   | [3, 4] | [3]    | [2, 3] | [2, 3] | [2, 3] |
| 7   | [4, 5] | [3, 4] | [3]    | [3]    | [3]    |
| 8   | [5, 6] | [3, 4, 5]| [3, 4] | [3, 4] | [3, 4] |
| 9   | [5, 6, 7]| [4, 5] | [3, 4] | [3, 4] | [3, 4] |
| 10  | [6, 7] | [5, 6] | [4, 5] | [4, 5] | [4, 5] |
| 11  | [7, 8] | [6]    | [4, 5] | [4, 5] | [4, 5] |
| 12  | [8]    | [6]    | [5]    | [5]    | [5]    |
| 13  | [8]    | [6]    | [5]    | [5]    | [5]    |

Three instances are proposed in the research. **Instance 1:** Five carrier aircrafts (Nos. 2, 3, 9, 10, 12), n = 5. **Instance 2:** Nine carrier aircrafts (Nos. 2, 3, 4, 5, 8, 9, 10, 11, 12), n = 9. **Instance 3:** 13 carrier aircrafts (Nos. 1–13), n = 13. The objects are the buffer, actual duration of the the average, max, min results, and variance, which are calculated with different wave carrier aircrafts. Table 3 shows the results of the MATLAB simulations of these three types of projects with different size. Figure 2 and figure 3 shows the gantt chart of optimal personnel allocation and station allocation in deterministic mission instance 2. The vertical axis represents the number of the supporting operational crew and resource station. \( L'_{ij} \) represents the ith operational crew of the jth major, \( L''_{ij} \) represents the jth support equipment of the kth resource station, and \( I_i - j \) represents the ith carrier aircraft number for the jth activity. Table 3 shows the results of the MATLAB simulations of these three types of scheduling projects with different size.

**Table 2.** Support time of each activity in a single carrier aircraft.

| Act | b(min) | a(min) | c(min) |
|-----|--------|--------|--------|
|     | 1      | 2      | 3      | 4      | 5      | 6      | 7      | 8      | 9      | 10     | 11     | 12     | 13     |
| 2   | 12     | 13     | 13     | 13     | 13     | 13     | 14     | 14     | 14     | 14     | 14     | 12     | 12     |
| 3   | 3      | 4      | 4      | 4      | 4      | 5      | 5      | 5      | 5      | 5      | 3      | 5      | 5      |
| 4   | 5      | 3      | 3      | 3      | 3      | 4      | 4      | 4      | 4      | 4      | 4      | 5      | 3      |
| 5   | 7      | 6      | 6      | 6      | 6      | 5      | 5      | 5      | 5      | 5      | 5      | 7      | 5      |

|     | b_2  - 2.5 | b_2  + 2.5 |
|-----|----------|----------|
| 2   | b_3  - 1.0 | b_3  + 1.0 |
| 3   | b_4  - 0.5 | b_4  + 0.5 |
| 4   | b_5  - 1.0 | b_5  + 1.0 |
Figure 2. Gantt chart of optimal personal crews in instance 2
Table 3. The results of Matlab simulation.

| Project size | PB(min) | Actual duration (min) | Variance |
|--------------|---------|-----------------------|----------|
|              |         | Average | Max | Min |          |
| Instance 1   | 5       | 43      | 45.5| 40.5| 2.053    |
| Instance 2   | 9       | 54      | 51  | 56.0| 3.246    |
| Instance 3   | 11      | 65      | 68.5| 61.5| 4.102    |

In the table 3, the project buffer, mean value, maximum value, minimum value and the standard deviation of the actual duration and simulated cost were compared with different scheduling instance. The project buffer determined by both CMM and the project size is a fixed value, and we take the average value of the 20 simulations as the project buffer of the proposed method. We see that the buffer consumption, the actual duration of the proposed CMM method and TFN increase with the increase in the degree of project size. The variance of the results also increases in the 20 simulations. Based on the results of these cases, we have reached that the buffer size is determined by the proposed method and the project size. It may make the buffer size increase linearly with the number of activities, resulting in an excessive buffer size. The proposed method of CMM with TFN can reduce the uncertainty in project duration and provide convenient guidance to carrier aircraft support and scheduling applications in the dynamic flight deck environment, and thus reduce the buffer. Therefore, it could further reduce the duration fluctuations and improve the on-time completion rate.

7. Conclusion

This paper presents a proactive robust optimization method named CCM based on fuzzy method for the MSSCA that considers as a comprehensive multi resource-constrained multi project scheduling problem. A triangular fuzzy number is used to calculate the resource requirement and considers the comprehensive factors affecting the resource constraints to adapt uncertainty scheduling environment. The MSSCA scheduling project consists of two parts, the duration and the buffer. An integer comprehensive mathematical formulation for MSSCA is established with the robust objectives of the
limitative makespan and the project buffer by considering the independent operational time and resource constraint of each activity. Simulation results shows that the proposed method can make a better robust proactive scheduling for the MSSCA project. In the MSSCA proactive scheduling, if the project buffer size is too big, the activity duration will be very short. It will be difficult to finish the operation activities on time. If the buffer size is too small, the proactive scheduling will not be overcome completely in the dynamic environment. In the future, we can make an important extension regarding research about the developed robustness scheduling method for the project buffer to improve with the proposed resource allocation schemes and adapt the dynamic flight deck environment.

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