A CP APPROACH TO THE SCHEDULING OF RESOURCE-CONSTRAINED MULTIPRODUCT CONTINUOUS FACILITIES

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Abstract— **This contribution presents a new Constraint Programming (CP) formulation to address the optimal operation of multiproduct continuous processes. In particular, facilities having continuous stages, which manufacture intermediate or final products and a limited number of intermediate storage tanks, are tackled. The problem involves finding (i) the optimal sequence of production runs and (ii) the optimal agenda of usage of each storage tank. The proposed formulation is able to handle different features found in industrial environments such as dissimilar machines, sequence-dependent change-over times, forbidden campaign-machine assignments, production runs´ length constraints, etc. Moreover, one of the main contributions of this paper is the handling of constrained resources of various types, such as intermediate storage tanks of limited capacity and qualified manpower required at some stages.**

Keywords— **Multiproduct facilities, Renewable and non-renewable resources, Constraint Programming.**

I. INTRODUCTION

The short-tem scheduling problem of multiproduct continuous plants has gained increasing attention in recent years. This is because many industrial plants usually involve continuous stages. Also, an additional motivation arises due to the increasing need for moving towards continuous flexible multiproduct plants that quickly respond to demand changes and to the need of processing a variety of products.

Most researchers have tackled this problem by formulating either, a mixed-integer linear mathematical model or a mixed-integer nonlinear one (Zhang and Sargent, 1998, Ierapetritou and Floudas, 1998, Méndez and Cerdá, 2002). However, these formulations have several disadvantages. On the one hand, the consideration of industrial problems leads to large-size models, which are generally hard to solve. On the other hand, certain approaches introduce hard assumptions about the problem. For instance, they assume that the production rate of intermediate products is greater than their associated consumption rate, which is not always true in practice.

This contribution presents a novel Constraint Programming (CP) approach to the previous problem. Constraint Satisfaction (CS) (Brailsford and Potts, 1999) is a relatively new approach, originated in the computer science and artificial intelligence communities. However, it has already been adopted in the Process Systems Engineering field (Maravelias and Grossmann, 2004). A constraint satisfaction problem (CSP) can be interpreted as the problem of selecting, from finite domains, values to be assigned to each variable so that every element of the set of constraints is satisfied. The implementation of special-purpose algorithms that are widely employed to solve CSPs is called Constraint Programming (CP). It uses tree search combined with domain reduction (DR) and constraint propagation (CPG) procedures to solve CSPs. CP implements systematic search procedures that, by fixing the order in which the variables should be chosen and a way to select a value from a variable domain, supply a proper assignment of values to the problem variables. When the search fixes a variable value, DR and CPG algorithms play an active role. Thus, if the domain of a variable participating in a given constraint is modified, the DR algorithm changes the domains of all the other variables in that constraint. Additionally, when a variable's domain is altered, the effects of this change are then spread by CPG to the whole set of constraints that interact with that variable. A wide variety of algorithms have been developed to efficiently propagate constraints and reduce domains so as to increase the global performance of CP. These algorithms are nowadays included in commercial CP systems such as ILOG solver and ECLiPSe or in free software such as OZ.

The goal of this paper is to propose and assess the quality of a new constraint programming (CP) formulation addressing the scheduling problem stated before. The proposed formulation is based on the constraint programming language (OPL) supported by ILOG Solver (2003a) and employs some specific scheduling constructs available in ILOG Scheduler (2003b).

II. PROBLEM STATEMENT

This work considers a generic resource-constrained multiproduct plant with two continuous stages producing intermediate and final products and storage tanks for temporary inventory of intermediates. Since the production and consumption rates of intermediate products are generally dissimilar, tanks are almost always required. However, in most of the cases there is a reduced number of tanks having a limited capacity. In addition, it is considered that certain tasks require manpower, but the number of available people is lower than the requested one.