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Design chain management: bridging the gap between engineering and management

Chih-Hsing Chu · Weidong Li · Roger J. Jiao · Jack C. P. Su

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Because of economic globalization, modern product development has become greatly dependent on effectively leveraging external resources with customers, suppliers, technology providers, and business partners by means of inter-organizational collaborations. Consequently, supply chain management has received considerable attention, with studied that have concentrated on sales forecasting, production planning, scheduling, and logistics. Few studies have explored global distributed product design, especially from either the engineering or management perspectives.

A design chain is a series of activates bound together to add and transform information required to realize a final design. Eppinger and Ulrich (2004) proposed five main activities to describe design chains: planning, concept development, system-level design, detailed design, and testing and refinement. They further identified the elements of these activities in the functional areas of marketing, designing, and manufacturing.

Distributed decision making plays an important role in design chain management for modern product development. Four important supporting functions are required to facilitate decision making in design chain management: information sharing, partner selection and involvement, coordinating mechanisms, and performance evaluations. These functions cover all main activities, as shown in Fig. 1.

Numerous scholars have studied product design-related issues. The nature of these issues could be engineering oriented, such as process modeling and developing computer-assisted software tools, or more management oriented, such as strategic issues of selecting business partners for information sharing. For the decision-making process, various previous studies have assumed that a single agent in the design chain has the primary bargaining power or a significant stake. Other players are either forced or willing to share information. The dominant player can make decisions to optimize the performance of the entire chain on behalf of everyone else; this is called centralized decision making. By contrast, a distributed decision implies that decisions are made by various decision makers who have their own interests and goals and occasionally have privileged information. Centralized decisions are rare and difficult to achieve, especially when design tasks are spread across organizational or geographical boundaries because of economic globalization. Therefore, the process of managing distributed decisions in design chains is essential.

We categorized prior studies on product design into four categories according to two dimensions: (a) establish if the issues are engineering or management oriented, (b) determine if the decision process is centralized or distributed. We positioned the studies of design chain management in the upper right corner, as shown in Fig. 2.

Researchers in management schools tend to investigate PD issues that are abstract or managerial. The results of their studies are not limited to a particular industry or product. However, they are likely to ignore engineering or technical

C.-H. Chu (✉)
Department of Industrial Engineering and Engineering Management, National Tsing Hua University, Hsinchu, Taiwan
e-mail: chchu@ie.nthu.edu.tw

W. Li
Faculty of Engineering and Computing, Coventry University, Coventry, UK

R. J. Jiao
School of Mechanical Engineering, Georgia Institute of Technology, Atlanta, GA, USA

J. C. P. Su
Anderson School of Management, University of New Mexico, Albuquerque, NM, USA

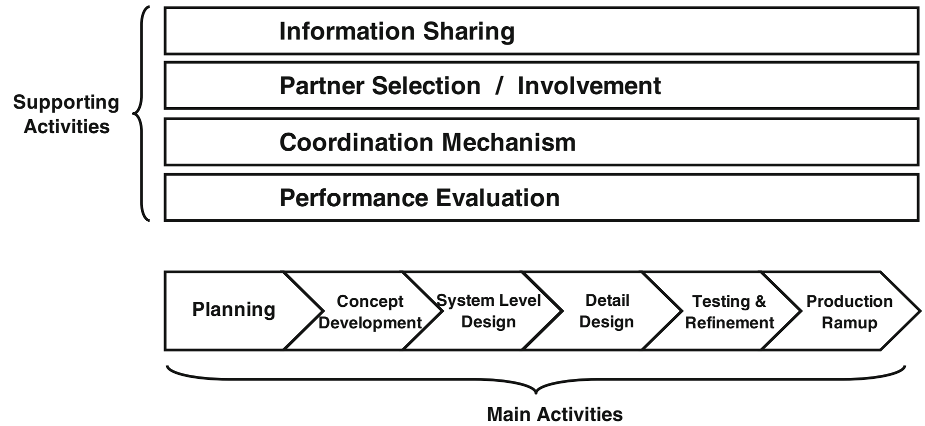

Fig. 1 Design chain management framework

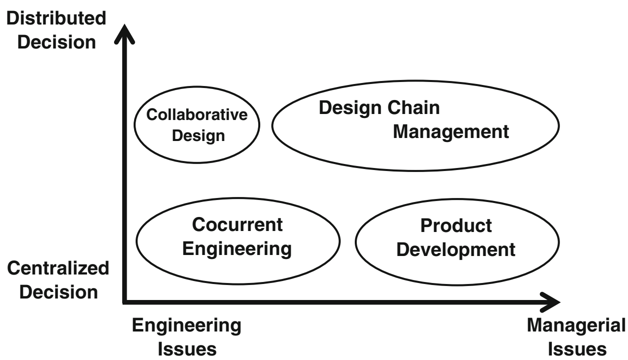

Fig. 2 Position of design chain management

details to generalize the results or polish their models. By contrast, most studies on concurrent engineering (CE) focus on engineering issues with specific technical details. Previous studies on PD and CE have assumed centralized decision making.

Studies on collaborative design (CD) concentrate on the engineering issues of information technology (IT) systems and design methodologies to facilitate information sharing in a distributed-decision environment. Design chain management addresses issues that extend from CD toward management. A typical example is resolving engineering design problems that are complicated by constraints derived from managerial perspectives. The hybrid nature of this subject poses a challenge to industry and academia because it is characterized by heterogeneous information, fewer quantifiable data, higher uncertainty, and greater risks compared to supply chain management. Few prior studies have examined distributed decision making in product design by considering both engineering and managerial problems simultaneously. We endeavor to bridge this gap by collating seven quality studies is special issue.

The first paper, "Multi-agent negotiation based on price schedules algorithm for distributed collaborative design", by Lin, Y. I., Chou, Y. W., Shiau, J. Y., and Chu, C. H. studies inter-organizational collaborative design with incomplete information transparency. Collaborators tend to hide individual design rationales while working together to develop solutions for the benefit of overall design. Traditional all-in-one (AIO) methods that assume a dominating collaborator owns all related information in the design decision making are not applicable. This paper models the distributed design process as a consolidated problem of resource allocation and proposes a negotiation mechanism based on the price schedules decomposition algorithm to search for optimal solutions. A central facilitator coordinates the collaboration among a group of design agents in the negotiation process. The facilitator receives a request on resources from each agent and adjusts individual virtual prices to equalize the demand to the supply. The design agents calculate optimal demands based on local objectives and inform the facilitator of their decisions. Such an iteration process continues until the optimum overall objective is attained. This mechanism does not require specialized participants (facilitator or design agent) with full knowledge of the entire design space. A prototype system is implemented with JADETM to realize distributed collaborative design based on multiple-agent technologies. A scenario of distributed tolerance allocation in collaborative assembly design validates the negotiation mechanism and demonstrates its effectiveness on automating collaborative design in a secure manner.

The second paper, "Multi-objective design and tolerance allocation for single and multi-level systems", by T.C. Hung and K.Y. Chan focuses on engineering design problems under various operating and environmental uncertainties. This work proposes a computational framework for simultaneous design and tolerance allocation with multiple objectives for hierarchical systems. The framework generates optimal design alternatives and to rank their performances when variations are present. The idea of influence range is developed to facilitate design alternatives selections with an influence signal-to-noise ratio indicating the accordance of objective variations to the Pareto set. The notion of influence area helps quantify the variations of a design. Multi-level systems are decomposed by integrating sensitivity analysis for uncertainty propagation with analytical target cascading (ATC). This work provides a systematic approach for decision-makers to select their best design alternatives on the Pareto set using three measures with different purposes. Examples of structure design demonstrate the effectiveness of the proposed framework on robust design for both single- and multi-level systems.

In the third paper, "SysML-based design chain information modeling for variety management in production reconfiguration", D. Wu, L. Zhang, R. J. Jiao, and F. Lu present a holistic view of design chain management along the product realization process. They claim that design chain information modeling is highly complex because of a series of multi-disciplinary activities and a collaborative distributed environment. To analyze design chain systems by multi-view information modeling is necessary. This work applies the Systems Modeling Language (SysML) to model design chain information. The goal is to support variety management decisions in a design chain that aligns the customer, product, and process domains. The SysML-based information models are further implemented as a variety coding information system. It enables multi-disciplinary participants of the design chain to share and exchange information among multiple domains by ensuring semantic coherence along the entire design chain, keeping the traceability across levels of abstraction, and improving the interoperability among heterogeneous tools. A case study of switchgear enclosure production reconfiguration system demonstrates that SysML-based information modeling excels in conducting requirements, structural, behavioral and constraints analysis.

In the next paper "Formalization of design chain management using environment-based design (EBD) theory", Sun et al. propose a formal conceptual model of design chain management, referred to as a wheel model, derived from a natural language description of the design chain. This model encloses three interrelated models: operation model, management model and collaboration model. The goal is to reveal unacceptable conflicts between environment components implied in the design chain environment by considering the design chain participants, design process, and the relationship between available technologies, supported by the EBD theory. An industrial example illustrates how the proposed model can be used to identify and solve conflicts in the design chain management.

The concept of design chain management is applicable to various industrial applications. Focused on engineering asset management, the next paper "A multi-agent collaborative maintenance platform applying game theory negotiation strategies" by A. J. C. Trappey, C. V. Trappey, and W. C. Ni presents a collaborative business model to integrate maintenance chain members with an intermediary service center. The collaborative business model links asset sites, system providers, and first tier and lower tier collaborators. A prototyping multi-agent system is implemented based on the model to integrate real time data collection with diagnostic and prognostic expertise generated from heterogeneous data sources. Agents with autonomy and authority work to assist service providers and coordinate communications, negotiations, and maintenance decision support. Game theory is used to design the decision models for strategic, tactical, and operational decision making during collaborative maintenance practices. This work provides a reliability and profit optimization mechanism to enable intelligent and collaborative maintenance procedures. Maintenance resources, asset conditions, multi-goals, and constraints, are considered to achieve improved maintenance system benefits.

The next paper "An analogy based estimation framework for design rework efforts" by P. Arundacahawat, R. Roy, and A. Al-Ashaab proposes an analogy-based framework to estimate design rework probability of occurrence and the efforts required in a product design project. This analogy-based approach compares similarity of a new product with previous products and then estimate cost based on degree of the similarity. Design rework factors are recognized from literature reviews and further developed as rework drivers by mapping with results from semi structure interviews with three companies in automotive industries. Design structure matrix (DSM) is used to determine critical sub-systems or elements prone to rework by estimating interactions among them. The proposed framework is applied to the development project of a water pump. The statistical results generated by the mean magnitude of relative error method are in an acceptable range and experts from companies agree on the validity of the design rework drivers. This work supports decision making in the early design phase to reduce design rework and the cost and duration of product design incurred.

Design chain management involves decision making with various uncertainties throughout the product development process. The last paper "Simulation-based conjoint ranking for optimal decision support process under aleatory uncertainty" by A.M. Ruderman, S.K. Choi, and R.J. Jiao studies how uncertainty and complexity inherent in the design process of complex engineering systems should be managed by effective decision support tools. The focus is on correctly modeling subjective data associated with decision makers' preferences in multi-attribute decision analysis. To implement an approach to address uncertainty of the system parameters and data driven by customers' surveys is also critical. A simulation-based ranking methodology incorporating with conjoint analysis is proposed to facilitate a schematic decision support process by alleviating the aleatory uncertainty from user fatigue. The added benefit manifests itself through the ranking of design alternatives based on both the performance value of each attribute and the accompanied uncertainty A case study of a power-generating shock absorber design demonstrates the efficacy of simulation-based conjoint ranking by showing its advantages over traditional survey-based ranking.

Finally, we would like to thank the reviewers who provided valuable comments and insights to all submissions to this special issue.