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Analyzing engineering change of aircraft assembly tooling considering both duration and resource consumption

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ABSTRACT

Aircraft assembly tooling is developed according to the constraints of geometric information and technical requirements of aircraft, and frequent aircraft changes can cause assembly tooling tasks to change frequently. Assembly tooling parts are large in amount and complex in structure. Due to the complex dependencies among the tasks of assembly tooling, change in one task can cause changes to many other tasks, which may require much time and resources to completely resolve them. However, long cycle and mass resource consumption for the engineering change would normally lead to high risk, high cost, high rework, and so on. The primary result of this work is the provision of a development support to find the optimal solution of assembly tooling change by examining the combined effects of duration and resource consumption. In this paper, engineering change progression of assembly tooling is modeled as a decrease of impact on affected tasks, which implies that the duration of certain changed task reduces gradually. Besides, a deterministic simulation model is developed to analyze the change propagation schemes. The model explores the combined effects of task parallelism, resource constraints and change propagation during the engineering change process of assembly tooling. Finally, a case study of an assembly tooling for the reinforced frame module is implemented and the analysis results suggest that the proposed method offers a valuable basis for providing targeted guidance on how to obtain the optimal engineering change scheme of assembly tooling.

1. Introduction

Aircraft assembly tooling plays an important role in guaranteeing the required location and orientation of aircraft subassemblies and parts. To deal with the consumer requirements, technology innovation, or mistakes, aircraft changes occur frequently, causing the assembly tooling tasks to change frequently. Aircraft assembly tooling subassemblies/parts are large in amount and complex in structure [1]. Its development accounts for 40% of the new aircraft development duration and costs about 20–30% of the development expenses [2]. Many tasks exist in the assembly tooling development and a later task needs the results of the earlier tasks as inputs. Meanwhile, the later task influences decisions made for the earlier tasks. In other words, these tasks are inter-related and mutually constraining. Therefore, any change in one task can invoke a chain of subsequent intra- and inter-related checking and changes. These changes often occur unpredictably in the assembly tooling development process, which can propagate through different tasks and generate significant impacts on the cycle and resource consumption. Thus, it is necessary to find the optimal propagation scheme for engineering change of assembly tooling in order to reduce the impacts as much as possible.

Long cycle and mass resource consumption for the engineering change of assembly tooling would normally lead to high risk, high cost, high rework, and so on. This can inevitably affect the time to market of aircraft and its competitiveness. CE (concurrent engineering) is an information sharing and parallel task approach that replaces the time-consuming linear process of SE (sequential engineering) [3]. In the CE, parallel execution of tasks can shorten the engineering change cycle and improve the efficiency of resource usage, which can minimize the duration and resource consumption for assembly tooling change. In this paper, the degree of task parallelism is described in the TP (task parallelism) matrix and the engineering change process is regarded as a process consisting of a series of tasks, e.g. developing the module of a tooling's cardboard. A task is composed of activities, e.g. the activities of designing, process planning for the cardboard module development. CL (change likelihood) matrix and CI (change impact) matrix are applied to describe the change likelihood and impact of assembly

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tooling tasks. Besides, resource (e.g. designers, process planners, machines, etc.) constraint is incorporated to schedule the engineering change process of assembly tooling. And two change indices: ND (normalized duration) and NRQ (normalized resource quantity), are proposed to assess the change propagation schemes.

The primary result of this work is the provision of a simulation-based method aiming at reducing the duration and resource consumption of the assembly tooling change. The framework of this method is shown in Fig. 1 and two aspects of the method can be concluded: PMREC (process model of resource-constrained engineering change) and SCPAM (simulation-based change propagation analysis method). In Fig. 1, three sub-models are divided from the PMREC and two algorithms are developed for the SCPAM. PMREC is the prerequisite of SCPAM. That is, based on the relation model between tasks, change propagation schemes of assembly tooling can be acquired with the algorithm of change propagation. Then, based on the acquired propagation schemes, task model and change process model, engineering change process of assembly tooling can be analyzed with the algorithm of scheduling changes.

The remainder of the paper is structured as follows. In the next section, some related research is reviewed. In Section 3, a novel engineering change process of assembly tooling originating from changed assembly requirement of aircraft is demonstrated. Section 4 presents a detailed description of calculating and analyzing the duration and resource consumption of engineering change schemes. In Section 5, an assembly tooling for the reinforced frame module is applied to demonstrate the proposed method. Subsequently, discussions about the method and its extension are given in Section 6. Finally, a summary of this work is provided.

2. Related research

2.1. Change management

EC (Engineering change) is an alteration made to parts, drawings or software that has been released during the product development process. The change can be of any size or type; the change can involve any number of people and take any length of time [4].

Many authors have concluded reasons of engineering change [5,6]. At the fundamental level, two reasons exist for changing a product: (1) to remove mistakes or make it work properly or (2) improve or enhance it for new requirements [7]. On this basis, Eckert et al. [8] categorize initiating changes, i.e. those start a chain of changes, as either emergent or being initiated from outside the product. However, it has been discussed in the academia that changes can also arise from other sources (e.g. new technology). A recent study of one hundred consecutive engineering change requests identified "other changes" as the cause of 36% of all the requests [9]. These ECs can significantly affect the product development time, cost and quality. Different reports suggest that EC uses around one-third of the engineering development capacity [10,11] and its management is essential. Five guidelines are suggested by Hamraz et al. [12] for change management: first, the occurrence of changes should be avoided as far as possible; second, changes should be detected as early as possible to reduce their impact; third, changes should be selected more efficiently, and fourth, implemented more efficiently; finally, the organization should learn from past changes to continuously improve the management of ECs [12]. Lindemann and Reichwald [13] conclude from an extensive study that efficient change management can provide a big advantage. This can be achieved through effective change prediction, which involves two activities: predicting the causes of change and predicting its knock-on effects [8].

2.2. Change propagation

A high degree of interactions between parts of a product leads to complex interactions during the development process [8]. Due to the complex interactions, a single change to one part may cause knock-on effects on other parts and additional changes [12]. This change snowballing can be in different forms and cause an avalanche. This process is termed change propagation.

Numerous change prediction models have been developed in the academia, focusing mainly on predicting knock-on effects and developing change management tools. One of the most established approaches is the CPM (Change Prediction Method) by Clarkson et al. [14]. DSM (Design Structure Matrix) is basically a square matrix with identical row and column headings [15]. And it is wildly used to record the complex relations between the product elements. Three types of elements: product requirement, change option, product component, and relations between them are recorded in DSMs to predict and manage undesired EC propagation during the development of complex products [16]. Koh et al. [17] introduce an approach that predicts how product attributes can be affected by EC propagation. Based on the STEP (Standard for the Exchange of Product) data model [18–20], Cohen et al. [21] develop a methodology called C-FAR (Change Favorable Representation), using existing product parameters, e.g., bottle size and bottle material, to facilitate change representation, propagation, and qualitative evaluation. Another recent method of change propagation analysis is proposed by Yang and Duan [22], who explore change propagation paths based on the parameter linkages.

2.3. Development process simulation

Many researches simulate the development process to understand the effects of changes and risk of product development. The difference among these approaches is the simulation method,

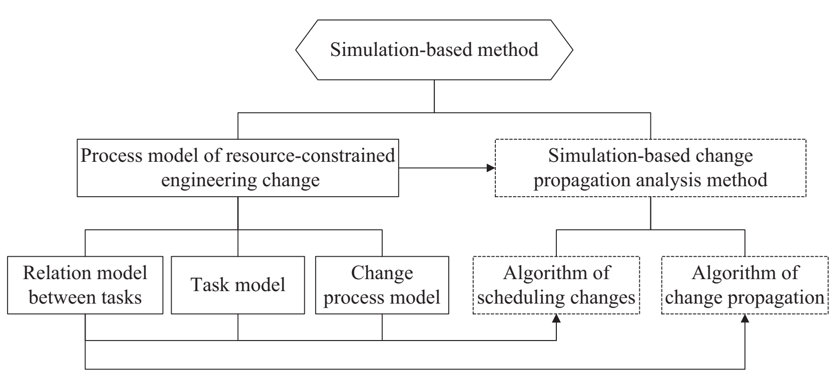

Fig. 1. Framework of the simulation-based method.