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An approach to airline MRO operators planning and scheduling during aircraft line maintenance checks using discrete event simulation

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Abstract

The process of scheduling and planning refers to examining aircraft history based on when and where the aircraft should go for service checks. In this paper, the authors focused on line maintenance activities and examined the impact of unexpected factors (Missing tools and safety requirements) on such activities during the process through a Discrete Event Simulation (DES) model. The DES was used to determine the following: 1. The plan time of each maintenance task according to maintenance scheduling based on the X airline company in Libya; 2. A tasks and productivity evaluation which involved examining the number of tasks required to do per check according to the scheduling plan and planned tasks performed by technicians, and; 3. The total elapsed time involved by analysing the average time for each task according to maintenance schedule planning. The results show that, for all scenarios conducted, the DES model was operating at a high level, and in some scenarios, there was a breakdown in service tasks; a clear indication that the workload factor was high during check periods. However, the main finding in this study highlights how a number of different tasks or the breakdown of maintenance work packages were not being completed before the actual time that had been allocated for the general external condition A-check of the aircraft. This made it necessary to study the work package for each check separately and examine these work packages as they relate to DES which presents a potential solution to a more efficient planning approach. This feature enhances the applicability of the proposed method in real-life, and helps airlines cope with the dynamic environment of airline MRO.

Keywords: Line maintenance; maintenance scheduling;maintenance planning; maintenance work package; DES

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1. Introduction

Aircraft normally require various maintenance checks, which incorporate transit/ramp-checks, A/B-checks (known as line maintenance) and/or C/D-checks (known as heavy maintenance). All of these mean that airline Maintenance Repair and Overhaul (MRO) operators have a complex, set of requirements to contend with, which must be met in order to service aircraft on time. This has led airline MRO service providers to develop focused maintenance strategies with the key objective of ensuring that aircrafts are hosted over shorter periods. This helps to reduce costs and keep the aircraft in the air and flying in order to meet passenger demand.

Generally, aircraft maintenance can be categorised as either scheduled or unscheduled. A planned schedule is determined based on flight hours, flight cycles and calendar days, while an unplanned schedule refers to unexpected maintenance which may occur at any time while the aircraft is being used. When airline MRO operators are cognisant of aircraft maintenance requirements, they are able to develop accurate, robust scheduling and planning. Planning consists of a large number of tasks which need to be carried out for each schedule. So, having accurate and achievable tasks is crucial in order to

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develop and design maintenance plans for the long, short and medium term [1]. In fact, airline MRO operators continue to face challenges related to aircraft planning, because each aircraft has different tasks that need to be performed. These tasks should be planned before maintenance time. Moreover, there are some factors affecting planning, such as workforce, workload, safety requirements, due primarily to the daily operations of aircraft. It is appropriate, therefore, to analyse planning based on the specific maintenance tasks by work package value (i.e. the impact of each task) through the DES approach as this can accurately record the duration of maintenance activities during the aircraft line maintenance period. The DES simulation approach will be run at different times for the execution of actual maintenance tasks in real-time and so will check for delays during line maintenance and simulation runs.

1.1 Contribution

The planning of maintenance schedules is a complex task because each aircraft type has a different maintenance logbook. Moreover, each airline's MRO has a different plan for scheduling. The focus of this study is on developing the airline MRO operators planning during line maintenance checks. The contribution of the paper is at least twofold: Firstly, it uses discrete event simulations to develop line maintenance schedule planning by using maintenance events as the elements that will form one part of the DES input, which will help to determine the time required for the ramp/A-checks. Secondly, the generic functionality for the DES is planned by dividing the ramp and A-checks into three parts. This will help to ascertain the number of maintenance tasks required for each maintenance check. This paper also proposes two variables that will give information about the duration of the maintenance service.

2. Literature review

This section briefly describes and discusses some of the major studies in aircraft maintenance planning, the maintenance planning process itself, as well as highlighting how airline MRO operators plan and schedule for line maintenance.

2.1 Maintenance planning process of MRO companies and airline MRO operators.

Based on a review of the extant literature, planning for scheduled tasks can be determined based upon calendar time and flight cycles or Flight Hours (FH). Each aircraft has its own logbook that records all the checklists that should be completed by the MRO airline or MRO companies during the aircraft's life-cycle. Aircraft maintenance, scheduling and planning are different as far as servicing aircraft is concerned. Planning refers to the process of estimating aircraft usage or mandatory maintenance (i.e. normal checks such as the A/B checks or unexpected checks such as planning for emergency work). Where planning estimates for aircraft usage is low or inaccurate, this can significantly affect maintenance operators who may have to re-calculate their time spent on checking/servicing aircraft as well as having to deal with the regular scheduled checks, such as layover/ramp checks, which are performed per-flight [2][3]

2.2 Airline MRO operators planning and scheduling for line maintenance

The line maintenance checklist has different tasks that need to be performed. Moreover, all checklist work depends on the type of aircraft, usage, age, type of operation (long vs. short haul), and environment [4]. In all cases, operators have a limited time between an aircraft's arrival and its departure. This time constraint has led airline MRO operators to divide the maintenance inspection process into several functions (known as the maintenance work package), which aims to expedite turnaround time and thereby avoid issues linked to servicing aircraft [5]. The number of tasks performed in a work package can be increased, particularly if there are any extra maintenance tasks arising from damage and failures discovered during the inspection process. Where feasible, tasks need to be performed before the next flight. Where not, the maintenance operator reschedules, all of which can result in increasing the total planned workload. Researchers have highlighted the workload factor as being one major obstacle airline MRO operators planning faces due to the extent of maintenance tasks and the age of the individual aircraft [6,7]. Furthermore, a related study has addressed human factors affecting work performance such as workload and workforce factors involved in line maintenance caused by maintenance personnel involved in MRO line maintenance. This is because, if all maintenance tasks have to be carried out in short span of time during the aircraft turn around, this can lead to an increased chance of human error [8]. This type of scenario has led to study on manpower planning in order to try and resolve maintenance planning and scheduling problems. In fact, it is a well-known fact that aircrafts undergoing maintenance checks are usually not available on time due to insufficient maintenance planning [9].

It has been reported that planning problems stem from overall scheduling of a fleet of aircraft and how maintenance personnel deal with multiple details and scheduling of activities. There appears to be a lack for communication between maintenance planning and operational planning, which can result in low operation reliability and high operational cost [10].

There are also issues linked to operational aircraft maintenance routing problems (AMRP). Specifically, these can be categorised as problems in weekly planning and scheduling, especially in heterogeneous aircraft which affect aircraft maintenance routing, fleet assignment, flight and crew scheduling [11]. Literature in this area has examined long-term maintenance check schedules for a fleet of heterogeneous aircraft to solve, minimise or optimise the wastage on intervals between checks. It has focused on individual aspects, such as aircraft type, status, and maintenance capacity. However, the problem of task allocation still remains and may be a factor in the increasing complexity of maintenance planning problems [12] The planning of maintenance tasks is usually divided into different work packages to develop services. It is necessary to design a detailed work package for each major service, where all planned checks and unexpected failure of aircraft components required in the service meet the timeframes established in the short, medium and long-term. However, if the airline MRO providers are following task planning, it may not be possible to cut costs [13].

It is known that work packages (calculated based on routine work, component change, delayed defects, modification/special inspection, skills, and spare parts) are a complex process that makes aircraft scheduling and planning problematic in terms of overall maintenance requirements. Spare parts issues refer to OEM suppliers and aircraft spare parts inventory, which stem from inventory management problems [14]. Nevertheless, there are problems faced by airline MROs in terms of job scheduling, and this introduces some challenges because maintenance tasks have deadlines and therefore, the level of skills technicians have and problems they face can possibly affect maintenance task planning [15].

Several researchers have highlighted that airline MRO continue to face challenges related to aircraft planning, because each aircraft has different tasks that need to be performed. These tasks should be planned before maintenance time. Most researchers have focused on the factors affecting planning, such as workforce, workload and safety requirements, due primarily to the daily operations of aircraft [1,4,6,7,8]. Despite the extensive research on airline MRO and MRO companies, little work has been done on how work package value can cause workload factors and delays, all of which affect planning.

3. Methodology

This section describes the process of designing and building an aircraft maintenance planning and scheduling. In order to create the functionality required, the DES models being proposed will be built based on a maintenance events for the Airbus 320. This is because the researchers collected real data for ramp and A-checks from X-company in Libya (See Table 1). [16]

Table 1. Maintenance events

Maintenance events			
Type of standard maintenance check	Frequency maintenance is carried out	Estimated time need for completion	Other checks Unexpected checks (aircraft component failures)
Layover-check	Per flight	30 minutes	
Ramp check	Daily check	30 to 60 minutes	
A1-check	6 months	8 hours	
A2-check	48 months	//	
A3-check	54 months	//	
A4-A5-check	72/96 months	//	

When it comes to planning, some studies have been conducted in this area, with some authors using simulations, such as DES [17], and system dynamics (SD), or models, such as maintenance integer linear programming, to design maintenance planning systems. Planning systems, however, also have their own issues as they necessitate being familiar with aircraft type, flight operation type, route, number of aircraft needed in the fleet and the number of services required per day. All of these elements may be difficult to gather and analyse in one model. However, the advantage of using such a method is clear as it gives organizations (airlines MRO and MRO companies) the ability to make accurate decisions for maintenance planning systems based on flight schedules and flight routes (known as airline scheduling and daily operation) [18]. Using this information, maintenance operators can plan and schedule based on the specific maintenance tasks required for different aircraft in the fleet [19,20].

3.1. Discrete Event Simulation (DES) structure

In this research, the author adapted a representation method based on the maintenance events. Each maintenance task is scheduled to move through the DES. The DES is a simulation used as a network of queues and events for modelling systems. This system works by using four elements: resources, activities, queues and entities. The system can be run by using simulated individual elements to create a number of activities that help users to understand output distribution. This potential for wider scale applicability has led some researchers to use DES for process management, investment planning, scheduling or evaluation of different for project management strategies. [21].

3.1.1 Input and output

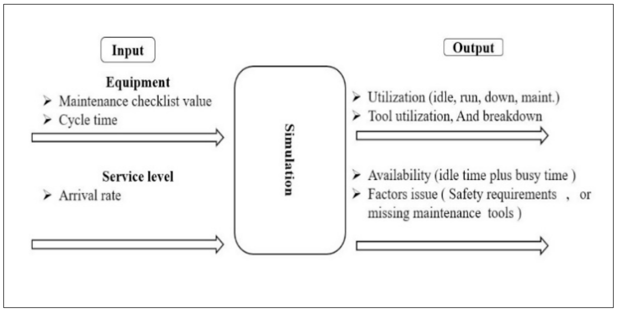


Fig. 1. DES input and output.

3.1.2 DES scenarios

Firstly, in order to carry out line scheduling and planning, robust strategies are required. The researchers will develop and build the DES simulation based on real data for ramp and A-checks for the A320 aircraft. The data used to run the DES comes from X company in Libya. Due to confidentiality requirements, not all data can be presented.

First scenario: The ramp-check tasks and A-check will begin processing and will be completed without interruption, while the second DES scenario begins processing and is completed. However, there will be interruption in some maintenance tasks which require tools and therefore need more time to be performed. The ramp checklist typically includes 58 checks that need to be performed in half an hour, while the A-checklist includes 128 tasks that must be performed in eight hours[16].

- Ramp-check
  There are 58 maintenance tasks divided into three categories (i.e. operation part - includes 40 maintenance tasks, inspection part – includes 15 maintenance tasks, and the service part which consists of 3 maintenance tasks, (see Fig. 2).
- A-check
  Here there are 118 maintenance tasks divided into three categories (i.e. operation – involves 56 maintenance tasks, inspection – involves 40 maintenance tasks, and service – involves 22 maintenance tasks, (see Fig. 2).

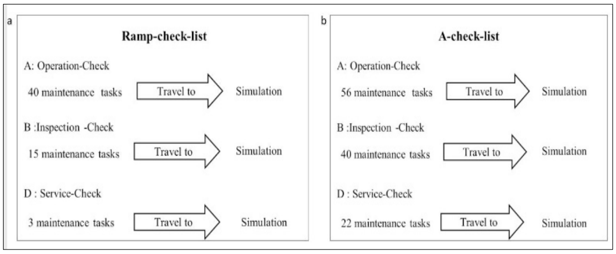


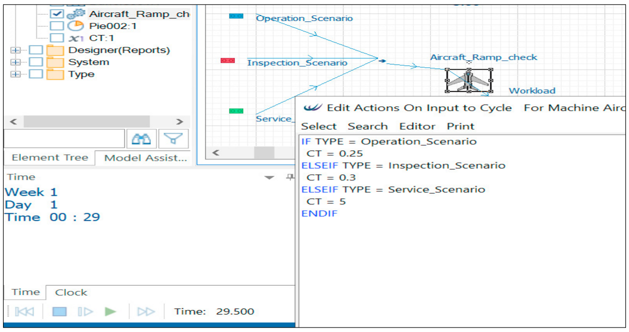
Fig. 2. DES modelling scenarios. (a) ramp-check; (b) A-check

The term 'operation tasks'(Op) used here by the researchers refers to all tasks that require tools for checking or services, such as the door escape slide, brake accumulator. DES modelling scenarios. (a) ramp-check Inspection tasks (In) refer to tasks requiring visual inspection only, such as fair door, portable oxygen cylinders. Finally, service tasks (Se) are all tasks that should be performed before each flight for the ramp-check, such as cleaning and refueling, or during the A-check, such as waste water drain and windows.

4. Testing

4.1. Testing - The ramp-check tasks and A-check will begin processing and are completed without interruption in first DES scenario.

This study developed the DES model based on the aircraft maintenance event, which was scheduled by X airline company. The authors divided aircraft maintenance schedules into three scenarios: 1) DES modelling, which comprises the operation, inspection and service scenarios for ramp/A-checks; 2) ramp-check tasks, which include 58 maintenance tasks completed in 30 minutes; 3) A-check tasks, which include 118 maintenance tasks completed in eight hours. Three scenarios were created with different machine time cycles to demonstrate the time consumed for each maintenance task from beginning to end. When the DES is running, the entities moved from the part to the machine and then machine-cycle time was set based on individual maintenance tasks (Fig. 3. and 4. below show screen shots of the maintenance tasks scenarios and both checks (ramp and A-checks).



```
IF TYPE = Operation_Scenario
 CT = 0.25
ELSEIF TYPE = Inspection_Scenario
 CT = 0.3
ELSEIF TYPE = Service_Scenario
 CT = 5
ENDIF
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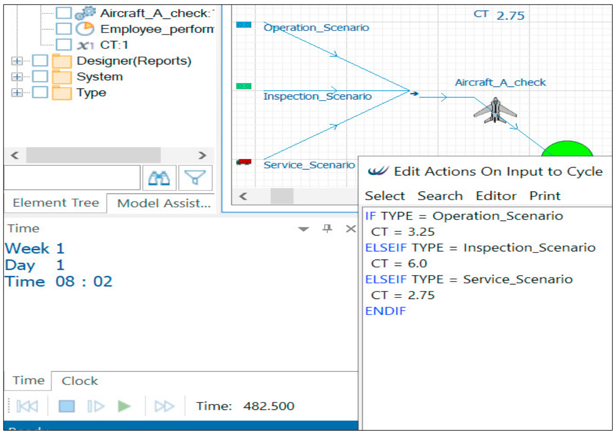
Fig. 3. Ramp-check



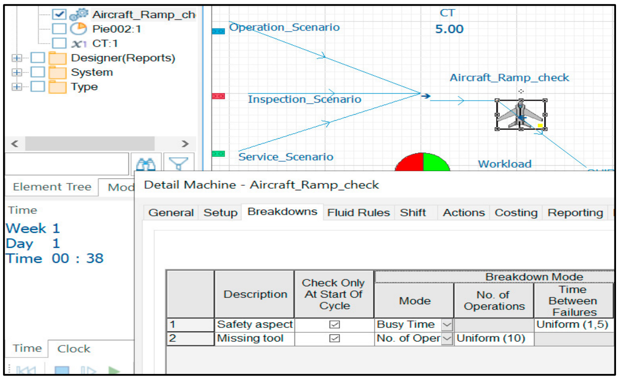
```
IF TYPE = Operation_Scenario
 CT = 3.25
ELSEIF TYPE = Inspection_Scenario
 CT = 6.0
ELSEIF TYPE = Service_Scenario
 CT = 2.75
ENDIF
```

Fig. 4. A-check

4.2 Testing the ramp-check tasks and A-check begin processing and are completed with interruption in some maintenance tasks in the second DES scenario.

After the DES runs in the first model, the authors added some variables which impacted the effects of the DES models, particularly the DES-cycle time. There were two problems pertaining to safety requirements and missing tools for the ramp-check and A-check.

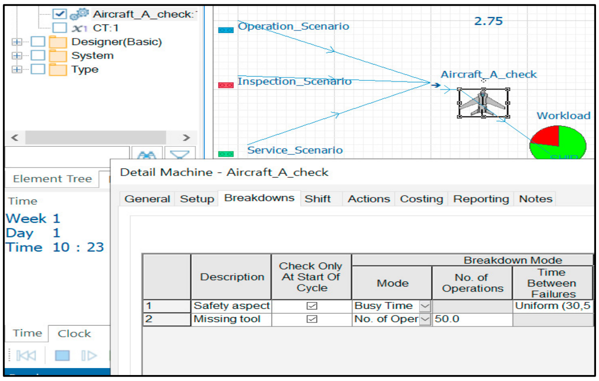
- Safety requirement problems for ramp check refer to the engine task because the maintenance operators cannot check the engine until it shuts down. This action was started between the first minute and 5 minutes from the aircraft's arrival at the gate. Meanwhile, the missing tools refers to solving task number 10, which is the toilet light (see Fig. 5).



	Description	Check Only At Start Of Cycle	Breakdown Mode		
			Mode	No. of Operations	Time Between Failures
1	Safety aspect	☑	Busy Time		Uniform (1,5)
2	Missing tool	☑	No. of Oper	Uniform (10)	

Fig. 5. Ramp-check

- Safety requirement problems for the A-check refer to the life vest task because around 130 life vests need to be checked visually to see whether they have expired. This action starts approximately between 30 minutes to 50 minutes after the aircraft scheduling for the A-check service. The missing tools refer to solving task number 50, which is landing gear tasks that involve the nose landing gear well, left /right main landing gear …. etc. (see Fig. 6).



	Description	Check Only At Start Of Cycle	Breakdown Mode		
			Mode	No. of Operations	Time Between Failures
1	Safety aspect	☑	Busy Time		Uniform (30,5
2	Missing tool	☑	No. of Oper	50.0	

Fig. 6. A-check

5. Results

The results of the first maintenance schedule plan via simulation modelling are presented in Table 2. It should be noted that the ramp-check took 30 minutes to complete the operation, inspection and service check. The A-check took 8.2 hours. The cycle time of each maintenance task was less than one minute for the ramp-check, while the A-check cycle time was between 3 and 7 minutes depending on the task that needed to be performed. In the ramp-check, the average work in progress (Avg W.I.P) was high for the operation part, while the average time was also high in the service part/element. In the A-check, the (Avg W.I.P) was high in the inspection part, while the average time was high in the service part/element.

Table 2. Results for the first simulation modelling

Results for the ramp-check tasks and A-check without interruption.							
		Ramp			A-check		
Number of aircraft maintenance tasks for each scenario		Op	In	Se	Op	In	Se
		40	15	3	56	40	22
Time	Avg W.I. P	6.95	6.05	2.39	10.75	25.24	20.64
	Avg time	5.13	11.90	23.50	7.28	16.77	31.50
	Total time consuming	29.5 minutes			8.2 hours		
% Idle		0			0		
% Busy		100%			100%		
% Broken down		0			0		

The results for the second maintenance schedule plan from the simulation modelling are presented in Table 3. The contents were similar to the previous model, which added variables such as missing maintenance tools and safety requirements. The aim was to observe the duration of the maintenance service. In this regard, it was noted that the duration of the maintenance service was longer when compared to the previous model. It took two hours for the A-check and more than 8 minutes for the ramp-check. In addition, approximately 23% of the maintenance tasks broke down for both checks (ramp and A). In the ramp-check, the average work in progress (Avg W.I.P) was high in the operation part, while the average time was high in the service part/element. In the A-check, the Avg W.I.P was high in the inspection part, while the average time was high in the service part/element (see Table 3).

Table 3. Results for the second simulation modelling.

Results for testing the ramp-check tasks and A-check with interruption							
		Ramp tasks			A-check		
Number of aircraft maintenance tasks for each scenario		Op	In	Se	Op	In	Se
		40	15	3	56	40	22
Time	Avg W.I. P	7.56	6.53		2.45	10.86	25.44
	Avg time	7.28	16.77		31.50	120.94	396.51
	Total time consuming	38.5 minutes			10.26 hours		
% Idle		0			0		
% Busy		76.62%			77.39%		
% Broken down		23.38%			22.61%		

6. Analysis and Discussion

Earlier study [11] presented lengthy processes that can cause delay and present factors that affect scheduling plans. The long process shown in the first DES modelling scenarios indicates that approximately 174 maintenance tasks for ramp/A-check should go through simulation. This result was due to the workload factor. This was the highest factor introduced in these scenarios, because the DES was busy 100% of the time. The DES results support the work of other researchers, which indicates that a problem was faced by the airline MRO operator [2,8].This refers to the schedule planning because the deadlines to finish the task generates two factors: workload and workforce [6]. Moreover, other researchers have reported that the major problem facing aircraft planning and scheduling is the time-consuming nature of inspection [1,3]. Due to this, the cycle time for each task in the first DES scenario was built based on the task duration to discover the rate and duration of the scheduled tasks according to the plan. However, the cycle time for each task was less than one minute for the ramp-check, while the A-check cycle time was between 3 and 7 minutes depending on the task that needed to be performed. The lower cycle time may induce a workload factor because the DES was busy for the duration. The number of tasks to perform per check and total task time according to the schedule plan were also busy for the entire duration. This percentage could introduce a maintenance workload factor.

A maintenance work package includes some tasks that are derived from the unexpected failure of aircraft components. Such actions affect planning [15]. The issue was examined in the second DES modelling scenario by adding two variables (safety aspect and missing tools). As a result, 23% of the tasks were broken-down into both checks (ramp and A). A-check took two and a half hours longer than the first DES modelling. The ramp-check also took 8 extra minutes compared with the first model. This result is also in line with the work of other researchers who confirmed that the aircraft maintenance program has multiple plans with the aim of determining the time of inspection or repair for each aircraft task [10]. The DES showed that the average work in progress was high in the service-part element for A-checks, with about 587 minutes needed to complete one of the items in service part. This result could be attributed to the absence of maintenance tools during the A-check period.

General external conditions for the A-check, which involves wheel and landing gear parts, can be done before the actual time of check. In contrast, ramp-checks feature some tasks that are performed close to the flight time, such as toilet lights, wing lights, etc., which may differ from one aircraft to the next and this could be a problem, particularly if there are no spare parts or maintenance tools available in the airport. From their point of view, the different tasks in ramp-checks may not affect safety and reduce maintenance workload. For example, toilet lights, wing lights and door markings cannot stop the aircraft from flying, particularly if the aircraft is to go back to its home base (i.e. aircraft hub) or the aircraft is scheduled for a domestic flight (short flight). This gives the airline MRO operator the opportunity to make short term planning schedules to service the aircraft and results in less workload and lower costs. Moreover, the A-check work package can be divided into several tasks which will be done during the daily aircraft maintenance routine. Airline MRO operators can take safety standards into account by highlighting the tasks that should be done as the last work package is conducted. When maintenance operators try to complete an incomplete work package, they will need to go back three tasks from the last task performed previously. This will help airline MRO operators to more effectively plan a long-term maintenance schedule and meet safety standards.

7. Conclusion and future research

The aim of this paper was to highlight line maintenance problems through scheduling and planning, and how airline MRO operators formulate plans for the long and short term to avoid delays. Designing and developing the plans for line checks can be a lengthy process; a factor that may affect plans.

Unexpected failure of aircraft components affects planning and is undoubtedly a significant problem faced by airline MRO operators, particularly as it pertains to the A-check. The results show that the A-check needs two extra hours, especially if aircraft components are damaged, or tools are missing. This highlights the importance of airline MRO operators updating planning to avoid workload and delays. One useful method for overcoming some of the issues linked to this process involves dividing the A-check work package into several tasks, which can be carried out during the aircraft's daily maintenance routine.

Future research should focus on unplanned workload during a line-check. This is because of the increase in the number of runs flying schedules to 7 days a week, and some tasks need to be deferred to the next flight because of the short time between flights. This is a crucial point for researchers to build a strategy for planning to avoid workload, especially on a transit check.

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