

Integrated support system for planning and scheduling of batch chemical plants

by

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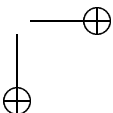
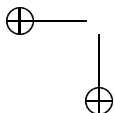
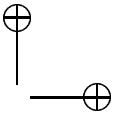
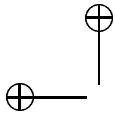
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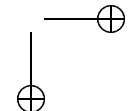
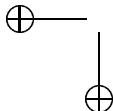
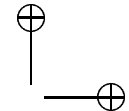
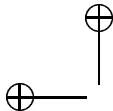
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A mis padres



There cannot be a crisis next week. My schedule is already full.

Henry Kissinger (1923 -)



Summary

The scheduling of batch processes is one of the most complex and important problems faced by a wide variety of processing industries. In spite of this importance, scheduling is often a manual procedure, which leads to operation characterized by high inventories, inefficient capital utilization and increased operation costs. There are also reported complains about the lack of powerful, easy-to-use, PC based tools able to solve detailed operational problems, as well as perform high level analysis across the supply chain.

This problem has been the focus of an important amount of research work in the recent years, specially from the early 1980's to nowadays, although the industry has been interested in effective ways of solving the scheduling problem since the early 1940's. An extensive work has been done but the complex nature of the scheduling problem results on the lack of a unique solution widely accepted in the industry.

This thesis describes a global generic framework for planning and scheduling of batch chemical plants. Different components have been studied: a data model, a timing model, heuristic sequencing and assignment strategies and optimization procedures.

One of the strongest points of the framework presented is its modularity. The fact of having the different components of planning and scheduling as separate modules sharing a common data model allows an easy use and adaptation of different techniques that can help solving the scheduling and planning problem in specific cases. This modular approach has been useful when applying the techniques presented to industrial scenarios. Adaptation to specific scenarios choosing the best alternative for each one is not only possible but also easy.

The key point for achieving this is to share the common data and timing model (the EON model). The extensible object oriented data model presented in this thesis allows an organized and systematic information management dealing with the detailed representation of batch processes in the chemical industry. The main strength of the EON model is the capability of representation of complex time constraints between operations in the same schedule using simple components. EON model is presented and developed in detail. A methodology for the

Summary

representation of storage constraints as time constraints as EON constraints is also presented. An iterative procedure allows also to take into account of limited resources as manpower, electricity, etc.

Dispatching-like rules have been developed for the calculation of the material balances, the unit assignment and the batch sequencing. The strength of this approach is based in the easy implementation and adaptation to a batch oriented framework. These rules can be applied to empty schedules or to schedules that already contain *frozen* batches, which represents the actual situation in the plant. This last aspect allows the use of this kind of rules when performing on-line scheduling.

Different optimization techniques have been used in this thesis to solve the scheduling approach presented. Stochastic and mathematical methods have been used and tested.

Regarding to the stochastic methods, a new optimization algorithm (MSES) has been introduced that improves the performance of the SA standard algorithm. A modified GA algorithm has also been proposed that transforms the infeasible sequences commonly generated into feasible ones. All the stochastic methods used were adapted to batch processing structures involving batch sequencing and rule driven unit assignment.

Regarding to the mathematical approach, the mathematical formulation presented in the EON timing model has been extended by introducing sequence and assignment variables as well as storage constraints.

The framework developed in this thesis has been successfully applied to different industrial scenarios that are shown. The proposed solutions have been able to represent all the complexity of the test cases studied providing a powerful tool for planning and scheduling of the different plants.

Resumen

La planificación de la producción en plantas de proceso discontinuo es uno de los problemas más complejos e importantes para una amplia variedad de procesos industriales. A pesar de esta importancia la planificación de la producción es habitualmente un proceso manual que puede conducir a un exceso de inventario, una utilización ineficiente del capital y aumento en costes de producción.

Este problema ha sido el sujeto de un importante esfuerzo investigador en los últimos años, especialmente desde principios de los 80 hasta la actualidad, aunque la industria se ha mostrado interesada en el problema desde los años 40. Durante este tiempo se ha realizado mucha investigación al respecto, pero la naturaleza compleja de problema hace que todavía no exista una solución aceptada ampliamente en la industria.

Esta tesis describe un entorno genérico para la planificación de la producción en plantas de proceso discontinuo. Se han desarrollado diferentes componentes: un modelo de datos, un modelo de temporización, estrategias de asignación y secuenciación y diferentes alternativas de optimización.

Uno de los aspectos más importantes del entorno presentado es su modularidad. El hecho de dividir el problema de planificación de la producción en diferentes módulos que comparten un modelo de datos común facilita la reutilización y la adaptación a escenarios industriales de las diferentes técnicas desarrolladas escogiendo la mejor alternativa para cada uno de ellos.

El modelo de información orientado a objetos que se presenta en esta tesis permite la organización sistemática de la información de planta, permitiendo una representación detallada de las restricciones presentes en la industria. Por otra parte, el modelo de temporización de operaciones (EON) desarrollado en la presente tesis es la capacidad de representar restricciones temporales complejas presentes en la industria utilizando componentes sencillos. Se ha desarrollado una metodología para generar modelos EON a partir del modelo de información utilizado incluyendo restricciones de depósitos y restricciones temporales entre operaciones. Adicionalmente, un método iterativo permite tener en cuenta otros recursos limitantes depen-

Resumen

dientes de calendario, como mano de obra, electricidad, etc.

En relación a las decisiones de nivel superior, se han desarrollado también reglas de balance de materiales, asignación y secuenciación que permiten obtener de una forma rápida y sencilla planes factibles a partir de un conjunto de demandas. Estas reglas se pueden aplicar tanto a planes de producción vacíos en situaciones de puesta en marcha de la planta, como a planes parcialmente llenos con la información de lotes que se están ejecutando en planta, lo que permite la replanificación en línea en caso de ser necesario.

También se han aplicado diferentes técnicas de optimización a fin de mejorar planes de producción. Se han probado tanto métodos heurísticos como modelización matemática.

En lo referente a los métodos heurísticos, se ha desarrollado un nuevo método de optimización (MSES) que mejora algunos aspectos referentes al algoritmo estándar de recocido simulado. Los algoritmos genéticos han sido también objeto de estudio, incorporando un algoritmo que transforma los individuos infactibles en factibles. Todos estos métodos han sido adaptados al entorno desarrollado permitiendo cambios de secuencia y asignación.

En lo que respecta a la modelización matemática, se ha desarrollado un nuevo modelo MILP basado en una extensión del EON introduciendo variables de decisión de secuencia y asignación así como restricciones asociadas a almacenamientos intermedios.

El entorno desarrollado en esta tesis ha sido aplicado a diferentes entornos industriales, proporcionando una validación de las tecnologías y modelos desarrollados. En todos los casos estudiados se han podido obtener planes de producción que cumplen con las restricciones presentes en planta, lo que permite establecer la validez de las metodologías desarrolladas para la planificación de la producción en plantas químicas de proceso discontinuo.

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