Advanced Engineering Informatics 23 (2009) 332–347

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Component-based records: A novel method to record transaction design work

L. Ding *, M. Giess, Y.M. Goh, C.A. McMahon, U. Thangarajah

Innovative Design and Manufacturing Research Centre, Department of Mechanical Engineering, University of Bath, Bath BA2 7AY, UK

ARTICLE INFO

Article history:
Received 21 May 2008
Received in revised form 3 December 2008
Accepted 20 March 2009
Available online 22 April 2009

ABSTRACT

The growing pressures from global competitive markets signal the inevitable challenge for companies to rapidly design and develop new successful products. To continually improve design quality and efficiency, companies must consider how to speed design processes, minimise human-errors, avoid unnecessary iterations, and sustain knowledge embedded in the design process. All of these issues strongly concern one topic: how to make and exploit records of design activities. Using process modelling ideas, this paper introduces a new method called component-based records, in place of traditional design reports. The proposed method records transaction elements of the actual design processes undertaken in a design episode, which aims to continually improve design quality and efficiency, reduce designers' workload for routine tasks, and sustain competitiveness of companies.

1. Introduction

To survive today's fierce competitive market; engineering companies must continually design and develop successful new products that have higher quality with lower cost and shorter product introduction lead times. Effective and efficient design processes are crucial in determining the capabilities, costs, and other attributes of products. Such processes depend on the knowledge and creativity of designers and the efficiency with which resources for designing are used. With the change towards whole product lifecycle support and the increase in the knowledge-intensivity and complexity of modern-day design tasks, recording of the information, knowledge, and experiences accumulated in designs is becoming particularly important today, not only for design of new products but also for product lifecycle support. Thus, major challenges for companies include: how to implement an appropriate design process to improve the performance of its products; how to make effective records of the work that is carried out in design activities; how to standardise and automate repetitive work to minimise error and rework in the design process; and how to capture the knowledge embedded in the design process to ensure the sustained competitiveness of a company. To respond to these challenges, various models and techniques for description or planning of design processes (i.e. design process model) have been proposed. Broadly, a process model can be descriptive, prescriptive, or have aspects of both [1]. A descriptive process model attempts to capture tacit knowledge about how work is really done (e.g. IDEFØ [2]). A prescriptive process model tells people what work to do and perhaps also how to do it (e.g. Signposting [3]).

Process modelling has achieved considerable success in improving the management of design processes, such as in lead time reduction, task scheduling, and project decomposition [4]. However, there are still a number of limitations need to be overcome [1,5], many of which are compounded by limitations in the way that actual design processes are recorded, such as lack of completeness of actual process descriptions, weakly structured and raw records, and poor capture of rationale.

Notwithstanding the difficulties in representing process steps, there is considerable value in better representation of design processes. Firstly, individuals and organisations tend to follow similar approaches in their work and learn and adapt through successive execution of processes [6]. Lessons from previous designs also benefit individuals and organisations by avoiding similar failures. Secondly, novice designers especially will benefit from a more complete record of such occurrences. Design processes, including design activities, decisions-made, and corresponding rationale, are currently largely still recorded in text documents (e.g. design reports, meeting minutes) and in some cases may be retained in employees' memories. It is difficult for novice designers to assimilate and digest processes recorded in text documents, and the employees who carried out the work may not be available. Furthermore, an analysis of information requests from novice designers found that they were aware of their knowledge needs in only 35% of their queries [7]. A useful process model will help designers, especially novice designers, pick up the correct information resources and methods at an early stage and minimise mistakes, false assumptions or incomplete information. Thirdly, better capture of processes will assist especially embodiment design for mature products, e.g. in automotive and aerospace engineering, in which a great deal of work is transactional, involving repetitive information access and manipulation steps. Fourthly, recording

* Corresponding author. Tel.: +44 1225 386131.
E-mail addresses: dlian2000@yahoo.com, l.ding@bath.ac.uk (L. Ding).

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doi:10.1016/j.aei.2009.03.001

design activities in a better structured form will strengthen data traceability and information retrieval. It especially benefits product lifecycle support, for example tracing design rationale from service feedback and understanding the performance envelopes as design intents for a product (e.g. food processing equipment [8]) redesign.

Using process modelling ideas, this paper introduces a new method to record transaction elements of the actual design processes undertaken in a design episode. The method, called component-based recording, is used in place of traditional design reports. The proposed method aims to (1) combine documentation and computer interpretable data to record the actual design work that has been done – recording information flow and dependencies, relationships between activities, successful and unsuccessful practices, and so on so that designers and engineers at later stages of the product lifecycle can look back to learn the lessons and continually improve design process; (2) allow routine work to be standardised and where appropriate reused, thereby freeing designers to focus their creativity and innovation on value-adding activities; (3) simplify definition of process model to make the recording of work quicker and easier; (4) allow both bottom-up and top-down recording of the process undertaken by an engineering team as it is carried out, and then browsing and retrieving of the record of the model from different viewpoints according to various users and purposes.

The following parts of this paper are organised as follows. Section 2 gives the background of this research, including relevant literature from process modelling; and a brief investigation of design records and design work. Section 3 presents the method of documentation of design records using a component-based model, including the basic framework, the definition of an activity, XML schemas, and a Topic Map approach for organising activity records. Section 4 describes the implementation of the proposed approach with a case study. Finally, Section 5 gives the conclusions and further research discussions.

2. Background

The following section presents a critical overview of process modelling, and the status of design work and design records.

2.1. An overview of approaches to process model

Compared to many other project-like activities, design processes may be characterised by involvement of large number of tasks, complicated interactions among tasks and people, and unavoidable inclusion of iterations and rework. These characteristics make design processes challenging to model and a number of process models and techniques have been proposed in recent decades for representation, scheduling, and capture of design processes.

A process is often modelled as an activity net. The early activity net-based techniques for project planning, task scheduling and control, including the Critical Path Method (CPM) [9–11] and the Project Evaluation and Review Technique (PERT) [12], form the foundation for many project management models. Generalized precedence relations (GPRs) [11] were then proposed to extend CPM from "strict precedence" (i.e. activity finish-to-start relationship) to four possible relationships (i.e., start-to start, finish-to-finish, start-to-finish, and finish-to-start).

CPM/PERT is often used to describe sequential tasks, while the DSM method, developed by Steward [13], is a scheduling technique that has been extensively used to support concurrent processes. The DSM uses a square matrix to represent a process by showing information flow between activities [13–16]. Typically, a cell on the diagonal of the square matrix represents each activity; the left of the matrix gives activity names; and a mark in an off-diagonal cell indicates an activity interface [7]. The DSM provides a simple way to visualise the structure of an activity network and to compare alternative process architectures [17]. Research has been carried out based on the original DSM method to manage issues like iterative groups and task overlapping. For example, two sequencing models [18–19] aim to reduce the number of information feedback loops, information crossovers, and the length of iterative cycles [4]; an extended framework [20] uses a graph theoretic approach for transformation and analysis of a network of design activities; a sequential iteration model [21] suggests an initial ordering of the coupled design tasks to minimise their expected duration; an extended sequential iteration model [22] allows for random duration of tasks as well as allowing multiple tasks to be attempted simultaneously; the work on transformation matrix method (WTM) [23] models design iteration by replacing the off-diagonal DSM elements with the strength of dependence between tasks, given rise to transfer of work, or rework involved in the iterations; an analytical model has been proposed which combines the decisions of overlap and communication in the presence of uncertainty and dependence between tasks, with the goal of minimising time-to-market [24]; and a second-generation simulation model [25] accounts for many important characteristics of engineering design process, such as information transfer patterns, uncertain task durations, resource conflicts, overlapping and sequential iterations, and task concurrency.

Besides the work on DSM, research work has been carried out to strengthen the guidance and scheduling of design process. The major efforts are: a Q-GERT model [26], which allows for queuing delays by considering probabilistic routing of tasks to servers, and probabilistic iteration; a triangularization algorithm [27] for organising design activities such that the number of cycles is minimised; a product development strategy combining parallel and serial processing [28] aiming to determine how much parallelism is desirable, and whether minimising development time justifies an increase in development cost; a model-based framework [29] based on the (evolution and sensitivity) properties of the information exchanged between overlapping consecutive stages of a development process; a multiple-phase project model [30–31], which explicitly models process, resources, scope, and targets so as to improve project performance and understand the dynamic concurrence relationships that constrain the sequencing of tasks as well as the effects of and interactions with resources, project scope, and targets; a signposting model [3,32], which associates confidence levels to the parameters in a task and uses these to prioritise or "signpost" the next appropriate task; a rich model of the product development process architecture [6], where each activity has an uncertain duration and cost, an improvement curve, and risks of rework based on changes in its inputs; and a generalized homogeneous and non-homogeneous state-space concept proposed to model concurrent, coupled and design tasks and to analyze and control the stability and convergence rate of the design tasks [33].

Many researchers have studied how to represent design process so as to aid understanding and capture of the design process and knowledge. The decomposition of large design projects into smaller elements is seen in the work of Alexander [34] and Kusiak and Park [35]. The Structured Analysis and Design Technique (SADT) is process model and representation method that has been widely used, particularly its well-known derivative, IDEFØ [2], one of the ICAM Definition Language family of modelling techniques. An IDEFØ model is composed of a set of hierarchically linked diagrams, which provide a static descriptive view of a process. Maimon and Braha [36] developed a method of modelling design processes based on the Analysis–Synthesis–Evaluation (ASE) paradigm. The proposed design process model is denoted as tuples containing artifact space, a set of explicit constraints, analyzer, synthesizer and evaluator. Zeng and Gu [37] proposed a design