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## Designing Contracts for Aero-Engine MRO Service Providers: Models and Simulation

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### Abstract

The aero-engine Maintenance-Repair-Overhaul (MRO) service provider has begun to adopt the product-service system (PSS) offering in order to maintain their competitiveness. Such total solution approach combines an availability-based service contract with product offerings (e.g., leasing). The current MRO service provider's contract design method is inadequate to support this offering. Miscalculation often occurs, because many of the decisions are often based on intuitions and experiences, resulting in lower quality, higher cost and longer turnaround time for the maintenance. This paper proposes an enhanced contract design method that is more scientific through the simulation modelling. The models incorporate both customers' requirements and the shop floor's operational availability. The paper provides discussion on how the results of the simulation of the models can be used to support decision making and the design of availability based contracts.

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*Keywords:* Availability-based contract; aero-Engine MRO; non-OEM MRO; service; contract design;

### 1. Introduction

The MRO (Maintenance-Repair-Overhaul) service providers of aero-engines are changing their business model due to high competitive pressure of the market. The traditional business model was a "garage model" in which engines are maintained whenever they need maintenance. Over the last decade, OEM engine manufacturers started to introduce availability-based contracts, which is a "servitisation business model" that combined products (engines) with services.

In order to compete with OEMs, nowadays non-OEM MRO service providers also offer availability-based contracts by bundling service with products. It is a reverse approach of the servitisation from the manufacturers [1]. However, traditionally, service contracts for the garage model were

designed primarily looking at only capacities mostly based on intuition and experiences. On the other hand, availability-based contracts should be designed scientifically, i.e., using models and simulation performed on them, because availability should be correctly understood, evaluated, and guaranteed. By doing so, both the MRO service provider and the customers (airlines) can identify a win-win solution.

This research aims at to obtain a better contract design method for availability-based contracts. To achieve the aforementioned aim of this research, the following research objectives were set.

- To identify the key parameters and factors which must be considered during contract design.
- To build a model about flight operations based on the identified key parameters.
- To build a model of the shop floor based on the identified key parameters.

- To simulate MRO operations with these two models.
- To analyse the trade-offs between MRO demands and the shop floor capabilities and capacity.

The paper consists of five chapters, including the introduction. Chapter 2 discusses the literature review. Chapter 3 presents the research method. Chapter 4 illustrates the scenarios used to design contracts and the findings for each scenario from the simulation process. Chapter 5 concludes the research and explain further for future recommendations.

**2. Literature Review**

To remain competitive, the aero-engine non-OEM MRO service provider has adopted the offering of the availability contract as part of the total solution to their customers. This strategy corresponds to the servitisation provided by the OEM manufacturers (products + services = Product-Service-System) [1]. As today’s market and business model are more complicated, the airline’s requirements have shifted to full operational support, On Time Performance (OTP) and implementing an outsourcing [2].

At the present, most literature discusses the reliability and availability contract of the aero engines from such viewpoints as the influence of operating environment on engine health [3], the lifecycle management of engines to provide maintenance service [4], the additional spare parts policy [5], the maintenance policy of the aging equipment [6], the engine reliability to decide the total aircraft spare parts [7], the dynamic behaviour of a PSS system [8], and the uncertainty management regarding cost to the contract [9].

In the traditional contract design method, situations of the shop floor are only discussed from the viewpoint of nominal capacity. However, obviously the shop floor will be more loaded due to fluctuations of engine arrivals damage to the engines. Therefore, it is crucial to consider not only nominal capacity but also flight operations and engine damage conditions into consideration. This means the airlines’ operational requirements need to be taken into consideration but existing literature does not explicitly discuss this issue.

**3. Research Method**

Fig. 1 illustrates the research method of this paper. First, to understand non-OEM aero engine MRO business, a case study on an MRO service provider was conducted to perform interviews, document assessment, and observation combined with literature survey. This was to obtain overview and accurate insights of the business strategy and the current application of the strategy.

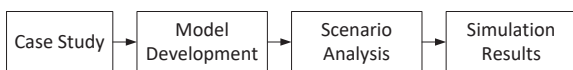


Figure 1 Research Method

Second, through this investigation, we could pick up parameters regarding the operational processes in the case company’s shop floor and scenarios to be applied to the

model and simulation. This investigation further resulted in a conceptual decision making framework for contract preparation depicted in Fig. 2 [10].

Third, this conceptual framework has been enhanced by adding external factors to predict a maintenance event which is then used as an input to the MRO service provider in assessing their capacity and capability. To do this, two scenarios to be simulated on this model were developed. One represents a contract with a LCC (Low Cost Carrier) airline, while the other a full-service carrier. The enhanced parameters include the airline’s flight operations in the contract, loading estimation, geographical condition, previous maintenance history of engines, and the operational policy such as the thrust settings and the de-rate level. These parameters increase the accuracy in delivering maintenance scheduling.

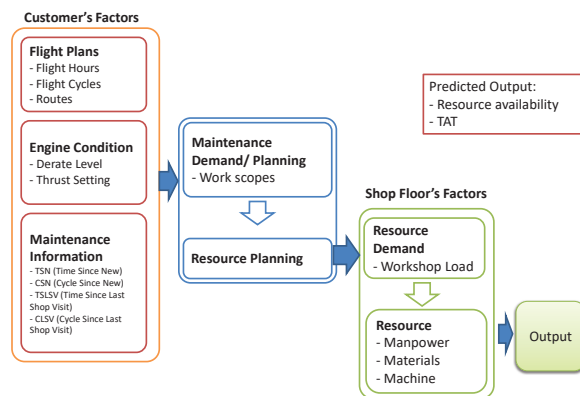


Figure 2 Conceptual Framework of Contract Design [10]

**4. Model Development**

As depicted in Fig. 3, this research used two models, which are a maintenance schedule model for aero engines derived from flight operations, and an operational model of the maintenance shop floor. The outputs of the aero engine maintenance scheduler become the interface between the customers’ flight operations and the shop floor operational availability. The output from the entire simulation on these models can be used for decision-making during contract design as well as investment planning.

The second shop floor model was taken from the non-OEM MRO service provider’s shop floor situation. It presents a general operational process adopted from the CFM56-3 Training Manual [11]. This manual defines each process for the work scope of the aero engine maintenance. The shop floor operation model uses the discrete event simulation to assess the shop floor operational availability and capability of future time maintenance (Fig.3).

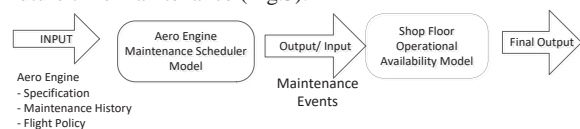


Figure 3 Model Development Interrelation

4.1. Aero Engine Maintenance Schedule Model

The aero engine maintenance schedule model has been developed in order to assess the down time for each aero engine. This model has two type of parameters. One is parameters to indicate the condition of the aero engine itself, such as the maintenance historical data including Time Since New (TSN), Cycle Since New (CSN), Time since Last Shop Visit (TLSV), and Cycle Since Last Shop Visit (CSLV). The second type of parameters include the external factors of flight operations, such as the geographical situation of the airports and the flight operational policy (thrust setting).

The customer (airline) creates flight plans in future to calculate common parameters for the maintenance schedule, i.e., Flight Cycle (FC) and Flight Hours (FH), from the maintenance historical data above. They also arrange data that represent the current situation and condition of the aero-engine itself. From these parameters and flight operational parameters (listed in Table 1) required maintenance events and their timing can be determined. These results become the input for the next maintenance shop floor simulation process.

Table 1 Model Parameters Input (example)

Engine Specification	Operational Specification	Contract Parameters
Type of Engine	Geographical Condition Flight Pattern	Initiation Start Data
Thrust Setting	Flight Cycle (FC)	Contract Duration
De-rate factors	Flight Hours (annually)	

The assessment of this method is adopted from Ackert [12] and Aircraft Commerce [13] combined with the data from the case company, which incorporates several external parameters for the maintenance events. To include the stochastic aspects, this research also integrates the unscheduled maintenance calculation by using Monte Carlo simulation.

The simulation results predicted the total maintenance events required for every aero engine and which maintenance work scope needs to be conducted. The work scope could be represented as performance restoration and/or the life limited parts (LLP) replacement (Table 2).

Table 2 Maintenance Event Prediction (example)

No	Maintenance Event Forecast	Date of Event (Month)	Workscope
1	Engine Shop Visit	Mar-16	Core Performance
2	Engine Shop Visit	Jul-17	Core Performance
3	Engine Shop Visit	Nov-18	Core Performance
4	Engine Shop Visit	Mar-20	LLP + Core Per.
5	Engine Shop Visit	Jul-21	Core Performance
6	Engine Shop Visit	Nov-22	Core Performance
7	Engine Shop Visit	Mar-24	LLP + Core Per.
8	Engine Shop Visit	Jul-25	Core Performance

4.2. Shop Floor Operation Model Management

To describe the process of the shop floor situation, we used a discrete event simulation method. The engine maintenance shop floor is modelled in Fig. 4.

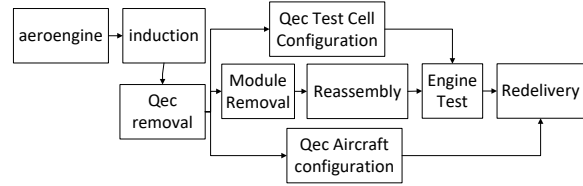


Figure 4 General Maintenance Processes

The induction process covers the preliminary inspection, maintenance history documentation check, and the borescope inspection. This inspection is conducted before the aero engine is sent to disassembling (i.e., active in operation). Then, this process is followed up by the decision as to which work scope of the aero engine maintenance will be conducted.

The maintenance work scope of the aero engine can be divided into several categories, such as minimum level, performance restoration level and full overhaul. The maintenance could be conducted in the shop floor of the hangar or on-wing on the ramp. In other cases, the aero engine is put in Quick Engine Change (QEC).

The most complicated and difficult workshop maintenance is completed in the full overhaul. This work scope covers the maintenance of several modules of the engine. It includes the disassembly, cleaning, inspection, repair, consumable top-up, and reassembly. Within the scope of the model, several scenarios, such as outsourcing and part provisioning are modelled in an integrated manner as maintenance process.

The aero engine test is conducted before redelivery (the engine is serviceable and then sent to the customers). In the test process, several processes are also carried out, such as the installation, configuration and documentation.

4.3. Shop Floor Model in Discrete Event Simulation

In order to build the model, we used a commercial discrete even simulator, Witness\*, to assist the representation of the scenarios of the model. The assumptions on how our model work are as follows:

- (1) The process time for each process are specified, based on the minimum and maximum time of the processes from the case company.
- (2) The maintenance processes in Witness will be similar to a general machine, which has an input and several outputs. An aero engine can be disassembled to several major modules, such as fan major module, core major module, Low Pressure Turbine (LPT) major

\* Witness is a trademark of Lanner Group Ltd.

module, accessories major module, and control major module.

- (3) The off-wing and on-wing maintenance work scope are represented in the process as a QEC (Quick Engine Change) test cell and QEC aircraft configuration, respectively. The QEC test cell configuration is applied to an aero engine which needs to be tested in the shop with smaller work scope than full overhaul. The QEC Aircraft Configuration (A/C) means that the maintenance is conducted while the aero engine is still installed in the aircraft.
- (4) The reassembly process models the assembly process from several major modules in the maintenance. The reassembly process replaces any damaged parts with the same type that was used in the initial construction of the aero engine.
- (5) The simulation of the maintenance process follows the (sub)major module's maintenance sequences. The aero engine arrival time profile is calculated by the maintenance schedule modeller from regular maintenance schedules and unscheduled maintenance events which happen randomly.

After arrival, the induction process takes place (off-wing or on-wing) to conduct general visual inspection and boroscope inspection. The outcome of the induction determines the work scope (on-wing, off-wing, or overhaul). The overhaul process is conducted in the full work scope process. The process of the maintenance, which is not presented, has been assumed to be integrated in the additional time of the process.

The disassembly process is modelled as a process with an input (aero engine) and multiple outputs (several major modules, namely, fan major module, core major module, Low Pressure Turbine major module, accessories major module and control major module). Each of the major module undergoes several maintenance processes, such as cleaning, inspection, balancing, repair, topping up consumables, etc. Each process also has particular cycle time obtained from the case study company.

Each maintenance process comes with mechanics, inspectors, and cleaners, modelled as labour elements provided from this software. The total labour requirement involved in this process is taken from the case company's document.

The total output of this simulation results in the total lead time, or Turn Around time (TAT) between arrival to the delivery of the engine to the customers.

## 5. Simulation Model

To investigate the demand fluctuation for maintenance, two scenarios have been chosen. The simulation runs two extreme cases which relate to the highest operating frequency (such as in the case of LCC) and the lowest operating frequency (representing a full-service carrier).

Flight cycles and flight hours are typically higher in LCC airlines. This results in a higher demand for maintenance and vaster maintenance work scope. In the case of a full-service

airlines, the maintenance demand is usually lower especially if the operation requires lower flight cycles and but higher flight hours. From these scenarios, the different characteristics of customer demand can be investigated. This demand therefore affects the maintenance frequency, maintenance work scope and the maintenance policy.

### 5.1. MRO Service Provider's Scenarios Simulation

Having developed the model, experiments incorporating a number of different parameters obtained from the real industrial cases were conducted.

Several scenarios which include the flight operations for all aero engines incorporated in the contract agreement were then tested to obtain when the maintenance is going to take place (the maintenance event). The maintenance requirements for these aero engines were then predicted using the model. The maintenance event and the requirement are based on the flight mission and the future plans. Routes, geographical condition, flight cycle, flight hours, total aero engine numbers and the maintenance history were also taken into account when scheduling the maintenance events.

The differing scenarios result in the fluctuation of the maintenance events of the aero engines. In this case, the situation of the shop floor also needed to be assessed. The assessment was conducted in order to investigate the shop floor operational availability with regards to their capacity and capability to conduct the maintenance in the future. The operational availability in the shop floor is related to the capacity and the capability of the sequence of maintenance process. This includes the availability of the material, machine, manpower (labour) and methodology to conduct the maintenance.

In the service design, the supply has to match the demand, thus the capacity and capability of the shop floor have to be based on the mean time and the situation of the capacity and capability at a particular time. The basis of the simulation depends on the discrete event simulation to assess the available time of the maintenance shop floor line, which is based on customer requirements in the future.

The scenarios were designed based on approaches, the maintenance schedules and the shop floor operational availability. The maintenance schedule, for instance, reflects the different flights schedules of the airlines. The maintenance events depend on the maintenance policy, based on the shop visit frequency. For more frequent shop visits, the maintenance cost can be cheaper and the maintenance TAT will be shorter; this ensures more availability of the aero-engine.

This research assesses one extreme situation of the maintenance frequency combined with the actual situation at the company. Higher frequency maintenance events certainly affect the operational shop floor operational capacity and capability.

### 5.2. Maintenance Event Scenarios

Several assumptions were made to deliver the condition and situation of the business strategy between the MRO

service providers and the airline. The contract duration that has been agreed for ten years with all aero engines was also included.

The maintenance events were triggered by the daily arrivals of aero-engines uniformly distributed between 1 and 5. Each type of aero engine is still in a configuration and this scenario does not incorporate any cannibalisation of the parts. Each part is signed and delivered, depending from where it is sent.

In this simulation, the most important parameter is the duration of the maintenance cycle time. Therefore, the sequences of the maintenance are modelled through the cycle time of each process.

**6. Results and Discussion**

The simulation model was then run for five-year simulation time. It reflects the common standard duration of the contract between the MRO service provider and the customers. It then continues on the basis of the capacity and sequential maintenance process mentioned before.

After several experiments, the capacity of the shop floor can be demonstrated. This is shown in Fig. 5.

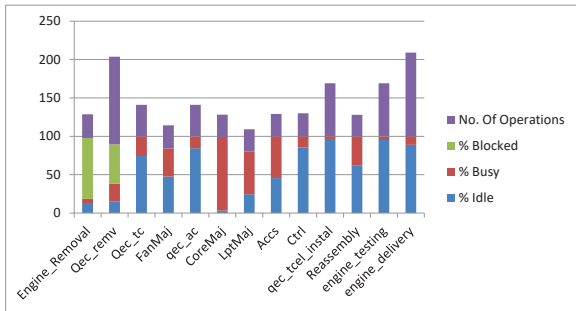


Figure 5 Simulation Results (1)

Fig. 5 also shows the bottleneck in the engine removal process. This is caused by the slower maintenance process in the core major module maintenance in the next process. This could be affected as the operation of the customers' needs more of the aero engines to have full overhaul work scope of maintenance (performance restoration and LLP replacement). As this situation covers more work scope on the major core module. This occurs because customer 1 (LCC) tends to have more flight cycles rather than flight hours. More flight cycles in the operations mean that the combustion chamber, high pressure turbine, and the high pressure compressor have a higher deterioration level through the frequently high temperature of the operations.

Another interesting finding is the labour shortages represented by the blue bars in Fig. 5. It is apparent that the process needs more labour. Followed by the high idle percentage mentioned regarding the other processes, the capacity and capability of the shop floor have been utilised optimally. Another opportunity, such as opening a service based on the shop floor operational availability could optimise the utilisation of the shop floor.

For another scenario (Fig. 6), the airline maintenance policy is to have an increased maintenance interval; however, the maintenance work scope remains the same, as referred to in the maintenance planning document.

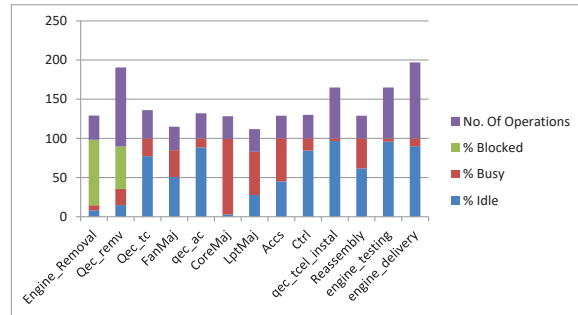


Figure 6 Scenario Result (2)

The most important information of the statistical process report illustrates that there is a bottleneck (purple bar) in the engine disassembly. This is caused by the high utilisation in the core major module. Another critical thought is the identification of the MRO service provider having a shortage labour for the maintenance processes.

Based on both the configuration and the results provided, the MRO service provider needs to invest more in the capacity and capability of the maintenance, especially in the core major module maintenance line. However, there is also a need to assess the strategy to tackle this problem. If there is capacity addition in the core major module, it could be predicted that the bottleneck also appears in other maintenance processes.

Therefore, the decision makers need to assess the best optimum solution for this situation. To use the other strategy as mentioned could be an advantage to the MRO service provider in providing the best solution to the airlines. They could also apply another strategy not only to provide the pure maintenance service provision but also to provide another solution, for instance by bundling spare engines as a trade-off to tackle the consequences when conducting business agreements with the customers.

**7. Concluding Remarks and Future Work**

This paper proposed a contract design method for availability based contracts. This method could benefit the MRO service providers not only in the assessment whether to engage in the business agreement with the customers, but also to inform them when making decision, whether to increase or conduct investment strategy. A more accurate strategy for the MRO service provider enhances their expansion strategy's efficiency.

The method proposed in this paper can be a solution to support the productisation implementation [14]. Through the simulation model, the decision-makers could also assess their capacity and capability to fulfil the operational needs in the future. This paper contributes to body of knowledge by proposing the productisation business strategy.

The model incorporated in this research requires further enhancement. Greater accuracy and level of detail in the model are needed in order to increase the applicability to industry.

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