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Capacity planning for a maintenance service provider with advanced information☆

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ABSTRACT

Analytical and iterative optimization techniques are employed to solve a job shop-like capacity planning problem for a maintenance service provider with contractually defined lead time requirements. The problem is motivated by a real-life case example, namely the overhaul of airline aircraft engines through an external service provider. The production network is modeled as a network of GI/G/1 queues, where the service rates are the decision variables and capacity costs and penalty costs for not meeting contractually defined lead times are minimized. In addition, we analytically investigate the effects of collaborative maintenance management as a source of advanced information regarding future maintenance demand. More specifically, we consider the benefits of improved service rates and service and demand variabilities on production capacities and total costs. Numerical examples are provided to verify the proposed optimization procedure and illustrate the effects of collaborative maintenance management.

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1. Introduction and overview

Today, the rise of Cyber-Physical Systems and the Internet of Things facilitates real-time condition monitoring and condition-based maintenance of technical equipment (Zhu, Peng, & van Houtum, June 2015). Combining real-time condition data with plans of future equipment usage makes it possible to predict future condition and maintenance requirements. This is what we refer to as *advanced information*. Huge data streams are collected, stored and used for the optimization of maintenance schedules, production plans and supply chain operations. Sophisticated technical equipment such as Rolls-Royce's Trent aircraft engines are equipped with sensors that measure different parameters and send the data to data warehouses in real time (Geer, Ellis). For Trent engines, this data includes more than 20 parameters such as oil pressure, oil temperature, and vibration levels that can be used for condition-based maintenance scheduling and optimized planning of maintenance operations. However, data usage is challenging in a service provider or contract manufacturer setting, as the data is collected by the owner and oftentimes not shared with the supplier due to privacy concerns. An analysis of potential benefits is necessary in order to convince customers to participate and invest in a collaborative planning system.

In this paper, we analyze the benefits associated with advanced information for a maintenance service provider that can be obtained through collaborative maintenance management. More specifically, we investigate how advanced information influences the optimal capacity allocations in a complex maintenance and repair process, the associated capacity costs and the potential penalties for tardiness. Since advanced information oftentimes requires substantial investments, it is important to understand the relationship between advanced information and the costs of the system. The results of our analysis help supply chain partners to decide whether or not to invest in advanced information technologies and collaborative planning systems.[1]

Our research is motivated by a practical use case, namely the overhaul of aircraft engines of multiple airlines through an MRO[2] service provider. Airlines ship their engines to the service provider when they need to be overhauled. The service provider then processes the engines and sends them back after completion. A typical MRO engine overhaul production system is illustrated in Fig. 1. There are two sources of uncertainty in this system. One is that the engine arrival stream is a stochastic process where the interarrival time between subsequent engines is a random variable. Second, the service times

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[1] The research described in this paper is part of a larger initiative whose objective is to investigate potential applications of secure cloud-based computation in supply chain management scenarios: PRACTICE - Privacy-Preserving Computation in the Cloud, http://practice-project.eu.

[2] Maintenance, repair and overhaul.

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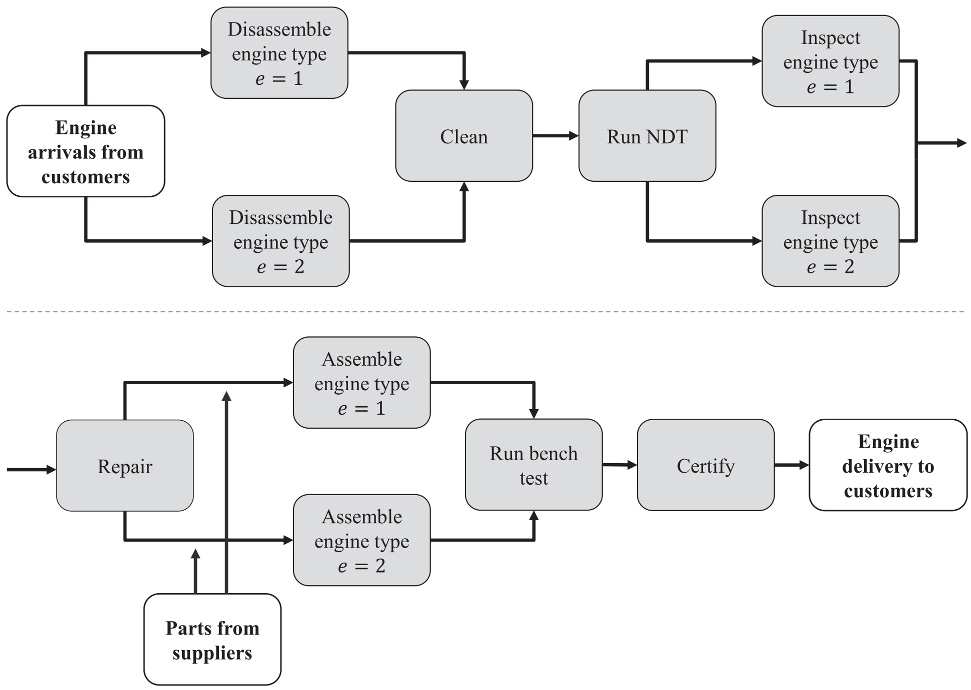

Fig. 1. Engine overhaul production network (on the basis of Zilli et al. (May 2015)).

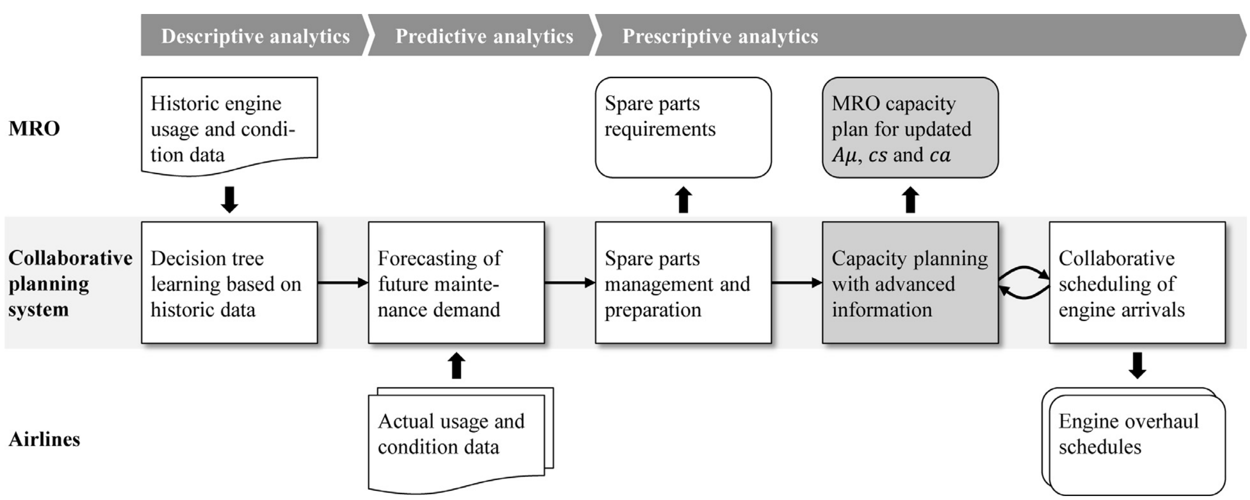

Fig. 2. A framework for collaborative aircraft engine overhaul management.

at the work stations illustrated in Fig. 1 are random variables and depend on the required service, on worker skill, and on spare parts availability.

In this paper we seek to determine the capacities of the work stations in the MRO production network such that total costs (capacity costs as well as penalty costs for not meeting contractually defined turnaround times) are minimized. In addition, we investigate the benefits of advanced information that can be obtained from a closer collaboration between the service provider and its customers. Through information sharing and collaborative scheduling of engine arrivals, the variabilities of engine interarrival and service times can be reduced, and the mean time required for service at certain work stations can be shortened. Investigating the influence of these effects on optimal capacity is a complex problem, as these parameters are interlinked throughout all work stations in the network. Fig. 2 illustrates a framework for collaborative maintenance management in the aerospace MRO business leading to the aforementioned improvements. While we focus on capacity planning (shaded in Fig. 2), we briefly explain the basic ideas of the other process steps in the collaborative maintenance management framework.

Using historical and actual engine usage and condition data, it is possible to predict when an engine will arrive at the service provider, and in what condition (this is *advanced information*), (see Taigel and Tueno (2015)). If the service provider is able to use this data, spare parts can be ordered such that service levels are improved. In addition, the provider can plan for and prepare overhaul operations beforehand to optimize the activities carried out when the engine arrives. Both improvements contribute to a reduction of mean service time and service time variability. Once a forecast of future engine arrivals is available, actual engine arrivals can be scheduled such that their interarrival time variability is reduced.

These improvements are only possible through investments in a collaborative planning system. Airlines need to be able to report their engine usage and condition data (captured through sensors) to a central data warehouse in a timely fashion. As the data reported by the individual airlines is highly confidential, cryptographic methods are

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