Constraint & Agent-based Environment for Configuration Management of Manufacturing Systems

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Abstract: Reconfigurable Manufacturing Systems are the most flexible and productive systems since they are based on standard/template sub-systems and elements. Configuring requires an analysis of the existing enterprise facilities along with its future goals. The results of such an analysis will be required for determining an appropriate reference configuration to build an enterprise. During the configuring, the structure and the elements of systems must be modified and adapted to new goals and new sub-systems or elements must be added. The organization of these processes, called Configuration Management, constitutes the main focus of this paper.

Keywords: manufacturing system, configuration management, multi-agent system, constraint network

Professor Alexander V. Smirnov received his Doctor of Sciences in Engineering degree in 1996 from SPIIRAS and his Ph.D in 1986 from St. Petersburg University of Electrical Engineering. His research expertise covers knowledge engineering, multi-agent systems, decision support systems, concurrent engineering, and virtual enterprises. Prof. Smirnov is Deputy Director and Head of Computer Integrated Systems Laboratory of SPIIRAS. He published over 100 papers in Russian and international magazines and proceedings. He also teaches several courses for undergraduate and Ph. D students at St. Petersburg Technical University.

1. Introduction

It is proven that modern manufacturing systems (MS) must incorporate flexibility, re-configurability, plug-ability, easy maintenance, user -friendliness, low investment costs.

It is generally known that the most efficient methods are those applied at preliminary engineering stages, which enable to form the concept of the "product - process - resource" system satisfying constraints on manufacturing resources, such as investment costs, production area, capacity, and lead time. The solution of the configuring problem of a rapid, flexible, and accurate manufacturing system will be derived through AI-based tools. General objectives of this paper are to determine a methodology, a set of models and a decision support system architecture based on constraint satisfaction and MAS technologies for the configuration management (CM).

2. Configuration Management As Reengineering Technology

New market opportunities require constant increase in product quality and decrease of costs in rapidly changing environment. This trend has become prevailing in the 90's. Consequently, the traditional concept of stable business and manufacturing processes is overshadowed by concerns with flexibility and competitiveness [1 – 4]. In order to cope with these new paradigms, companies need to deeply transform their product development structures and the structures of business processes. This must also be accompanied by on-line transformations, called reengineering [1, 5]. Reengineering helps to keep legacy applications in businesses by transforming their current architectures into new, highly maintainable ones.

Cooperation is one of the central requirements for engineering today. The area of business reengineering with teamwork involvement or the area of distributed production in temporary consortia will also be analysed [6]. Multi-agent system technology can be considered as the basis for components' integration into cooperative reengineering process [7, 8].

In reengineering CM is one of the main concerns for improving the system productivity and reliability. CM is the approach of a system configuring at discrete instants of time, meant to introduce controlled changes in the configuration and to maintain the integrity of the configuration throughout the system life cycle. A scheme of CM technology would result when applying an existing control theory for CM (see Figure 1). The main elements composing a CM process are the following [9]:

- Configuring/Reconfiguring - defines different baselines and associated components of the system, and any change made on the components of baselines.

- Configuration Control – develops a changes plan for components and baselines.

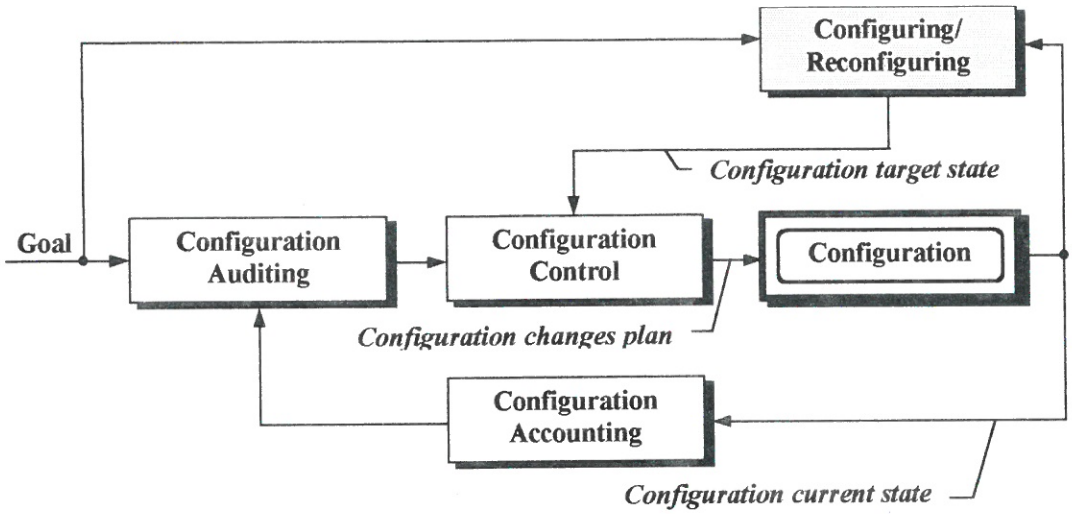

Figure 1. General Configuration Management Scheme

- Configuration Status Accounting - realises an administrative record of the system evolution.
- Configuration Auditing - determines whether the baselines meet the set requirements.

Modern problem -solving strategies in manufacturing are based on a combination of such methods as: constraint-based problem-solving, constraint-based heuristic search, human decision-making, etc. [10]. It is generally accepted that engineering and management (E&M) activities could be regarded as those involving search to satisfy constraints. This model has been applied to a wide variety of E&M domains including MS reengineering [11 – 13].

3. Constraint-based Configuration Management Models

Goal-oriented CM approach basically necessitates the realization of the following major configuring life-cycle phases: identification of the problem/goal, formulation and specification of the current configuration, reengineering and validation of the configuration, data collection and analysis, pertinent to the particular problem at hand; determination of variable values, model-oriented solver selection and constraint-based generation of new appropriate configuration solutions, interpretation and analysis of the solutions, evaluation and modification of the configuration.

The general objective of the current research is to contribute to building a new consistent technology concept and a set of models via integrating the experience of different users/experts into (i) evaluation of external enterprise requirements, (ii) mapping external requirements onto internal requirements (MS requirements), (iii) configuring/reconfiguring goal-oriented MS. To realize the above decision making scheme in the domain concerned, the following methods are proposed [9]:

- contribution-margin ratio analysis and cost-volume-profit analysis for external enterprise requirements specification;
- analytic hierarchy process method [14] with conformation of decisions to internal enterprise requirements specification, alternatives evaluation and selection;
- constraint-based structural synthesis and analysis for obtaining MS configurations.

Appropriate models will be developed to sample and order external requirements depending on system goals, as well as to order and choose among the alternative configuration solutions obtained. For this purpose external experts estimate alternative sets of requirements or solutions from different viewpoints reflecting various aspects of reconfiguring. The GDSS is interfaced through appropriate techniques to an intelligent front-end for group expert decision support in functional and quality coefficients sampling, weighing and evaluating with a subsequent acceptance of conformant decisions.

Some of the most important template-based/artifactural reconfiguring problems under consideration are: (i) determination of the system structure including its components and their relations, (ii) decision -making on components realization, (iii) checking decision on components to guarantee their integration within the framework of the general project. They are all based on constraint satisfaction/monitoring procedure (Figure 2). A structure of constraints in the general MS project as a "product-process-resource" system is shown in Figure 3.

Problem domain is specified in terms of template component types in order to compose the manufacturing system under configuring. Each component type is defined by attributes, arithmetic and functional constraints on these attributes and by relations with other types. The object-oriented programming paradigm is used for knowledge representation. Components catalogue databases are dedicated to each com-

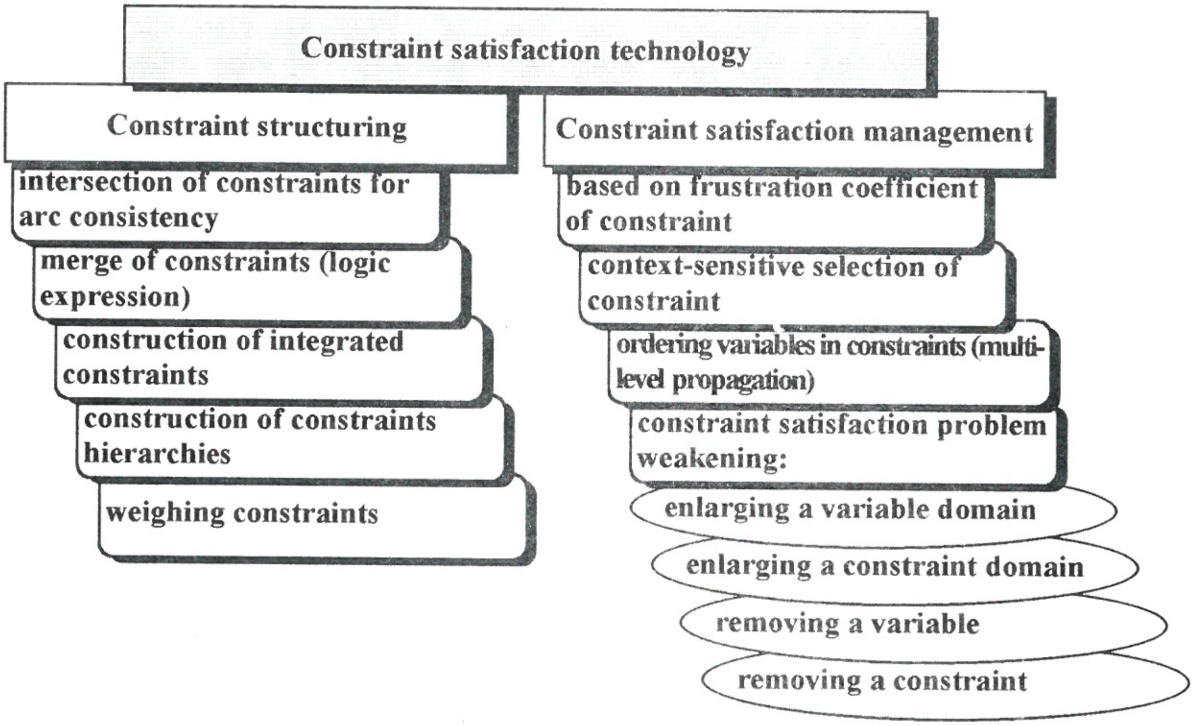

Figure 2. Effectiveness Increase Methods of Constraint Satisfaction Technology

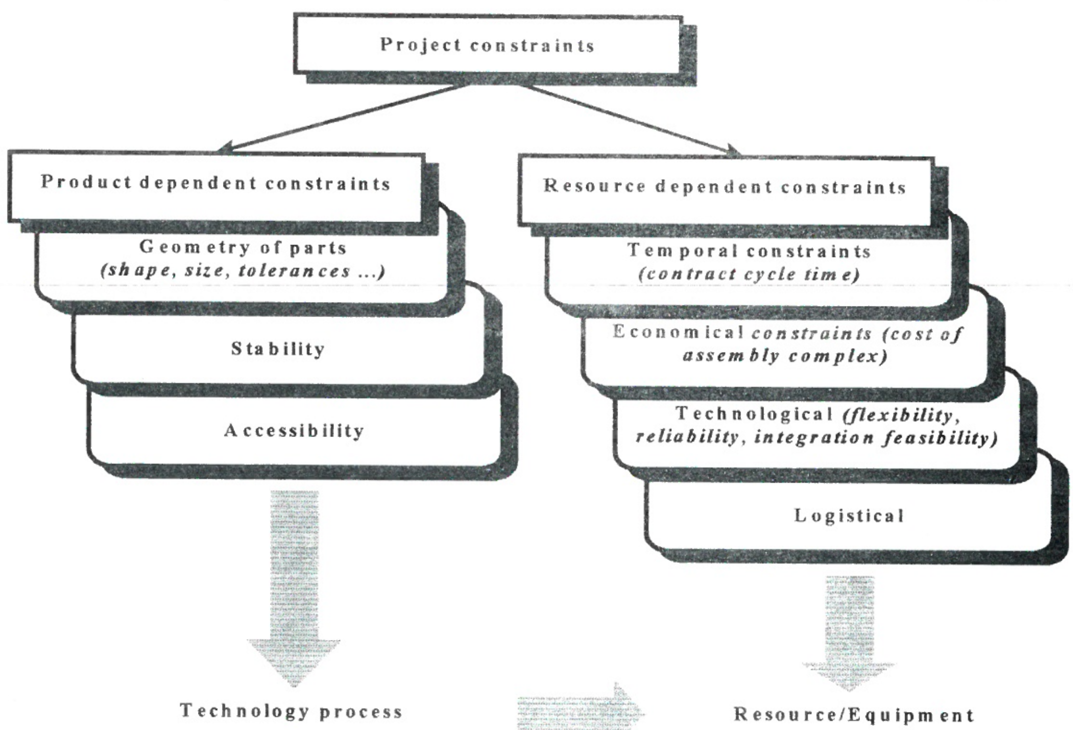

Figure 3. A Constraint-based Structure of "Product-Process-Resource" System Project

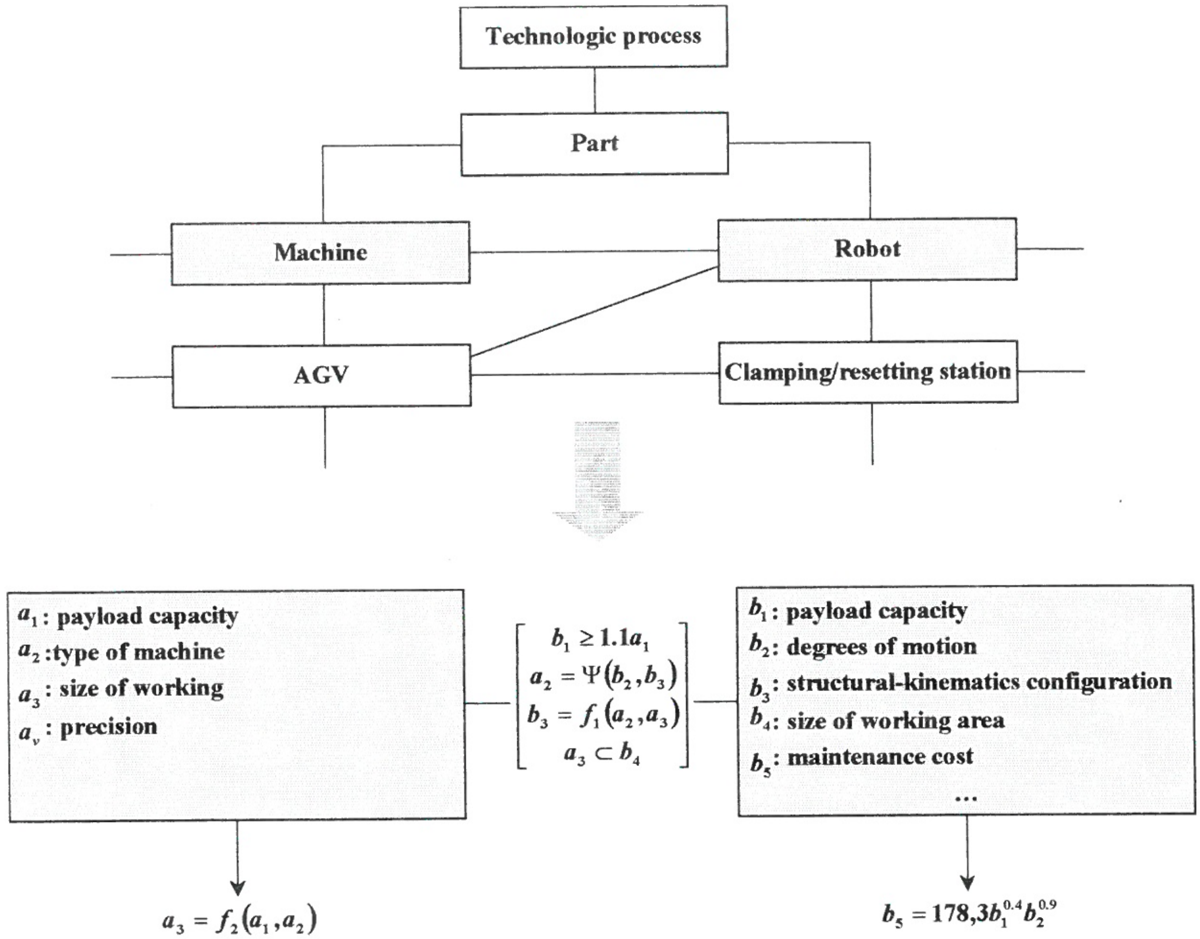

Figure 4. A Fragment from Constraints Network "Manufacturing System"

ponent type. They represent template solutions for would-be configurations. A constraint network represents the object. It is important that each component has two sets of constraints. The first one is the set of internal constraints, the second is the set of external constraints.

A fragment from the constraint model of a problem domain is depicted in Figure 4, which presents connections between component types and connections between variables (a_i and b_j) for "Machine Tool" and "Robot" expressed by logical (b_1, a_2, b_3, a_3) and functional (a_3, b_5) constraints. The Figure shows the way of mapping relations between components, defined at the class level, onto the level of variable values consistency.

4. Multi-agent Group Decision Support System

Currently MAS and WWW technologies are in wide use. Intelligent agent is an autonomous software entity that can navigate heterogeneous computing environment and can, either alone or working with other agents, achieve some goals. It has to present the following properties: autonomy, social behavior, reactivity, and initiative. Allocate the following agents: (i) regulation agents (they react to environment conditions and always know what to do) and (ii) planning agents (they have the properties of regulation agents and additionally, they can plan their actions depending on external conditions) [15].

MAS technology could be considered as the basis for GDSS. WWW technology and intelligent agents are widely used in Cooperative E&M and Electronic Commerce [8, 16].

A configuration management GDSS is based on a dynamic constraint networks model for knowledge representation, object-oriented programming technique and cooperative decision-making. The described environment supports users' facilities for requirements specification indexes sampling, weighing and multi-level configuration synthesis. Different configuring problems are treated as separate tasks with embedded constraint satisfaction and consistency support facilities [17].

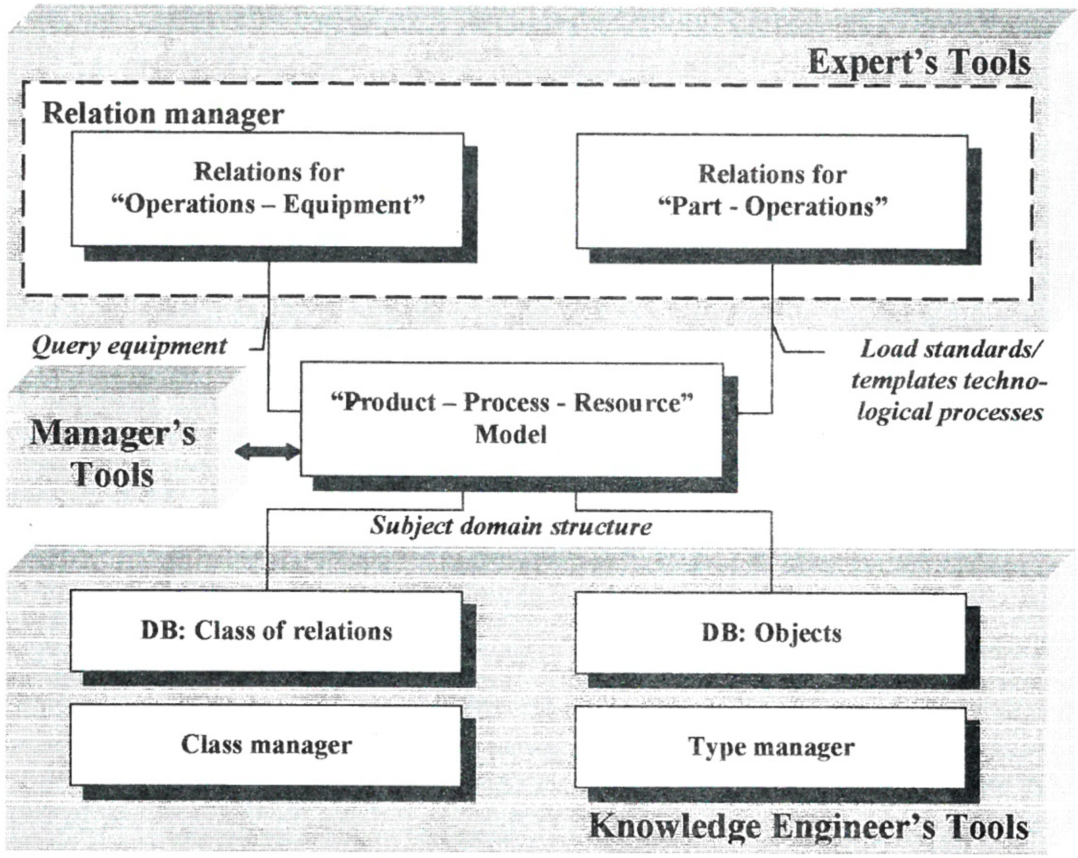

Figure 5. General Structure of Manufacturing System Configuration Management Environment

The implementation of the basic E&M principle - its collaborative nature - is based on concurrent procedure distribution among different users (or different agents) in the common knowledge space. In this case it is more natural to represent the CM knowledge as a set of interactive autonomous agents. The structure of the multi-agent environment (Figure 5), supporting a teamwork, consists of three types of agents: (i) leader agent and (ii) unit agent (manager's tools); (iii) service agent (knowledge engineer's tools and expert's tools). Depending on the information exchange this agent performs different functions. Through an agent classification our agents could be related to the following types of agents: (i) service agent is a regular agent, (ii) leader and unit agents are planning agents. The research prototype scenario is given in Figure 6.

5. Conclusion

Manufacturing System Configuration Management is a truly innovative technology in the field of manufacturing. The use of constraint & agent-based configuration management technologies enables that fewer managers make fast and better quality decisions on manufacturing configurations, based on standard template solutions under rigid constraints and with reduced variance. The implementation of this technology will result in improved quality, reduced cost, minimal errors, less personnel required, better configuration solutions.

The discussed approach implementation could be further extended to neural networks application in MS reconfiguring, based on previous learning with the help of MS configuring simulation.

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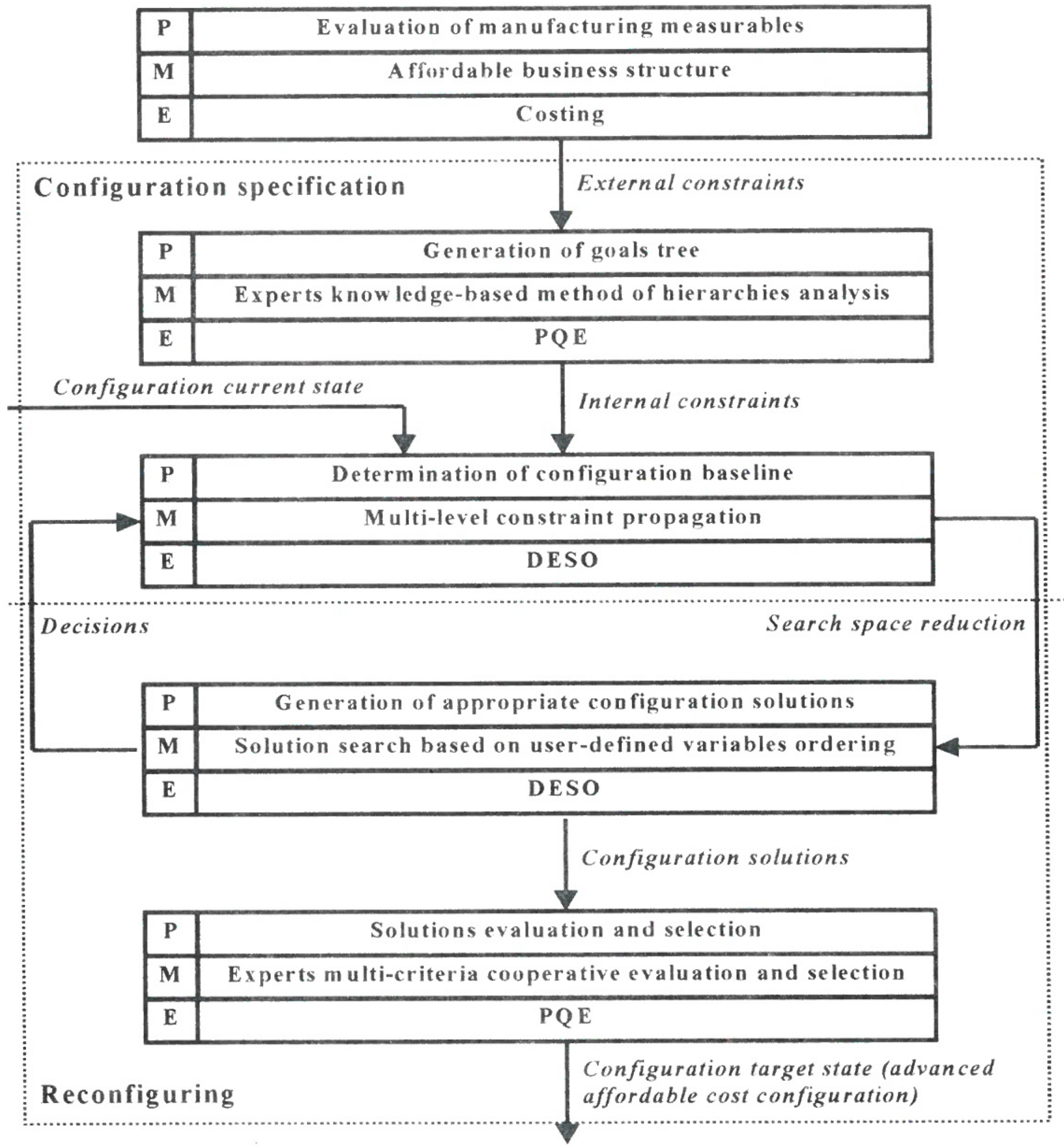

Figure 6. Basic Scenario of Manufacturing System Configuration Reengineering Technology

P - Problem
M - Method
E - Environment
Costing - Direct Costing Environment (Excel 97)
DESO - Design Environment of Structured Objects (Access 97 and Visual C++ 4.1)
PQE - Project Quality Evaluation (Visual FoxPro 3.0)

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