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Decision Process Modeling in Chemical Engineering Design

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Abstract

Documenting the rationale in design processes is commonly accepted to be rewarding, but rarely done in practice due to the required time and effort. We propose an integrated approach to work process and decision modeling, characterized by both an improved usefulness of the models and less effort for their creation.

Keywords: Chemical Engineering Design, Design Rationale, Decision Process

1. Introduction

The purpose of a design process is to construct an *artifact description that satisfies a given functional specification* [1]. Design processes in chemical engineering comprise all the activities related to the design of a new product and the associated production plant including the process and control equipment as well as all operation and management support systems. While performing a design process, engineers do not only create technical specifications and auxiliary documents such as flowsheets and mathematical models; they also produce design rationale (DR), i.e., *reasoning that goes into the design* of the artifact [2], including evolving cognition of the requirements the artifact must fulfill, possible design alternatives, and arguments for and against the alternatives. The benefits of documenting such DR are manifold; some examples will be discussed in the remainder of this paper. However, typical

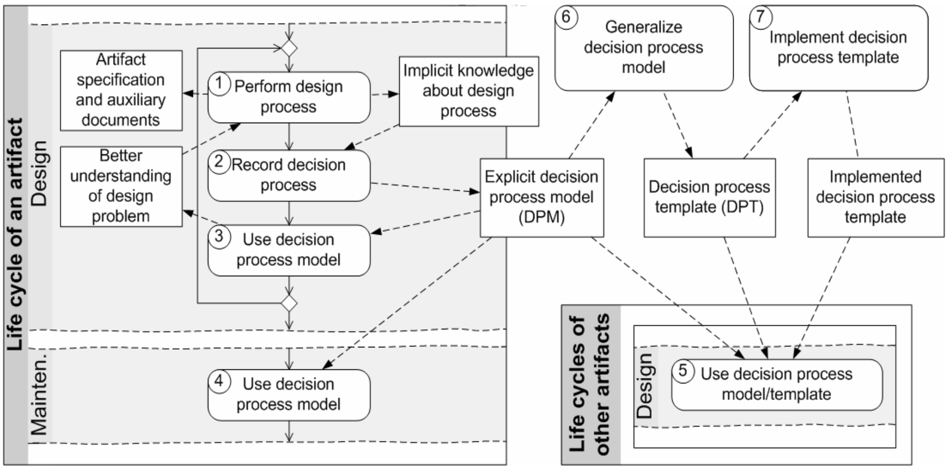

Figure 1. Overview of the approach to decision process modeling (in C3 notation).

approaches and systems do focus on a single or at best few possible applications, such as supporting collaborative decision making, keeping track of possible effects when changing the requirements for an artifact, or documentation for later reuse. Also, use of DR in industrial projects is limited, which is mainly due to the inherent overhead of producing DR documentation and the resulting costs in time and money.

In this contribution, we propose an approach to decision process capture and modeling that is intended to overcome these issues. A decision process model (DPM) incorporates both a design process and the underlying design rationale. The key ideas of our approach are (a) to use a representation for a DPM which enables a wide range of possible applications of the model, and thus to *improve its usefulness*, and (b) to *reduce the effort* for its creation.

2. An Approach for Decision Process Modeling and Improvement

Fig. 1 depicts an overview of the approach. Engineers performing a design process (1) for a particular artifact (e.g., a chemical plant) gain tacit knowledge about their work processes and the rationale underlying their design decisions. These two aspects are recorded (2) in an explicit DPM which is meant to support the original design process, subsequent phases in the lifecycle of the same artifact, and other similar design processes in various ways.

- *Supporting the original design process* (3). The DPM helps to improve the communication between different stakeholders on the status of the design project. Team members add criteria, alternatives, and evaluations of the alternatives with respect to the criteria to the DPM. For this purpose, easy access to the DPM must be provided to all team members.

Decision making in design projects can be supported by Multi-Criteria Decision Analysis methods (MCDA, see [3] for an overview) such as Utility Analysis and Analytic Hierarchy Process (AHP). MCDA seeks to formally assess the importance of several criteria and the grade to which the criteria are respected by different alternatives, to detect inconsistencies in the assessments, and finally to recommend the best fitting alternative. Several applications in the domain of chemical engineering are reported in the literature (e.g., [4]). In order to simplify the use of MCDA and possibly other methods, the information contained in the DPM must be easily reusable in suitable software tools.

- *Supporting subsequent phases in the lifecycle* (4). The DPM constitutes a valuable asset for later phases in the life cycle of the artifact. For instance, assume a damaged reactor in a plant which needs to be replaced. Due to technical progress and changes in the market since the design and construction of the plant, there may be better alternatives than the installation of a reactor of the same type. However, normally only a technical specification of the old reactor is available at best, but there is no documentation of the requirements to be met by the reactor which would be necessary for the selection of a better reactor.
- *Supporting further design processes* (5). Knowledge from previous design projects can be reused in similar design tasks. Concerning the rationale aspect, a DPM contains information about constraints to be respected and questions to be posed which otherwise might be neglected or forgotten. The model also describes the work processes previously performed in order to come to a decision; these work processes can possibly be adapted and repeated in a new design project. A crucial issue for this kind of support is the provision of adequate retrieval mechanisms for relevant DPMs.

However, each DPM is specific to a particular project, and the information relevant for a new project may be scattered among several models. Therefore, knowledge from completed projects which is considered to be important for other design projects can be collected, generalized (6), and finally represented as a *decision process template* (DPT) which provides for simpler retrieval than a set of DPMs. As the relevant parts of the template can directly be incorporated into the new DPM, the effort for documenting the design process and rationale in a new project is considerably reduced.

Even better support for both decision making and decision documentation can be provided if parts of the design process are automated. As the implementation (7) of software tools for such support requires the involvement of experts from other domains than chemical engineering, empirically proven expert knowledge about chemical engineering design must be made available to the developers of the tools. This knowledge transfer is simplified by the DPT.

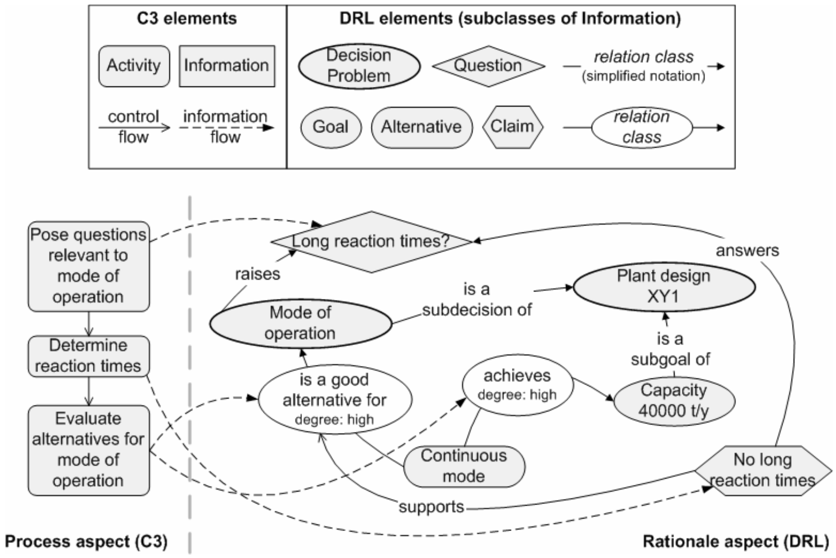

Figure 2. Simple decision process model.

3. Decision Process Models

The realization of the described approach requires a modeling technique for decision processes sufficiently simple and intuitive such that engineers and other people involved in design processes, who cannot be expected to be experts in knowledge representation, can create and interpret models without a considerable learning effort. It should also be noted that the method described in Sec. 2 does not impose any obligation on its users to apply the entirety of the steps given in Fig. 1 or to incorporate all details of a decision process in a model. For instance, creating a model sufficiently expressive for MCDA means a considerable effort and should be restricted to cases when a profound decision seems to be unreachable otherwise. Thus, an important demand on the modeling technique is its adaptability to the users' needs.

Several modeling techniques exist for the rationale aspect of a decision process. The best known is IBIS, developed in the early seventies of the past century [5]; an application in the domain of chemical engineering is described in [6]. However, we have opted for the Decision Representation Language (DRL, [7]), which allows for the explicit representation of the requirements an artifact should satisfy (denoted as *Goals* in DRL). We have adopted and extended DRL to satisfy the particular needs imposed by design decisions in chemical engineering. The right part of Fig. 2 shows a simplistic DRL model describing the choice of the mode of operation of a chemical plant for an annual production of 40,000 t. A continuous mode of operation achieves this requirement to a high degree. A further factor to be taken into consideration for this decision is the

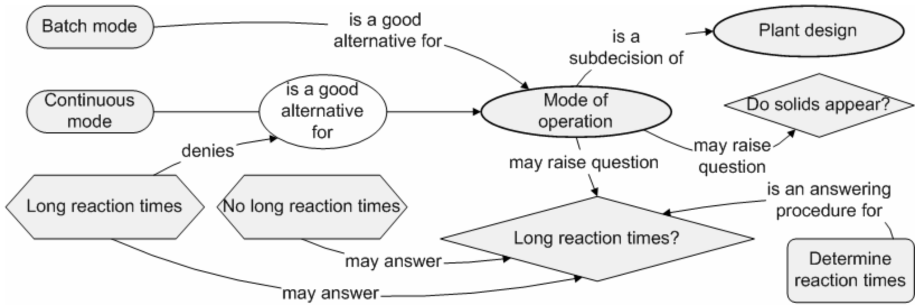

Figure 3. Decision process template for choosing the mode of operation of a plant.

possible occurrence of long reaction times which could object to the continuous mode alternative. However, in the example this does not apply, such that the continuous mode is still a good alternative.

The process aspect of a decision process can be described by means of the C3 modeling language [8]. C3 extends UML activity diagrams with modeling concepts taking into account the creative character of design processes. In the left part of Fig. 2, some *Activities* related to the argumentation described above are given. The elements of the DRL model are linked to the *Activities* via *information flows*, emphasizing that the rationale is a product of the work process.

In Fig. 3, a simple DPT is shown which generalizes the DPM. Several questions are given which may arise when choosing the mode of operation of a plant, as well as the activities to be performed for answering the questions. The activities can be linked to work process models describing in detail how they are to be performed (not shown in the figure). The DPT also lists possible answers to the questions, together with their effect on the acceptability of typical alternatives.

The described combination of C3 and DRL allows for the representation of decision processes on a semiformal level, i.e., important information contained in the models is encoded in natural language and not accessible for automated treatment by a computer. However, some of the applications discussed in the previous section require a more formal representation of decision processes. Therefore, we have created a decision process ontology based on C3 and DRL which can easily be extended to provide the expressiveness and degree of formality required for a certain application. An exemplary extension with modeling concepts for the construction of a DPM with information for AHP has been realized.

4. Implementation

The Workflow Modeling System WOMS [8] was originally created for C3 modeling (with untyped *Activity* and *Information* items). WOMS has been extended with facilities for the specification of *Activity* and *Information* classes as well as for the assignment of attributes to these elements, so that WOMS can serve as an DPM and DPT editor. Thanks to its XML export, the tool allows for simple transformation of the models for use in other applications. Support for the incorporation of decision process templates in a particular DPM is still restricted to simple copy and paste.

Storage and retrieval of DPMs and DPTs are realized via the Process Data Warehouse (PDW) described in [9]. Instead of keyword search or other simple query forms, the PDW allows for a systematic semantic search among the stored models based on the formally defined classes and relationships in the decision process ontology.

As an exemplary integration of a decision analysis tool into the approach, we have implemented an automatic transformation of DPMs to input files for the Super Decisions software [10], an implementation of the Analytic Network Process, a generalization of AHP.

5. Conclusions and Future Work

We have presented an application-independent method for decision process modeling which maximizes the benefits of creating decision process models and minimizes the cost for doing so. An industrial validation, focusing on a wide variety of work processes in chemical product and process design and process automation, is planned in cooperation with four major companies. To this end, an improved version of the modeling tool WOMS is under development.

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