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Functional Modeling for Process Safety

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Keywords: Multilevel Flow Modeling (MFM), Model Validation, Model Reasoning, Process Safety

Abstract

Process safety is of considerable concern for society, in order to reduce the risk for major accidents with severe consequences for human lives and economy. The accidents also indicated process complexity as a major challenge for process safety. Presently process safety is evaluated using qualitative methods which rely upon careful bookkeeping for reevaluation when process modifications and improvements are considered. Consequently it is desirable to develop a more systematic modeling methodology which may be applied for safety assessment and which conveniently may be reused when necessary.

An established qualitative modeling framework is Multilevel Flow Modeling (MFM) which is based on functional modeling. It has been suggested that MFM can deal with the complexity of design and operation of process engineering systems with a promising application future. Qualitative modeling and reasoning as implemented with MFM can with advantage be combined with quantitative methods in order to automate analysis and evaluation of safety in industrial processes, especially in oil and gas industry with increased coverage of the analysis or for validation purpose.

The paper will point out the difference and connections between the qualitative modeling (e.g. functional modeling) and quantitative modeling (e.g. differential and algebraic equations, DAEs) in the process safety context. Then the MFM method will be introduced. A recent HAZOP study of an oil and gas separation plant is summarized. It is shown that validation is a key issue here. It has been investigated how the reasoning results from an MFM model could be validated by comparing it with simulation using a quantitative model. However, due to the complexity of advanced industrial process system, MFM still faces many challenges in industrial process safety application. Finally, the suggested future work within the aspects of supporting for MFM modeling construction, reasoning, validation and counteraction planning are discussed.

Keywords: Multilevel Flow Modeling, Model Validation, Model Reasoning, Process Safety

1. Introduction

Process safety is of considerable concern for society due to occurrence of major accidents with severe consequences for human lives and economy. Industry uses currently predominantly manual methods (e.g. HAZOP) which are combined with quantitative physical models and probability models for calculation of consequences and risk of safety critical events. The purpose of the paper is to summarize the first author's PhD project which is to develop innovative modeling methods for automated analysis and evaluation of safety in industrial processes, especially in oil and gas industry. Validation of functional models for process safety is a key issue dealt with.

2. Modeling Framework and Modeling Tasks

2.1 Modeling framework

Knowledge representations [1] used in engineering (Fig.1) categorizes into qualitative and quantitative. Quantitative models (e.g. differential and algebraic equations, DAEs) [2] are developed from knowledge of physical, chemical, and biological mechanisms (i.e., first-engineering principles modeling or mechanistic modeling) which are convenient for detailed calculations but require a large amount of background data which often are not available. Quantitative methods can therefore with advantage be combined analyses based on qualitative models, which are effective for global analyses and require less amounts of background data. Qualitative models and associated methods for safety and risk analysis based on logical inference is under development and can with advantage be combined with quantitative methods.

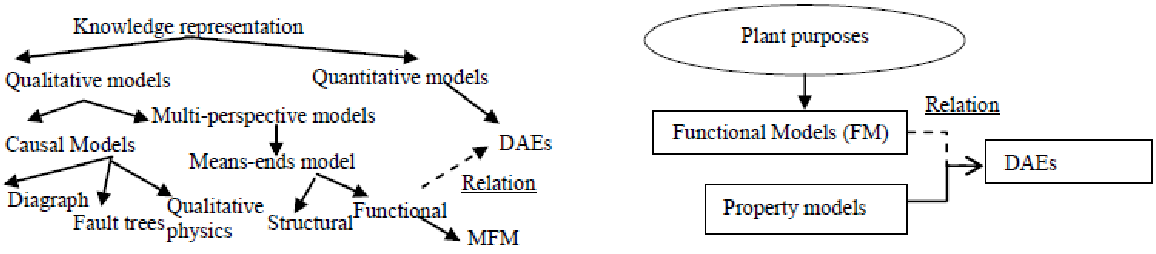

Fig.1 Knowledge representations in engineering & Relation between FM and DAEs

2.2 Multilevel flow modeling

MFM developed by Lind and coworkers [3] has been proposed to be used for both information sharing and coordination as well as for decision support in process operations. MFM is a methodology for functional modeling which has attractive features for modeling complex systems. The main features are 1) MFM represents systems and their interactions on several levels of abstraction, 2) MFM supports cause-effect reasoning, 3) MFM provides formalized representations of operational situations and 4) MFM concepts are coherent with human cognition. These four features are important when coping with operational problems in safety critical systems such as specification of operational situations, identification of causes and consequences of failure, situation assessment, derivation of counteraction plans and ensuring effective communication between decision makers and decision support systems. The MFM method is well accepted with increasing interest and has been applied in nuclear power industry and chemical plants.

2.3 Modeling tasks

On this basis, the basic idea is to investigate the application and further development of the MFM. Addressing the modeling problem in the process safety context poses a number of key challenges, such as for example, how to:

1. Break down of the complexity of the rather open-ended modeling problem by adequately defining, representing and modeling a number of less-complex and more well-defined subtasks.
2. Reason on the fulfillment of the modeling purpose by the available process means, i.e. the process functionality.
3. Track the lack of goal fulfillment, i.e. failure of purpose fulfillment.
4. Perform counteraction planning.

The PhD project attempted towards addressing important elements of these four challenges (Fig.2). This paper summarized a recent HAZOP study of an oil and gas separation plant. This application is based on the development of a formalized MFM modeling procedure, the "extended MFM" modeling and reasoning framework, a validation procedure for causal relations in an MFM model in the PhD project.

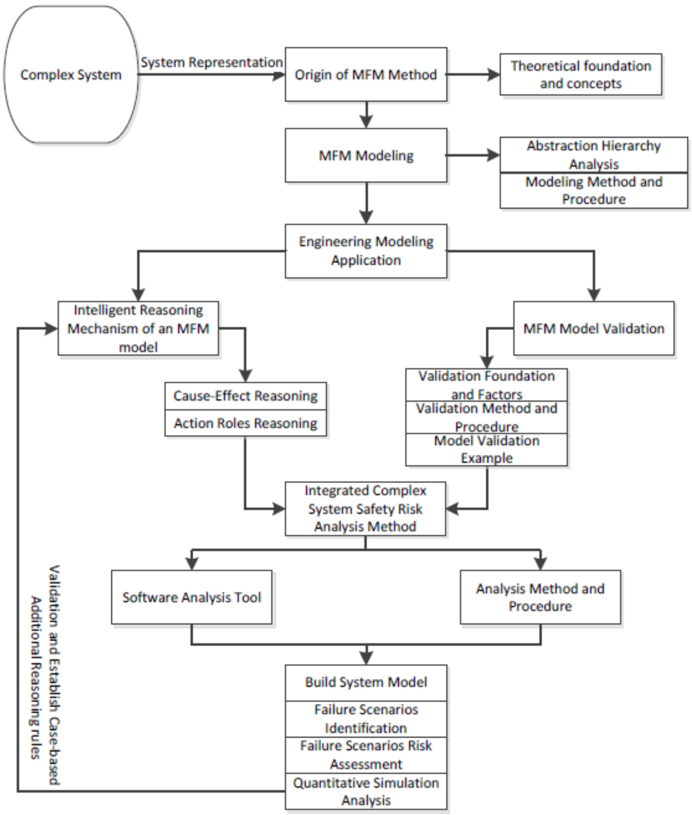

Fig. 2 Elements of modeling tasks for process safety addressed in the PhD project

3. HAZOP Study of an Oil and Gas Separation Plant

The recent HAZOP study of an oil and gas separation plant [4] illustrated an integrated qualitative and quantitative modeling framework in particular the cause-consequence reasoning capability of the MFM reasoning engine. A 5-steps integrated methodology was proposed in the framework.

First step is to build an MFM model following a formalized MFM modeling procedure: ① knowledge acquisition;②system decomposition into subsystems;③subsystem decomposition into functional nodes;④means-ends analysis in terms of components, functions, objectives; ⑤MFM modeling⑥Model verification and validations. A validation procedure for an MFM model proposed in reference [5] is utilized for model verification and validation.

Second step is to conduct qualitative HAZOP analysis for process based on the MFM model. In order to validate the results produced by the cause and consequence analysis for each deviation based on MFM reasoning, the qualitative manual HAZOP analysis is carried out as well.

Third step is to select potentially high risk hazard evaluated by the risk matrix.

Fourth step is to validate the unacceptable failure scenarios identified by the qualitative analysis by using qualitative dynamic simulation. The failure of the control function of an anti-surge valve is demonstrated as an example.

Fifth step is to conduct detailed analysis for highly unacceptable consequences for further mitigation suggestions, i.e., quantification the deviation for identifying the process status at four levels (deviation, abnormal, critical, and catastrophic). It is demonstrated for the parameter of plugging fraction of the anti-surge valve.

This research reveals feasibility and a promising potential of the integrated knowledge-based tool to assist both the more trivial tasks involved in a HAZOP and in particular also some of the more complicated analyses of high risk hazards. Consequently it potentially contributes to better use of resources and time for a HAZOP team.

4. Conclusions and Future Work

It has been suggested that MFM can deal with the complexity of design and operation of process engineering systems with a promising application future. However, due to the complexity of advanced industrial process system, MFM still faces many challenges in industrial application, i.e., process safety. It requires future work within the following aspects:

(1) A methodological approach and tools to support the construction of MFM models of complex systems. Therefore, the building of a MFM modeling library for each process unit is desirable to reduce the required MFM modeling effort and improve the model quality.

(2) To improve the MFM reasoning ability, the reasoning strategy for roles is proposed in reference [6]. However, it requires rewriting the reasoning rules which do not presently exist in the reasoning system in MFM. As a consequence, the reasoning procedures will be as detailed as we would like to be in the future.

(3) A validation procedure for an MFM model is proposed in reference [5] and here it has also been investigated how the reasoning results from an MFM model could be validated by comparing it with simulation using a quantitative model for a HAZOP study. However it does not address the validation of the objective, i.e., the goal hierarchy. It requires more work on model validation.

(4) System level knowledge is important for modeling of the complex system and no single model can contain all necessary knowledge associated with risk assessment. Therefore, the combined qualitative and quantitative method is needed to deal with the system dynamics and complexity. The paper proposed an integrated method for a HAZOP study. However it lacks decision support for counteraction planning within the same integrated framework, which could be benefit for accident mitigation.

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