An Architecture of Automated Consultancy Tools for Benchmarking and Implementing Production Planning and Control Software

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Objective of this study is the development of automated consultancy tools (*ACT*) to support the evaluation, selection and implementation phases of production planning and control software (*PPC*). The methodology and the architecture of a *knowledge-based consultant's workbench* are presented to help solving this time-consuming and costly problem. The main aim is the production of tools for identifying the PPC software configuration and customization requirements combined with the required feasible organisational changes of the industrial firm. The *ACT workbench* is implemented in the form of a database-oriented suite of software tools connected to an expert system shell.

1. INTRODUCTION

The task of implementing manufacturing software is extremely complex and usually needs the involvement of professional consultants and trainers. As Scheer (1993) reports, the implementation costs of such systems, including requirements analysis, software package selection, customization, installation and training amounts to *5 or 6 times* the combined hardware and application software costs. This problem is crucial particularly for small and medium sized firms (SMEs), due to their lack of internal expertise and resources. This situation leads to the need for time-consuming and expensive consultancy services that tend to become a serious barrier to the adoption of integrated PPC systems by the majority of SME's. The only way to overrun this barrier is to provide automated consultancy tools using current information technology and knowledge engineering. These tools will help both consultants and industrial users to cut down the large manpower resources needed, and to make PPC projects affordable.

The reported efforts in the literature for the determination of PPC systems requirements and the implementation of manufacturing software have their origin in different science fields using different approaches. Three main research streams can be identified related to different problem stages, i.e. the requirements analysis, the software package selection and the system implementation. The requirements analysis approach is represented by the CASE (Computer Aided Software Engineering) tools supporting a variety of well-known structured

systems analysis and design methods (Yourdon, De Marco, Gane and Sarson, Jackson, SADT or IDEF0, SSDM and Object Oriented Analysis). More closely to the PPC requirements determination and implementation problem is the CIM-OSA (1991) model, the Scheer (1993) methodology of industry-specific reference models and the GRAI method (Doumeingts, 1989) which puts the emphasis on the decisional rather than the informational structures of a PPC system.

An example of the software package selection approach is the well accepted PPC software evaluation system BAPSY of the TH Aachen (Speith and Brief, 1982), which uses multi-criteria and value analysis methods to compare different PPC commercial software packages and select the most appropriate for a specific manufacturing firm. A similar methodology which is less theoretically sound but more practically oriented is the Geitner (1993) PPC market analysis database system.

Representatives of the system implementation stage is the system TWAICE of Nixdorf Computer (Mensel and Michel, 1985) which is mainly a software configuration system to support the Nixdorf COMET integrated manufacturing package and the needs of its customers for customization and consultation, as well as the Mertens (1993) tools to regulate parameters of MRP systems and the earlier efforts of this author (Tatsiopoulos, 1990).

Among the ESPRIT research projects, relevance have the projects AMICE and VOICE which promote the CIM-OSA architecture for developing CIM systems and, more closely to this proposal, the project CIMple which produced the FTM (Fast Track Modelling) product to help the definition of CIM requirements.

2. THE OVERALL ARCHITECTURE

This study adopts the systems engineering concept of dual architecture of Daenzer (1973) who defines two series of systems engineering phases, i.e. the life-cycle phases that represent the time dimension and the problem-solvings steps which are recursively applied to all the life-cycle steps. However, the definition of phases and steps follows the Checkland's (1983) proposals for the treatment of changes and, moreover, is specifically adjusted to the production planning and control systems environment.

LIFE-CYCLE PHASES

- P1. Initial Study* (feasibility, root definitions, constraints, strategic decisions)
- P2. Main Study* (PPC requirements definition, conceptualisation, reference models)
- P3. Detailed Study* (comparison of software packages)
- P4. Development of Potential Changes* (software customization and organisational changes)
- P5. Implementation of Desirable and Feasible Changes*
- P6. Appraisal* (internal and external benchmarking of PPC function)

PROBLEM-SOLVING STEPS

- S1. Current situation analysis*
- S2. Objectives setting*
- S3. Synthesis/analysis of alternative solutions*
- S4. Evaluation of solutions*
- S5. Realisation of chosen solution*

The systematisation of knowledge needed to the consultancy support of each one of the life-cycle phases follows the combination of phases and problem-solving steps. The result is a consultant's workbench consisting of six main knowledge-based systems which correspond to each one of the life-cycle phases, and thirty subsystems corresponding to the combinations of phases and problem-solving steps. There follows a short description of the main systems of the workbench.

P1. Initial Study

A short-listed 'menu' of alternatives has to be evaluated and presented to higher level management. These alternatives include the *make or buy* decision concerning PPC software packages, the range of budget as compared to the degree of automation (i.e. *low-budget 'hamburger'* solution which meets only the most pressing of the user's objectives, *medium budget 'fried chicken'* solution or a *higher-budget 'chateaubriand steak'* solution) and the Hardware/System Software *platforms* where the PPC application software will run under the constraints of the overall information technology strategy of the company.

P2. Main Study

It addresses the problem of determining PPC software requirements on the basis of pure technical characteristics expressed in the form of a *criteria catalogue*. A knowledge-based model is proposed whose objects and relations describe the type of production system through the representation of a *production systems typology* which leads to a *company typological profile* and the *reference model* of a generic PPC software package. The specific criteria out of the knowledge base of criteria catalogues that satisfy the needs of the customer's industrial firm are sent out to vendors of PPC software packages in the form of a requirements catalogue for bidding on their part.

P3. Detailed Study

Its main purpose is the comparison of existing PPC software packages in the market on the basis of the answers of their vendors to the requirements catalogue which has been sent as the result of consultancy work at the main study stage. It consists of the *coverage analysis* to determine the degree of covering the company's requirements by the candidate packages' offered features. On the basis of this analysis, an evaluation of packages takes place that leads to the proposed by the consultant solution. We must here take into account that the coverage analysis is done on the basis of the firm's specific 'ideal' reference model as compared to the generic PPC reference model and the model of features of every software package.

P4. Development of Potential Changes

Software development is not usually part of the consultant's job. The support that is offered by the ACT workbench at this stage is the detailed determination of inconsistencies between the chosen software package, which now takes the place of the 'ideal' reference model, and the current situation in the firm.

The two extreme decisions are that either the procedures of the selected software package should be accepted exactly as they are, which should lead to extensive reorganization within the firm, or the software package should be modified to the extent that it should completely reflect the specific needs of the firm. Both solutions are impracticable in real production management environments. What is really done is to find a solution in

between, i.e. to modify both the software package and the organization of the firm to a certain limited extent which represents an accepted total of tangible and intangible costs.

P5. Implementation of Desired and Feasible Changes

This system tries to transform the potential changes derived during the previous phase (P4) into changes which are agreed to be both desirable and feasible given the resources and the attributes of the organisational environment. As a result the *type* (structural, procedural, attitudinal or environmental) and *amount* of feasible changes are produced both for the customisation and configuration of the software and for the firm's organisation.

Next, we shall describe in more detail, as an example of the methodology, the main study (P2) phase, which also is in a more mature status in the ACT workbench project.

3. MAIN STUDY

It is suggested here that the software technical evaluation procedure should produce a set of "ideal" PPC requirements at three levels: (a) The functional production type (e.g. job-shop), (b) The industrial sector (e.g. clothing industry), (c) The specific manufacturing firm.

The requirements for all functional production types will be based on a taxonomy according to functional characteristics (e.g. product standardisation, factory layout, etc) and the knowledge domain of production management theory about the needs of a particular production type. The industry sector-specific requirements are imposed by technological processes, special problem areas, objectives, measures of performance and environmental factors, even aliases of production management terms which are characteristic of each separate industrial sector.

For the determination of PPC requirements of a specific manufacturing firm, a "normative" approach (Davis and Olson, 1985), using a generic description of an "ideal" generic PPC software package (*reference model*) will be followed at this stage for two main reasons: a) It is quite common that the proposed information system embodied in the production management generic software package may be fundamentally different from existing patterns (in its content, form, complexity, etc.), so that anchoring on an existing information system or existing observations of information needs will not yield a complete and correct set of "ideal" requirements. b) Usually in practice there is not enough time at this stage to proceed to a detailed analysis of the company's current production information processing and organisational procedures.

The systematization of expert knowledge needed at this life-cycle phase (P2) includes the knowledge bases (KBs) which are necessary at each of the problem-solving steps (S1 - S5).

3.1. Step P2.S1 - Main study's current situation analysis

This includes the description of the firm's production structure and the classification of the firm's production system according to a knowledge base of functional production types and industrial sectors. The following two KBs apply to this situation:

- P2.S1-KB1 Taxonomy of Production Systems*
- P2.S1-KB2 Reference Model of System Variables*

P2.S1-KB1 Taxonomy of Production Systems

Many authors have proposed classifications of production systems, e.g. Schmenner (1981), Schmitt et al (1985) and Kettner et al. (1984). Their common characteristic is that they adopt a narrow view of the physical production system dealing only with functional characteristics like shop layout and process flow classifications, which are not enough to determine production management requirements. Factors like management objectives and measures of performance, main problem areas, special technological processes and specific environmental constraints which are connected to the various industrial sectors and subsectors are equally important for the determination of PPC requirements.

The proposed taxonomy in this study is of a twofold nature, a functional taxonomy and a taxonomy based on industrial sectors. For the first one, a system of classes of parameters and values has its origin in the Schomburg (1980) classification model which was built specifically for engineering firms. However, the taxonomy proposed here is extended and built in a software tool using object-oriented programming concepts. This software tool facilitates the connection of the functional taxonomy to the industrial sectors taxonomy and all relative classes, i.e. problem areas, objectives, environmental factors and aliases (terminology of production management across industrial sectors) as seen in Figure 1.

Figure 1. Knowledge Base of Production Systems Taxonomy

As far as industrial sectors and subsectors are concerned, the formal classification of National Statistical Service has been used. For the classes of functional production characteristics, the classification model of Schomburg (1980) enlarged by Tatsiopoulos (1988) is used. This model uses 9 classes, each one of them having several instances.

P2.S1-KB2 Reference Model of System Variables

A structured analysis of the firm's current system would normally include the development of detailed Extended Data Dictionaries including Data Flow Diagrams and Entity Relationship Diagrams. However, for the objectives of a consultancy workbench we consider this procedure extremely complicate and time-consuming. Instead, we base our description on the concept of the Burbidge's (1984) variable connectance model, which is applied to the following six basic production planning and control functions, likely to be apparent to all manufacturing firms:

PDM = Production Data Management CRP = Capacity Management
 MPS = Master Production Scheduling SFC = Shop Floor Control
 MRP = Materials Management PUR = Purchasing

For each one of the above functions, a reference model of the following sets of parameters consists the P2.S1 - KB2 knowledge base. The firm's current model can be constructed out of this generic reference model by choosing the relevant parameters.

A *DESIGN PARAMETER* is a variable which can take one or a combination of a limited number of alternative values, defined in advance. Examples of design parameters are the 'planning frequency', the 'planning horizon' and the 'length of planning periods'.

A *REGULATORY PARAMETER* is a variable to which a range of different values, not defined in advance, can be assigned.

An *OUTPUT VARIABLE* is a variable which can only indirectly be altered by changing parameter values (usually measures of performance).

Examples of Regulatory Parameters and Output variables are: Run Quantity, Transfer Quantity, Buffer stock (Regulatory), Throughput time, Storage time (Output). What interests in terms of the production management requirements is the capability of the PPC system to provide decision-making for the Regulatory Parameters and to measure the Output Variables.

An *ENVIRONMENTAL (or Input) VARIABLE* is a variable whose value is imposed by the Environment in which the system exists and over which it has little or no control. Examples of this kind of parameters are given below:

- Traceability regulations (LOT TRACKING, CONFIGURATION CONTROL, SERIAL NUMBERS)
- Stock recording by government contract (YES,NO)
- State tax regulations, e.g. obligation for tracking of tax-free materials (YES,NO)
- State import-export regulations (e.g. tax-free raw materials if included in export products (YES,NO)
- Foreign currency transactions (YES,NO)
- Number of possible material suppliers (ONE,FEW,MANY)
- Reliability of suppliers (GOOD,FAIR,POOR)
- Number of competitors (NONE,FEW,MANY)
- Strike potential (RARE,POSSIBLE,FREQUENT)
- State regulations regarding hiring, firing and overtime (NEGATIVE,RESTRICTIVE,POSITIVE)

3.2. Step P2.S2 - Main study's objectives setting

The search for objectives is based on the current situation analysis and is crystalised in the form of knowledge bases of hierarchically structured classes of objectives. Important at this stage is that objectives are classified in absolutely "*must*" objectives and "*desired*" but not necessary objectives. A further classification of objectives is undertaken in three dimensions, the *context* (functional, financial and personnel), the *time* (short-term, medium-term, long-term) and the *place* (system internal, external environment).

The objectives setting step has to take objectives of the PPC system, which have been found at the current situation analysis phase in the form of *Output or Performance Variables*, and then classify and structure them in a hierarchical and consistent way as described above. Only then it is possible to proceed to the following step which is the synthesis/analysis of alternative PPC reference models in the light of the pre-defined objectives. The knowledge base used at this stage is:

P2.S2-KB1 Classes of Objectives

3.3. Step P2.S3 - Synthesis/analysis of alternative solutions

The potential alternative solutions at this stage include different *reference models of 'ideal' PPC requirements* which would be suitable for the particular manufacturing firm. The chosen reference model should be sent to candidate software vendors in the form of a *requirements catalogue* for bidding.

Alternative reference models are produced out of a generic description of a PPC software package, which is formulated in classes of technical *features*, through the configuration of features to be included in the required PPC reference model for the specific manufacturing firm.

P2.S3.KB1 The Generic Reference Model of a PPC Software Package

Most of the available commercial software modules for production management belong to large integrated packages of manufacturing management software which even though they use slightly different names for their modules, it can be said that the terminology and content of the most functions offered is fairly standard as, for example, MRP for materials management or MPS for Master Production Scheduling.

The purpose of this study is to build a knowledge base of a generic PPC reference model which contains, in terms of parametric "modules" and "features", all the Knowledge domain of current PPC information technology and production management theory. The typical Data Dictionary for documenting software applications contains the entities Application (Program), Module, Database, File (Table), Data Group (User View), and Data Element. This study adopts the opinion that such a detailed data dictionary is quite impractical in the case of PPC packages due to their immense size and complexity. Instead, from the level of module downwards, the notion of "*Features*" and "*Parameters*" with their corresponding instances is used for description of the reference model.

For the module parameters, the terms used in this study correspond to the reference model of system variables defined previously in paragraph 3.1.

Module Features (the example of the MRP module)

The concept of *module feature* is characteristic in the world of commercial software being of a rather verbal nature. Usually it represents some sort of functionality and how it

is performed. Its analytical description and documentation would require extensive data flow diagrams and flowcharts which is not practical for our purposes. Therefore, the "feature" is described by a short phrase and a set of values corresponding to alternative methods of performing its function. In this study an attempt is undertaken to codify, standardize and store in a knowledge base all known PPC software features and their alternative values. In terms of the requirements of the production management system, first we are interested in the very existence of a specific feature and then in its value, i.e. the method used. Next is given an example of codified features for the MRP module.

01. MRP operation (BATCH, INTERACTIVE, BOTH)
02. Form of MRP explosion (REGENERATIVE, NET-CHANGE, BOTH)
03. Requirements presentation (BY PERIOD, BY DATE, BY JOB)
04. Calculation of lead times (BY ITEM, BY PARENT-SON RELATION, BY BATCH PROCESS TIME)
05. Form of orders issued (WORK ORDER, FLOW ORDER, BOTH)
06. Pegging of Requirements (SINGLE LEVEL, FULL LEVEL EXPLOSIVE, FULL LEVEL IMPLOSIVE, MRP BY CONTRACT)
07. Selection of depth of requirements explosion (YES,NO)
08. Simulation net-change capabilities (YES,NO)
09. Lot sizing techniques (USER INPUT, PROGRAMMED RULES OF THUMB, PROGRAMMED OPTIMIZING)
10. Phantom items (YES,NO)
11. Blanket material acquisitions for large orders (YES,NO)
12. Allocations (BY PRODUCTION ORDER, BY CONTRACT, TIME-PHASED, AUTOMATIC MULTI LEVEL, ALL, NO)
13. Allocation of safety stocks (USER INPUT, PROGR.RULES OF THUMB, MATHEMATICAL)
14. Backflushing (YES,NO)
15. Government contract support, i.e. purchase and production orders by contract (YES,NO)
16. Lot tracking (YES,NO)
17. Variable Yield (YES,NO)
18. Configuration control (YES,NO)
19. Support of co-product and by-product creation (YES,NO)

In order to decide on the selection problem of module features and parameters, the production systems taxonomy and the generic PPC software knowledge bases have to be combined and inferred under the logical schema of Figure 2.

Figure 2. Generic Reference Model of a PPC software package

A PPC software structure derived from a certain production system type can be covered by the existence of a particular software module (MOD) and/or the value of a module feature (FTR). For example the module MRP has as a submodule the "KNOW ABOUT THE CONSEQUENCES OF A LATE PURCHASE ORDER ON THE PROGRESS OF A CUSTOMER ORDER" which is required by the PSP parameter value "Demand Dependent on the Customer Order" and is covered by the software module feature MRP-06 (FULL LEVEL IMPLOSIVE).

3.4. Step P2.S4 - Evaluation of solutions

There is a broad spectrum of "Suitability" of a particular software module feature from very good to very bad. For this reason there is often a temptation to use quantitative methods like value analysis which specify the decision on a numerical scale, say from 1 to 100. However, the factors talked about in this study are general guidelines, often not very well specified, and in a real-world situation they may not be known with great accuracy. This suggests that a 0 to 100 decision may be a meaningless breakdown given the fuzziness

of the factors that go into making the decision. A better choice would be to limit ourselves to a three-way decision: *CRITICAL, DESIRED, NOT NECESSARY*.

3.5. Step P2.S5 - Realisation of chosen solution

This step of phase P2 (main study) means the consolidation of a criteria and requirements catalogue in the form of a questionnaire and its sending to all candidate PPC software vendors according to a mailing list database of their names and addresses.

P2.S5.KB1 Mailing list of PPC software vendors

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