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Development of timed Colour Petri net simulation models for air cargo terminal operations

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Abstract

This paper presents the development and the application of simulation models for air cargo terminal operations. As air cargo volume is fast increasing in recent years, air cargo terminals which handle cargos for carriers face challenges to streamline their operations. Air cargo terminals employ diverse storage media and are also equipped with various material handling equipments. Due to the complex and stochastic nature of terminal operations, which makes formulation of analytical model difficult, in this study, simulation models are developed to analyze the air cargo terminal operations. We first employ timed CPN (Colour Petri nets) to model the terminal operations, and then the corresponding simulation model will be developed. In order to validate this simulation model, we run the model based on actual cargo retrieval schedules obtained from an air cargo terminal. The results show that this model provides a good estimate of the terminal performance. The model is then employed to analyze the performance of the airline assignment policy for the objective of minimizing the cargo processing times, and the results show that the proposed policy significantly improves the operational performance of air cargo terminals. Second, the simulation model is employed to analyze the performance of an AS/RS (Automated Storage and Retrieval System), and the performance of the proposed storage policy is compared with that of the current policy. The simulation experiment also validates the optimal parameter value from the analytic model. The developed models simulate air cargo terminal operations effectively and efficiently, and will aid future studies in the design and control of terminal operations.

Keywords: Colour Petri nets; Discrete event simulation; Airline assignment; AS/RS storage policy; Air cargo terminal

1. Introduction

In recent years, air cargos are no longer confined to rapid shipment or to fulfill emergent demands. As air cargo volume is fast increasing and airports need to compete with each other, air cargo terminals which handle cargos for carriers face challenges to streamline their operations. For cargo storage, terminals employ diverse

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storage media, such as AS/RS, storage racks, carousel, and so forth and are also equipped with various material handling equipments, such as forklifts and tractors. Incoming cargos must go through many different processes, such as being broken down at workstations, being transported by forklifts and being built into skids.

In this paper, we analyze the performance of air cargo terminal operations for the objective of improving its performance. Due to the complex nature of cargo processes and stochastic customer requests and processing times, which make formulation of analytical model difficult, in this study, a Petri net (PN) model is developed to describe terminal operations, from which a corresponding discrete event simulation model is developed. Actual cargo data are employed to validate the proposed model. This model compares the performance of different resource configurations, and the optimal resource configuration will be identified.

The PN modeling of complex systems for the performance analysis is provided in the following; for more details on PN, readers are referred to Jensen (1997). PN have a well-developed formalism and semantics that can model systems with interacting concurrent components, such as operators, forwarders, forklifts, and mechanized machines commonly operating in parallel. In any net, there are two basic elements: nodes and links. PN have two types of nodes: places and transitions. Places are used to represent resources such as storage spaces, or states of processes such as cargos waiting for retrieval. Transitions are used to indicate actions or operations, e.g., forklifts transferring cargos from AS/RS to a truck dock. PN employ directed arcs to connect from places to transitions or vice versa. The dynamic feature of PN is achieved by tokens, which can represent cargo retrieval requests. An arbitrary distribution of tokens on the places is called a marking. Each marking corresponds to one state of modeled system. The execution of PN is regulated by the number and distribution of tokens and changes the system state. By equipping each token with an attached token colour, standard PN are extended to colour PN, which can represent a large and complex system in a much more compact and manageable way. In our model, each type of cargos that require distinct retrieval process is assigned one colour. To investigate performance of terminal operations by means of cargo processing time, we construct timed colour PN; that is, allowing each token to carry a time stamp. In timed colour PN, transition rates can be either deterministic or random with a specified distribution. For example, when retrieving cargos stored in racks, the searching time can be constant or random variable following a pre-defined distribution.

PN have been widely used in modeling of complex systems for performance analysis. Two papers from Fota, Kaaniche, and Kanoun (1999) Kanoun, Borrel, Morteveille, and Peytavin (1996) studied the air traffic control system by means of stochastic PN. However, in stochastic PN, transition times must either be deterministic or follow exponential distributions, which makes it not applicable to our study. Bruno, Raineri, Raiteri, and Spiller (1989, 1991) conducted a case study on automatic warehousing systems by using high-level PN. However, air cargo terminals are different from other warehouses and have their unique characteristics. To our best knowledge, the model in this paper is the first study of modeling an air cargo terminal by means of colour PN.

This paper is organized as follows. In Section 2, we describe cargo import handling processes for an air cargo terminal. The details on modeling import cargo terminal operations by means of colour PN are provided in Section 3. Section 4 shows the numerical results to validate the developed model. In Section 5, the validated model is used to analyze the performance of the airline assignment policy and in Section 6, the simulation model is employed to identify the best-performing AS/RS storage policy. Finally, several concluding remarks are provided in Section 7.

2. Import terminal operations

In this section, a brief description for cargo import processes is provided. The following description is based on our observation in one of the busiest airports in the world.

The cargo flow in import terminal is shown in Fig. 1. After inbound cargos arrive in the terminal, import checkers break down cargos at a workstation. Then cargos are stored in different storage media according to their conditions: cargos remain on a big pallet or in a container are stored in Material Handling System (MHS), cargos on a wooden pallet are put into storage racks in Floor Goods (FG) area, loose cargos are put into standard-size bins and stored in Automated Storage/Retrieval System (AS/RS) and vulnerable cargos are stored in a cage. After a forwarder arrives in the terminal, an officer assistant (OA) dispatches retrieval jobs to operators. Transporting cargos from MHS is performed by mechanical rollers and Elevator Transfer