PRODUCTION PLANNING FOR COMPLEX PLANTS USING FUZZY COGNITIVE MAPS

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Abstract: This work emphasizes on the implementation of soft computing techniques for the production planning of complex manufacturing plants. A hierarchical control structure has been assumed to control and to optimize the chemical process of a complex plant with successful results and at the highest hierarchical level the production planning should meet the fluctuating demands in optimal way. This level integrates the operational and business management requirements where the soft computing technique of Fuzzy Cognitive Maps is proposed to model these tasks. The strategic planning for the hierarchical integrated system realizes the optimal total management at the corporate level. The obtained simulation results prove the applicability of the proposed methodology and the advantages of using soft computing modeling techniques for the sophisticated high level of hierarchical systems.

Keywords: Complex Industrial Plant, Production Planning, Intelligent Integrated Control System, Hierarchical Structure, Fuzzy Cognitive Maps

1. INTRODUCTION

Today's complex manufacturing systems operate in a changing environment rife with uncertainty. The performance of manufacturing companies ultimately hinges on their ability to rapidly adapt their production to current internal and external circumstances (Shobrys & White, 2002; Metaxiotis, *et al*., 2002). Many problems in modern engineering practice (as well as in societal, economic and environmental processes) are characterized as highly complex, nonlinear, large in dimension and very frequently ill defined with vague variables and states. Modern complex manufacturing systems employ today's advanced technologies that require deep interdisciplinary expertise for successful implementation (Stylios *et al*., 2000). At the same time successful integration and hybridizing of technologies and functions require technical and functional breadth along with much effort.

Coordination of the technological, operational and business management with the capability to meet the fundamental customers' needs and requirements are the leading power of modern competitive plants. Turbulent market imposes new decisions to cover with optimal way almost every technological and business situation (Silva Fo & Ventura, 1999).

This study emphasizes on modeling the production planning functions for an integrated hierarchical intelligent control system. The production planning is evaluated with an objective function, which is the plant profit maximization. Due to the large degree of uncertainty that characterize the production planning procedure it is proposed the use of the soft computing technique of Fuzzy Cognitive Maps (FCM) (Kosko, 1986). The resulting production planning model is led by the key concept of market policy that represents the overall target for the supervisory level, and especially for multifunctional dynamic scheduler. The proposed methodology has been applied to a chemical plant and supplements an integrated intelligent system that was already developed (Groumpos *et al*., 2000). Discussion and analysis of the obtained results are presented.

2. PRODUCTION PLANNING LEVEL IN INTEGRATED CONTROL SYSTEM

Intelligent control is the ability of a controller to operate in multiple vague environments by recognizing which environment is currently in existence and servicing it appropriately. An adaptive control system should learn to operate efficiently in dynamical environments possessing a high degree of uncertainty.

In this study, a complex plant has been considered and a Hierarchical Control Structure is considered to control and optimize the production process. At the hierarchical integrated system for the lower levels the appropriate generic objective functions for control, optimization and coordination are: the maximum capacity (with constraints); minimum unit's production expenses (for given capacity); and specific technological oriented objective functions. The coordination problem of the whole system is under consideration using material and energy balances maneuvering, production capacity of different stages determining and local criteria of effectiveness agreement.

A hierarchical control system to ensure a maximal profit over the period of the planning horizon has been created. The aim is the development of a hierarchical multilevel strategy, taking into account all properties of the plant from technological and management point of view. An intelligent integrated system with local stage optimization, as well as overall coordination of the production and resources supply by dynamic scheduler is designed. A hierarchical multilevel structure (Silva Fo & Ventura, 1999) is consisted of:

- *Basic level* of control addressed to the unit process variables - temperature, pressure, etc.
- *Optimisation level* – to deal with the management and control of separate units.
- *Supervision level* – to coordinate the wide plant production by multifunctional scheduling.
- *Production planning level* – to meet the fluctuating demand in optimal way.

An illustration of the proposed control scheme is presented at Figure 1. Alternative approaches are investigated in order to determine the appropriate for each hierarchical level attributes: models, control objectives and control algorithms as well as to find a realistic way for solving the multidimensional global optimization problem. A special attention is paid to develop a hierarchical supervisor at the third level. For the production planning level some new ideas based on Fuzzy Cognitive Maps (FCM) (Stylios & Groumpos, 1999) are developed in order to integrate technological, operational and business management. For the description of the interacting procedures along the basic as well as with the supervisory level, suitable objective functions should be determined, based on rigorous mathematical models.

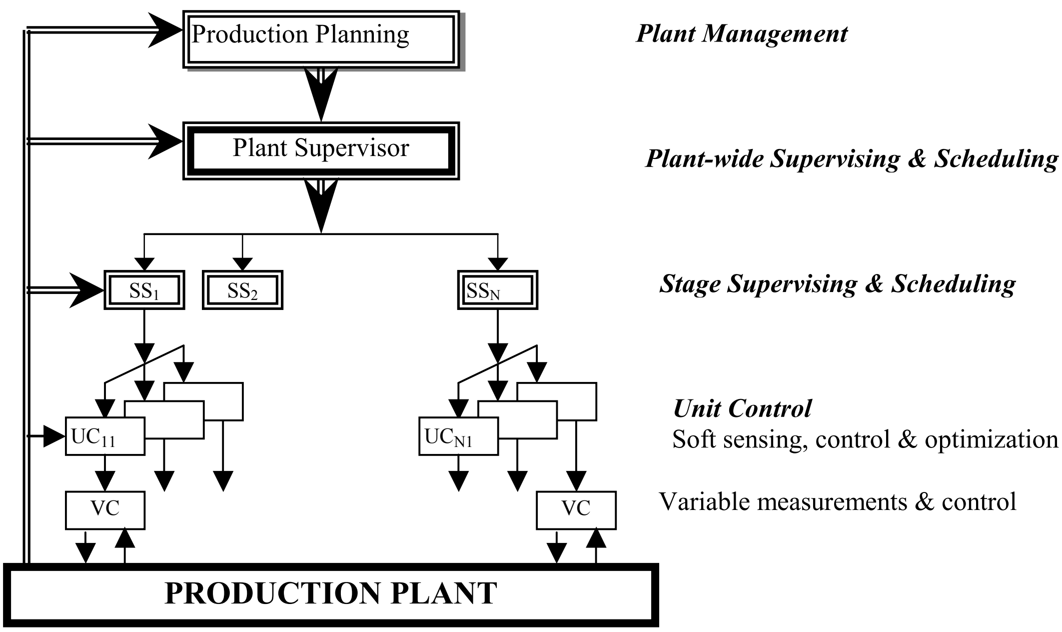

Figure 1. Hierarchical integrated control system

The production planning activities constitute the selection of production sequence, establishing the resource requirements (raw material, storage and production resources) and determining the initial and final time of each operation. The Production Planning level considers the products required by the market, required maintenance of equipment and installations, total cost of production for alternative production schedules, etc. The decision making is reduced to an optimization problem which is based on economic models for the operation of the production system, product and material process, different costs, forecasting of future demands, etc. The result of this optimization is a planning procedure which is used to determine the best operations for planning and scheduling (Metaxiotis, *et al.*, 2002). This approach is based on an economic model where the plant and process operations are entered simply as costs and products. Static models are used when the process is in equilibrium state and models can be augmented by dynamic equations describing gradual effects, to improve the range of their operational validity.

Production scheduling is concerned with the optimal timing of different operations runs and involves the combination of feedstock types and specification of the required type/quality of end products from all production locations. The highest level acts as the interface of the production layers to the market and provides the central managerial commands and objectives for the operation of the production system.

3. BASIC DESCRIPTION OF FCM

Fuzzy Cognitive Maps (FCMs) have been introduced by Kosko (1986) and are dynamical models that represent fuzzy rules and causal relationships among connectionist concepts. FCMs incorporate fuzzy principles with neural network, in order to increase the user flexibility and robustness of a system (Kosko, 1986; Jang, *et al.*, 1997).

FCM structure is consisted of concepts, which illustrate different aspects in the behaviour of the system. Each concept represents a characteristic of the system, which is modelled as an FCM; in general concepts stand for states, variables, events, actions, goals, values, trends of the system. These concepts are interconnected with weighted interconnections representing the cause and effect relationships among them that reflect dynamic behaviour of the system. FCM infrastructure integrates accumulated experience and knowledge on the operation of the system, because of the method that it is created, i.e., using human experts that know the operation and behaviour of system (Stylios and Groumpos, 1999).

Graphical illustration of FCM is a signed directed graph with feedback, consisting of nodes and weighted interconnections. Nodes represent the concepts that are used to describe the behaviour of the system and they are connected by signed and weighted arcs, representing the causal relationships that exist between concepts (Figure 2). Each concept besides its description is characterised by a value A_i, which results from the transformation of the real value of the system's variable, for which this concept stands, in the interval [0,1] or this value represents the calculated value/outcome of the FCM. Values of FCMs are fuzzy, and so weights of the interconnections have defuzzified and transformed the interval [-1,1]. The weight of the interconnection between concept C_i and concept C_j, is denoted as weight W_{ij}, and it can be either positive $W_{ij}>0$ representing positive causality or it can be negative $W_{ij}<0$ for reverse causality or there is no relationship between concept C_i and concept C_j, thus $W_{ij}=0$. Knowledge and experience of the dynamic behaviour of the system is stored in the causal infrastructure of the FCM in the weighted interconnections that summarise the correlation between cause and effect.

Value of each concept is influenced by the values of the interconnected concepts with the corresponding causal weights and the previous value of each concept is used in the formula. So the value A_j for each concept C_j is calculated by the following rule:

$$A_j^s = f\left(\sum_{\substack{i=1 \\ i\neq j}}^{n} W_{ij} A_i^{s-1} + A_j^{s-1}\right) \qquad (1)$$

where A_j^s is the value of concept C_j at step s, A_i^{s-1} is the value of concept C_i at step s-1, A_j^{s-1} is the value of concept C_j at step s-1, and W_{ij} is the weight of the interconnection between C_i and C_j, and f is a threshold function. Threshold functions squeeze the result of multiplication in the interval [0,1]. Equation (1) includes the previous value of each concept, and so the FCM possesses memory capabilities and there is a smooth change after each recalculation.

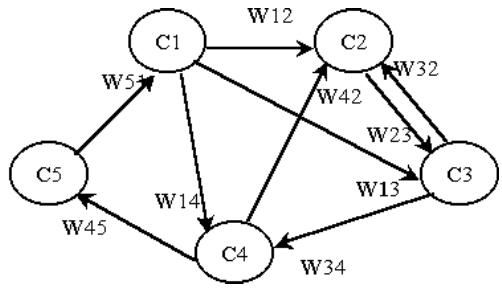

Figure 2. A simple Fuzzy Cognitive Map

Experts, people with knowledge and experience on the system, develop FCMs using an interactive procedure to interpret their knowledge on the operation and behaviour of the system. The procedure for constructing FCMs is: experts define the concepts that represent the model of the system; they describe the structure and the interconnections of the FCM using fuzzy conditional statements. They use ***IF-THEN*** rules to describe the causal relationship among concepts, and so the FCM structure is developed and the weights are determined (Stylios, *et al*., 2000).

4. SOLVING OF THE PRODUCTION PLANNING PROBLEM BY USING FCM

The purpose of this research work is the development of an advanced model for the overall coordination of the production of a complex plant along with the dynamic schedule of the resource supply that will lend to the development of an intelligent integrated system (Groumpos *et al*., 2000). The highest level of production planning should meet the fluctuating demand in optimal way. The coordinator of the system represents very abstract information taking under consideration many complementary and sometimes controversial factors; thus for modeling the coordinator is proposed the Soft Computing Technique of Fuzzy Cognitive Maps that can handle with this kind of systems. FCMs best utilize existing knowledge and experience in the operation of the system and are a useful method for complex system modelling and control, which can perform planning and decision analysis of any system. A generic graphical illustration of the proposed methodology for the planning level design is depicted on Figure 3.
FCM is a symbolic representation for the description and modelling of the production planning of plants that can describe different aspects in the behaviour and operation of plant in terms of concepts; and interactions among concepts show the dynamics of a system. A hierarchical structure is proposed following the principle of "decreasing precision and increasing intelligence" (Saridis, 1989) where a FCM models the production planning.

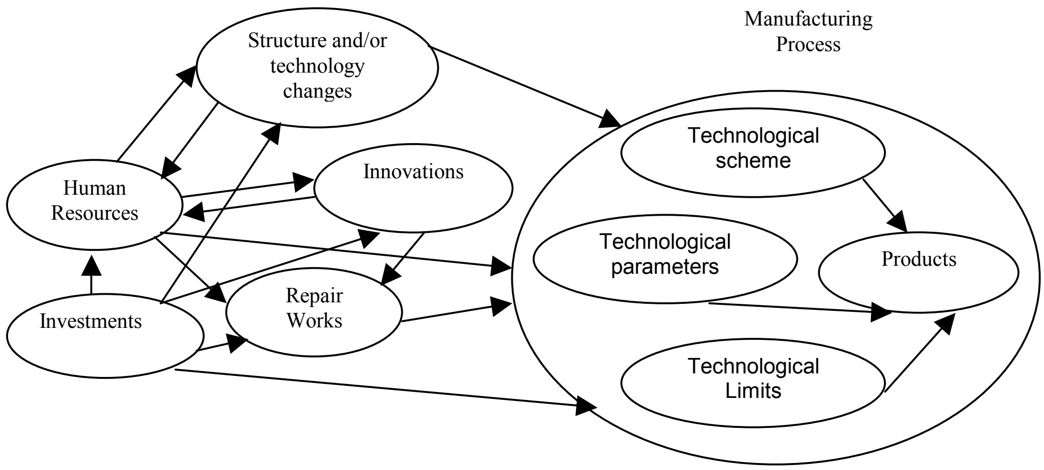

Figure 3. Model of the production planning level

5. INDUSTRIAL APPLICATION

The control of technological plants with uncertain, hardly measurable control variables remains a very difficult task. The proposed methodology has been applied to control complex multistage technological processes, where a number of output control variables are unmeasured or available from laboratory analysis only after a large time of delay and thus inconvenient for real time control (Boshnakov & Hadjiski, 1999).

The coordination problem of the whole system is considered using material and energy balances maneuvering, production capacity of different stages determining and local criteria of effectiveness agreement. It was found that appropriate combination of algorithmic, model based and fuzzy logic approaches for inference measurements, complex parameter estimation, local variables and whole units control as well as process scheduling formation permits a reasonable compromise to be reach, satisfied the technological requirements and specifications (Hadjiski, *et al.*, 1999).

This study deals with the problem of Dimethyl terephthalate (DMT) plant optimisation production (Groumpos *et al*., 2000). DMT production plant involves about 40 units. The whole chemical process could be grouped in five main stages: oxidation, esterification, distillation of row ester, crystallization and DMT-distillation, as well as regenerative subsystem. The oxidation is semi-batch process, crystallization is batch one and the rest processes are continuous. The multistage DMT production plant includes a number of buffer tanks. The recycles and the tanks influence considerably on the static and dynamic behavior of the plant wide. In the context of modeling, control and monitoring only methods taking into account the uncertainties could be appropriate. Each stage of the process presents a group of parallel working units with a different capacity, so the problem of optimal load distribution must be solved taking into account that the operational conditions for each unit and the whole plant vary in a wide range. A detailed description of integrated control system is (Hadjiski, *et al.*, 1999).

The supervision level should accomplish the following tasks:

- To meet the planned demand with the plant production by generation of schedule for the main stages and regeneration system.
- To generate optimal schedules for the units in every stage operating in parallel and out of phase, taking into account all constraints.
- To address adequate values of the key parameters into the relevant control systems at the second level for re-optimization.

The Plant Supervisor defines production rates for each planning period and for each stage on the base of DMT demand given from the Production planner for the all predicted horizon and co-ordinates the satisfying of the process constraints. The Plant Supervisor sends its control actions to the Stage Supervisors (Figure 1).

The generic scheduling approaches, developed in (Terpstra, *et al.*, 1994) for the case of DMT production should be extended at the corporative level to solve a number of particular problems:

- Monitoring and control of some important technological characteristics of the process.
- Taking into account the behavior of the buffer tanks.
- Coordination of cyclic state scheduling in the separate stages to keep the stages and the plant as a whole within the bounds of critical constraints.

This work emphasizes on the production planning functions at the Production planning level. An aggregated generic model has been developed, keeping all main properties of the treated multistage process.

The production planning FCM model was developed with the procedure described in Section 4. The FCM model is illustrated in Figure 4 and it is consisted of 14 concepts that represent the main technological characteristics of the production process, as follows:

Concept C_1 – Flow rate of p-Xylene (pX);
Concept C_2 – Flow rate of working p-methyl toluate (pMT);
Concept C_3 – Ratio of feeding rate of p-Xylene (pX) and working p-methyl toluate (pMT);
Concept C_4 – “Acidity number”;
Concept C_5 – Concentration of p-methyl toluate (PT) in the working p-methyl toluate (pMT);
Concept C_6 – Flow rate of oxidate;
Concept C_7 – Volume of oxidate buffer;
Concept C_8 – Flow rate of row ester;
Concept C_9 – Volume of row ester buffer;
Concept C_{10} – Flow rate of row DMT;
Concept C_{11} – Volume of row DMT buffer;
Concept C_{12}–Volume of the working p-methyl toluate (pMT) buffer;
ConceptC$_{13}$–Concentration of undesirable by-products in whole multistage process, accumulated during the operations;
Concept C_{14} – Flow rate of the produced DMT

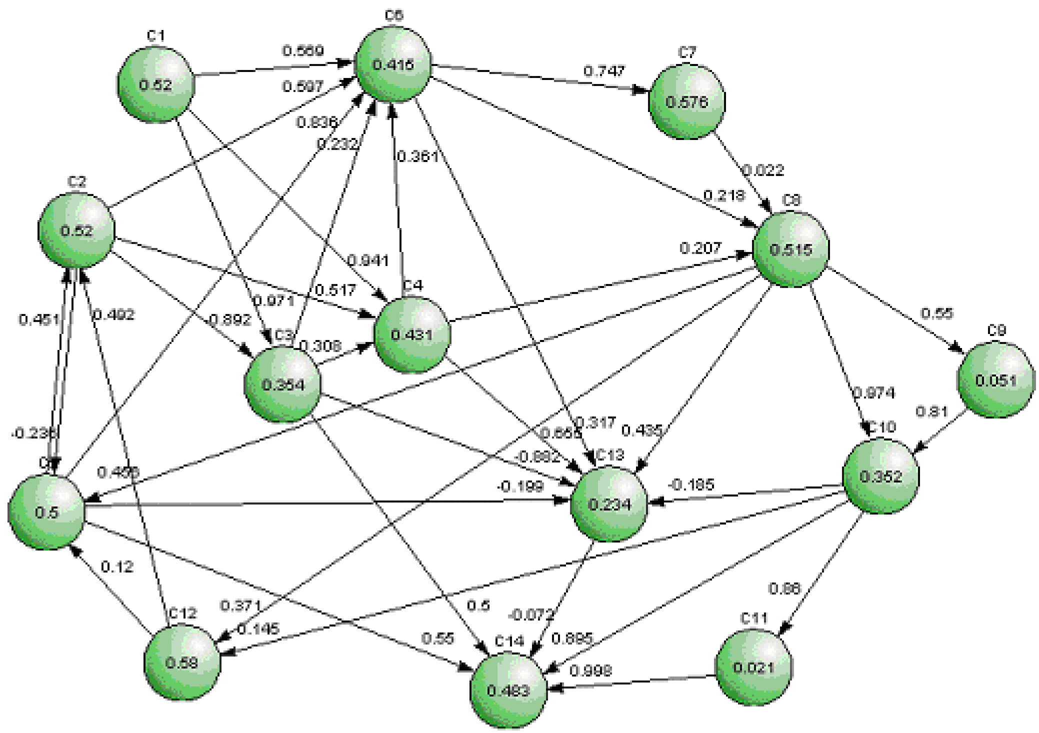

Figure 4. The designed Fuzzy Cognitive Map for DMT production

Experts described the FCM structure, they determined the weights of interconnections and they suggested initial values for concepts. The FCM model simulates the production planning procedure; it starts to interact for the initial values of concepts. Some of these initial values are measurements from the plant and have transmitted from the lower levels; other values represent desired values for the concepts, which stand for the planning variables. Figure 5 depicts the variation of the values of 14 concepts for 10 simulation steps and it is shown that after the 4^{th} step the FCM model reaches an equilibrium region, where values of concepts do not further change. The values of concepts at equilibrium region represent the values that plant variables must take in order to achieve the desired corresponding production-planning scheme. Values of concepts are transmitted to the lower level of the integrated control system influencing the corresponding variables of the plant. Such an interaction procedure among the levels of the hierarchical system will continuously repeat, transmitting actual values from the plant to the production model and vice versa.

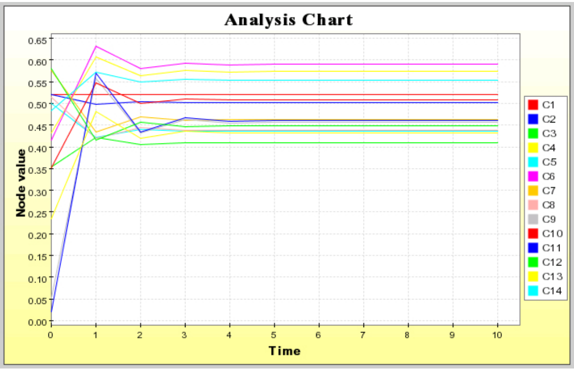

Figure 5. The surface of values of 14 concepts for 10 simulation steps

An extensive analysis and evaluation of the proposed methods proofed their ability to be implemented into integrated control systems. The proposed method could be implemented successfully in any case of heterogeneous multistage interconnected processes.

6. CONCLUSIONS

In this paper, the strategic planning for the case of a complex industrial plant was discussed that is characterized by the presence of a great number of unmeasured variables, ill-defined states and large uncertainties. The aim of this research was the development of an intelligent integrated system. The proposed approach was based on developing a hierarchical system for the production planning and business optimization of complex plant. The use of the Soft Computing approach of Fuzzy Cognitive Maps has been proposed and discussed its efficiency to develop integrated technological, operational and business management systems.

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REFERENCES

Boshnakov, K. and M. Hadjiski (1999). Model Based Control of Semi-Batch Oxidation Reactor, *Proc. of the DYCOMANS Workshop*, Bled, Slovenia.

Craiger, J. P., D. F. Goodman, R. J. Weiss and A. B. Butler (1996). Modeling Organizational Behavior with Fuzzy Cognitive Maps. *Int. J. of Comp. Intelligence and Organizations*, vol. 1, No. 3, pp. 120-133.

Groumpos, P., M. Hadjiski, K. Boshnakov and N. Christova (2000). Modeling and Multilevel Control of Complex Multistage Processes With Recycles and Intermediate Storages. *Proc. of MIM'2000*, Patras, Greece, pp. 211-216.

Hadjiski, M., K. Boshnakov and N. Christova (1999). Coordinated Inference Control of Interconnected Multistage Processes, *ASI'99*, Leuven, Belgium.

Jang J., C. Sun and E. Mizutani (1997). *NeuroFuzzy and Soft Computing*, Prentice Hall Publishing.

Kosko, B. (1986). Fuzzy Cognitive Maps. *International Journal of Man-Machine Studies*, vol. 24, pp. 65-75.

Metaxiotis, K. S., D. Askounis and J. Psarras (2002). Expert Systems in Production Planning and Scheduling: A State-of-the-art Survey. *Journal of Intelligent Manufacturing*, vol. 13, pp. 253-260.

Saridis, G. (1989). Analytic formulation of the principle of Increasing Precision with Decreasing Intelligence for Intelligent Machines, *Automatica* **25**, 3, pp. 461-467.

Shobrys, D. E. and D. C. White (2002). Planning, Scheduling and Control Systems: Why Cannot They Work Together. *Computers and Chemical Engineering*, vol. 26, pp. 149-160.

Silva Fo O.S. and S.D. Ventura (1999). Optimal Feedback Control Scheme Helping Managers to Adjust Aggregate Industrial Resources, *Contr. Eng. Practice,* **Vol. 7**, No. 4, pp. 555-563.

Stylios, C.D. and P. P. Groumpos (1999). A soft computing approach for modeling the supervisor of manufacturing systems. *Journal of Intelligent and Robotics Systems*, **26,** No 3-4, pp. 389-403.

Stylios, C., G. Langer, B. Iung,, Y. T. Hyun, C. Sorensen, M. Weck and P. Groumpos (2000). Discipline research contributions to the modeling and design of Intelligent Manufacturing systems. *Studies in Informatics & Control*, **9**, 2, pp.111-132.

Terpstra V.J., R.M. De Bruijckere and H.B. Verbruggen (1994). On-line Schedule Optimization for Mixed Batch/Continuous Plants, *ADCHEM'94*, Kyoto, Japan.