Model Management for Refinery Multi-level Simulation and Optimization

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Abstract: A comprehensive simulation and optimization platform which offers a lot of functions such as decision analysis, production scheduling optimization and process dynamic simulation is urgently required for today’s process industry. But this will generate a series of model management problems because models integrated in the platform belong to different classifications and interact with each other in some special applications. In this paper, a model management platform for refinery multi-level simulation and optimization is introduced. The platform, referring to a classical model management framework in decision supporting area, integrates different refinery models for different users and can coordinate computational tasks between models for multi-level application.

Keywords: model management, refinery simulation and optimization, hierarchical model

1. INTRODUCTION

Simulation enables to run experiments and what-if scenarios without disturbing existing production system and is widely applied in product or process design in various industries. Optimization is a method to find the best solution to a given process like scheduling or planning within constraints. The integration of simulation and optimization can provide more convenience for the users.

Research of simulation and optimization in chemical process has been of great interest to governments, academic and industries and has made huge progress. Up to now, there have been many commercial technologies (e.g. AspenTech’s Aspen Plus and PSE’s gPROMS) by which process simulation can be developed with high-fidelity unit models for off-line production design. P.A. Rolandi gives an innovative integrated model-centric framework which enables these tools to have new functions of on-line simulation, optimization, parameters estimation and data reconciliation (Rolandi, 2010). For improving interoperability of process simulation tools from different vendors, an interface standard named CAPE-OPEN is being developed (Barrett, et al., 2005). CAPE-OPEN standards divide the simulation software into two kinds of components: process modeling components and process modeling environments which are both plug and play and compatible with products developed by different vendors.

Enterprise-wide optimization (Grossman, 2005) brings new challenges that simulation and optimization are necessary not only to provide service for traditional manufacturing process, but also to support decision-making for supply chain of the whole company. Suresh implements dynamic simulation of refinery supply chains (Suresh, et al., 2005) in Matlab/Simulink which segments the plant into two kinds of entities: external supply chain entities (e.g. suppliers, logistics services provider and customers) and refinery supply chain entities (e.g. procurement department, storage department, operation department, sales department). However, the seamless integration of simulation and optimization in both manufacturing process and supply chain is intractable. In fact, the former is a real time process and often deals with only one unit; otherwise, the later is mainly about a month-long plan or week-long scheduling in the whole plant. I can be seen that models with different functions have different time-scale and space-scale.

For managing these multi-scale models and implementing the interaction between models in different applications, model management system is needed. Galina Setlak presented an intelligent system (Galina, et al., 2009) for process planning which is a framework for integrating models of plan optimization. H. Bley proposed a distributed model management system (SimBase) (H. Bley, et al., 2000) for material flow simulation. In this work, a RMMS (refinery management system) is presented, which consists of multi-scale models from refinery unit operations to supply chain entities. All the models of simulation and optimization are divided into three levels (Bruce M, 1995) according to the hierarchical model definitions of AMR (American Advanced Manufacturing Research,) and integrated in a unified framework to support different applications in the refinery.

This paper is structured as follows. Refinery multi-level simulation and optimization will be introduced in section 2. The architecture of model management system will be described in section 3. How to implement the RMMS will be discussed in section 4.

2. REFINERY MULTI-LEVEL SIMULATION AND OPTIMIZATION

For enterprise-control system, ISA95 defines a five-level hierarchy model (ISA, 2005), responding to the three-level model defined by AMR. The hierarchical models defined by two organizations are shown in table.1. We refer to the definition by AMR and analysis the simulation and optimization in each level as follows.
Table 1. Hierarchical Model defined by ISA95 and AMR

<table>
<thead>
<tr>
<th>Levels</th>
<th>ISA95</th>
<th>AMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 4</td>
<td>Business Planning &amp; Logistics</td>
<td>ERP</td>
</tr>
<tr>
<td>Level 3</td>
<td>Manufacturing Operations Management</td>
<td>MES</td>
</tr>
<tr>
<td>Level 2</td>
<td>Control (Monitoring, supervisory)</td>
<td></td>
</tr>
<tr>
<td>Level 1</td>
<td>Control (sensing, manipulating)</td>
<td>PCS</td>
</tr>
<tr>
<td>Level 0</td>
<td>Production Process</td>
<td></td>
</tr>
</tbody>
</table>

2.1 Simulation and Optimization in PCS level

In PCS (Process Control System) level, the simulation models are a set of equations for mass and energy balance, thermodynamic properties and kinetics of chemical reactions and of transfer processes. If the equations are all algebraic, the simulation is steady; otherwise, if there are differential equations, the simulation is dynamic. Traditional flowsheet simulation technologies such as Aspen Plus and CAPE-OPEN are applied in this level.

Optimizations in this level have two functions: determining optimal operating parameters to maximize output field and finding out the optimal dynamic subset of input process variables to minimize the cost of fluctuation in production.

For refinery production process, the spatial resolution of the models in PCS level depends on the requirements of applications. In this paper, PCS models cover all operational units (such as CDU and so on), pipelines, oil tanks and their topological inter-connections. Usually models’ time-scale in PCS level is minutes or seconds.

2.2 Simulation and Optimization in MES level

MES (Manufacturing Execution System), the bridge between ERP (Enterprise Resource Planning) and PCS, is a level of manufacturing operations (e.g. production operations, maintenance operations and quality operations) management using on-line production information. The time-scale of models in MES level is hours or one day.

In this level, refinery manufacturing operations include crude oil unloading, crude oil mixing, production operations, oil blending.

Optimizations can solve problems:

1. Finding an optimal crude oil scheduling with the constraints of crude arrival time and production targets.

2. Searching a feasible and optimal production scheduling based on upstream and downstream production constraints and unit capability.

3. Finding a most profitable finished product blending scheduling with the constraints of storage, product quality and demand requirements.

The simulation models in this level are not as complex as those in PCS level. For refinery process simulation, the unit models are yield accounting model based on conservation principles such as mass balance. The oil tank models are defined as models of logical tanks which are comprised of real physical tanks storing the same materials.

2.3 Simulation and Optimization in ERP level

In ERP level, supply chain management is considered since the demands of crude oil and finished product oil do not change as frequently as in manufacturing process. What to do in this level is to make a plan according to the state of supply chain. The time frame in this level is weeks or months.

The objective of refinery plan optimization is to minimize the total cost including production, inventory and simultaneously to fulfill customer demand with the constraint of units capacity.

For simulation, the unit models are the same as those in MES level, but the connections between units are simplified and the half-finished oil tanks are eliminated.

2.4 Multi-level Simulation and Optimization

Multi-level simulation and optimization integrates the three levels of PCS, MES and ERP into a synthesis through an information flow illustrated in Fig.1. It can provide supports for the strategic (long-term), tactical (medium-term) or operational (short-term) decision making.

Fig. 1. The process of multi-level simulation and optimization

Firstly, in ERP level, the planner makes a manufacturing month-plan through optimization of supply chain, and then run the ERP simulation to test the feasibility of the plan in different scenarios. Secondly, planner disaggregates the verified month plan to week plan and transfers it to scheduler who executes corresponding MES simulation and
optimization as what planner does in ERP level. In the end, we can run real process production simulation to find optimal operational parameters.

3. THE ARCHITECTURE OF MODEL MANAGEMENT

The mature model management system for decision supporting is comprised of seven components (see Fig. 2.).

Fig. 2. Framework of model management (Liang, et al., 2008)

Model base is a library which stores models classified according to model dictionary. Model development environment (MDE) is a platform on which models can be created, updated, saved and deleted. Models can be executed in model execution environment (MEE) in which users can manipulate selected models, configure models parameters and start, handle or stop execution process. Solvers are the components which help users calculate simulation process or solve optimization problems and then return the results to MEE. Data management system (DMS) is composed of a number of data/information repositories (e.g. relational database management system, Excel). DMS not only implements model base, but also stores model parameters configured in MEE and intermediate and final result in the process of calculation.

4. REFINERY MODEL MANAGEMENT SYSTEM

Based on the framework of model management, RMMS for multi-level simulation and optimization is developed. The components are illustrated in table.2. Each part of RMMS will be elaborated below.

### Table 2. Components of RMMS

<table>
<thead>
<tr>
<th>Function</th>
<th>Level</th>
<th>MDE</th>
<th>MEE</th>
<th>Solver</th>
<th>DMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simu</td>
<td>ERP</td>
<td>Visio</td>
<td>DLL (C#)</td>
<td>DLL (C#)</td>
<td>Oracle</td>
</tr>
<tr>
<td></td>
<td>MES</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>PCS</td>
<td>Aspen Plus</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opti</td>
<td>ERP</td>
<td>ILOG</td>
<td>DLL (C#)</td>
<td>CPLEX</td>
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<tr>
<td></td>
<td>MES</td>
<td>OPL</td>
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<tr>
<td></td>
<td>PCS</td>
<td>Aspen Plus</td>
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</tbody>
</table>
4.1.3 Solvers

For simulation, solver is a component (DLL) which executes simulation calculation based on the initial data and model parameters stored in DMS.

For optimization, solver is CPLEX (Cplex, 2007) component which is a calculating engine of solving linear programming problems and provides standard interfaces interacting with other software.

4.1.4 MEE

For simulation, MEE includes three parts: model parameters configuration, simulation manipulation, result reporting. The MEE in MES level is illustrated in Fig. 7. “Set Batch” button is used for model parameter configuration manually and “Select Batches” button is used to select batches for simulation. The simulation process can be activated, paused and stopped. The simulation results can be observed through report.

For optimization, MEE downloads optimization model from model base, and then call solvers (CPLEX) to calculate. If the calculation has optimal solution, the result is written into DMS. Otherwise, models need to be modified in MDE.

4.2. DMS

DMS (data management system) is developed with Oracle, a commercial relational database management system. DMS not only stores information of models in model base, but also store equipments information and process data illustrated in Fig. 8. Simulation and optimization data including the intermediate data, result data and configuration parameters usually is time-variable in manipulation process. Equipments information that describes the attributes of refinery units, tanks or streams is invariable after the objects are determined. Further more, simulation and optimization data depends on the equipments information which maps each other between adjacent levels.

As an example, the diagram of equipments information in MES is illustrated in Fig. 9. In order to extend the RMMS to enterprise wide, the structure of refinery is start with factory identification. Inside the refinery, department is the upper-level of imports and exports, unit and tank area, which is established to cooperate with producing flow. Streams come from unit, tank or imports and then are sent to unit, tank or exports by pipeline movement. Moreover, the flow rate of the movements and the storage are measured by instruments such as flowmeter or voltmeter.

4.3. Components in PCS Level
In PCS level, Aspen Plus is integrated into RMMS through its standard data interface to DMS. Aspen Plus is a commercial process modeling tool (ASPEN Plus 1988) for chemical simulation and optimization which contains abundant built-in components for building refinery units operations models.

5. CONCLUSIONS

Multi-level simulation and optimization includes many models with different time-scale and space-scale for production process and supply chain. How to coordinate the development and execution of models and how to store and maintain these models is a big challenge.

Based on a classical model management framework in decision supporting area, a system named RMMS for supporting multi-level applications is developed. Different models for ERP, MES and PCS are integrated in the system and the data in different levels can interact through DMS. Some components of the system are developed in C# language like MEE in MES level and others are commercial components such as ILOG OPL and Cplex. Further more, RMMS is an open system to be extended and can integrate other commercial optimization software (e.g. LINGO, LAMPS) and other simulation software (e.g. gPROMS).

6. RPOBING FURTHER

Research in this area still has two challenges. One is the data integration of different tools of simulation and optimization. These tools may use different data model and different schemas for special purposes, so how to deal with heterogeneous data is intractable. The other challenge is how to apply RMMS to the refinery field. This work only introduces an offline platform for integrating the models of simulation and optimization to satisfy management and manufacturing requirements. Integrating RMMS with the field existing software such as scheduling or advanced control for online application needs further research.

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REFERENCES


