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Design of a multi-disciplinary and feature-based collaborative environment for chemical process projects

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ABSTRACT

Currently, the lack of interoperability across different engineering disciplinary domains remains a big issue in industrial practice, such as those major chemical process projects. Detailed engineering information is mainly exchanged verbally or, to a very limited extent, manually by technical documents, and hence the interdisciplinary dependencies, especially those tedious and error-prone references across domains, are not well maintained. The interoperability is hindered by the heterogeneous domain models used, and engineering semantics are not well maintained during the project lifecycle. This paper attempts to solve the informatics interoperability issue by proposing an *inter-domain functional feature* framework based on the *associative feature* mechanism and the exploration of commonalities of product and process models between chemical and mechanical domains. The schemas of feature models are developed explicitly to represent the characteristics of multi-domain entities and flows, while a mapping mechanism is realized to support inter-domain information sharing. Inter-feature relations are systematically managed so that the intricate engineering knowledge is incorporated into design tasks. The prototype software developed shows that design conflicts can be detected by the system intelligently; and the effectiveness towards engineering consistency management is promising.

1. Introduction

A chemical process engineering project can be characterized as a series of complicated, multi-phase, and interdisciplinary design and engineering activities that involve interdependent contributions from chemical, mechanical, and electrical engineers. The complexity of such projects has led to the development of computer-aided software packages. Such computer-aided tools provide engineers with powerful and intelligent functions and capabilities for individual engineering areas, such as chemistry analysis, chemical process design, and mechanical design. For example, Aspen Technology packages are commonly used for chemical process conceptual design and optimization; Intergraph SmartPlant™ for chemical process and plant design; and Siemens NX™, Dassault Catia™, and Solidworks™ for mechanical design.

There is always strong demand for systematic modeling of associations among the entities generated from different software packages due to the dependencies among engineering activities. For example, the conceptual chemical process analysis provides input to the detailed chemical process engineering, and it also influences detailed mechanical design. Unfortunately, software tools are usually developed by different vendors emphasizing individual domains of engineering, and hence have different semantics and data structures. While such individual tools are widely applied, there is still no integrated solution for industry use. This situation leads to collaboration difficulties among engineering disciplines, as well as the corresponding tools, due to the difference of specific syntax and semantics embedded in the proprietary data representations (Schneider & Marquardt, 2002).

The keen market competition calls for a short lead time for any chemical process projects, with zero tolerance for faulty design. Typical activities involved in a chemical process project are illustrated in Fig. 1. Engineers from different disciplines need a collaborative design and engineering environment to work effectively and efficiently. Due to the lack of a common infrastructure support for collaborative engineering, two urgent problems exist for engineering informatics researchers. First, there are no well-defined mechanisms to pass the information from one domain to another—for example, from the chemical process design domain to mechanical design—and hence, information transfer is tedious and error-prone. The same problem exists when feedback information is passed from a downstream engineering domain to the

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upstream one. Second, costly problems commonly occur due to the lack of the anticipation for downstream engineering considerations in the early conceptual design stages.

For example, without integrated collaboration information support, the conceptual process design could be neither viable at the early design stage due to equipment constraints nor accurate without cycles of revisions that are made necessary due to the current pieced-information feeding practice. It is also very costly in time and effort to verify and change inter-disciplinary design models according to the current practice. For example, the designed process operating parameters, such as temperatures and pressures, are the original drivers for the downstream mechanical design and engineering phase. Yet, these operating parameters are dependent upon or closely associated with the mechanical design and selection of best-fit equipment items or components with economic and safety considerations. Currently, the changes of those driving parameters lead to significant redesign efforts in the project. During the mechanical design process, the equipment items are usually classified into two categories: proprietary equipment (PE) items and non-proprietary equipment (NPE) items (Towler & Sinnott, 2013). For those NPE items, such as pumps, compressors, it is more economical for the owners or the engineering procurement and construction (EPC) companies to get them from those off-the-shelf products instead of making the specially-designed ones. The off-the-shelf equipment items can be supplied and produced in batches. For example, an off-the-shelf vessel that is larger than the volume requirement usually costs less than a customized vessel with the exact size of the volume requirement (Couper, Penney, Fair, & Walas, 2010). In contrast to the NPE items, the PE items warrant more collaboration between chemical process and mechanical engineers. To keep the data consistent, based on the input of chemical process engineering, mechanical engineers design the PE items cyclically. After determining the PE item design, the PE item's new mechanical properties or specifications have to be used to update the parameters in the chemical process model. The new process model needs to be further verified by mechanical engineers. In the current industry practice, such cyclical work is done manually by engineers in EPC companies. It is cumbersome, time-consuming, and error-prone. Many errors are hard to detect which, more often than not, lead to problems in the testing and even operating phases. To design a multi-disciplinary engineering collaboration environment, the associations among different engineering entities of different disciplinary domains need to be represented explicitly and uniformly as well as a systematic propagation method for numerous expected design changes.

So far there have been few research efforts reported developing a multi-disciplinary design engineering environment to associate different engineering domains, despite the tremendous potential for quality improvement and cost reduction. Most researchers still mainly consider domain-specific problems; they have focused on either chemical process design or mechanical design of the process equipment items. The system interoperability problem remains without a unified framework and the explicit representation of the intricate associations.

This paper proposes a multiple-view feature modeling method, which is intended to integrate multiple engineering domains, especially chemical process engineering and mechanical product engineering. Under the framework proposed, the associations among the features across the domains are modeled in detail, and example associations are established, implemented and managed in a prototype system. The preliminary functionality demonstrated by the prototype shows that the engineering information can be shared across the domains consistently and efficiently. Potentially, well-informed decision-making throughout the engineering project cycle can be supported.

This paper is organized as follows: Section 2 is a comprehensive literature review of the state-of-the-art research on integrated product and process modeling for chemical and mechanical engineering domains. The concept of advanced feature technology and the relevant recent progress in the field are introduced in Section 3. Section 4 gives the definition and the composition of a key feature type, i.e. chemical process feature. Section 5 describes the proposed interdisciplinary engineering framework, under which the definition and mechanism of inter-domain functional feature are given to manage the interdisciplinary associations. An implemented pilot system is illustrated in Section 6, and the contribution is highlighted in Section 7. Finally, conclusions are drawn in Section 8.

2. Literature review

As shown in Fig. 1, the engineering design of a chemical process project is a multi-disciplinary engineering process to transform the business concept into operation. The scale of a project and those numerous close associations among the entities and processes within and across the disciplines make the requirement of a unified engineering system a great challenge, and hence, should draw great attention to the academic research.

2.1. Integrated product and process modeling in the chemical engineering domain

Advances of the research to integrate chemical product and process modeling can be represented from a systemized engineering point of view (Eden, Jørgensen, Gani, & El-Halwagi, 2004; Stephanopoulos & Reklaitis, 2011). For example, one of the efforts was to link the molecular product and separation process design by reverse problem formulation (Eden et al., 2004). In Gernaey's work (Gernaey & Gani, 2010), a systematic model-based approach is proposed to take into consideration both pharmaceutical product and process design. In these works, the interactions between chemical product design and conceptual chemical process design have been modeled by constraint modeling. A feedback mechanism was provided to bridge these two aspects.

The computer-aided process engineering (CAPE) community has been working on the integration effort from the conceptual process design to detailed engineering (Klatt & Marquardt, 2009). One important set of standards that was defined in CAPE Open

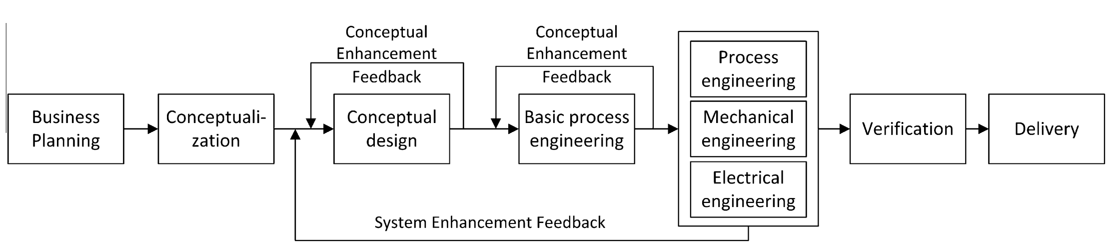

Fig. 1. Typical activities involved in the lifecycle of a chemical process engineering project.