I-Promise - Intelligent Protective Material Selection

Mirko Đurić[1] and Vladan Devedžić[2]

[1] "Tipoplastika" Holding Co.

Radovana Grkovića bb, 32300 Gornji Milanovac, Yugoslavia

E-mail: tipopl@eunet.yu

Tel: +381-32-717260, Fax: +381-32-717274

[2] FON – School of Business Administration, University of Belgrade
POB 52, Jove Ilića 154, 11000 Belgrade, Yugoslavia

E-mail: devedzic@galeb.etf.bg.ac.yu

Tel: +381-11-3950856, Fax: +381-11-461221

Corresponding author:

Vladan Devedžić, Fax: +381-11-461221, E-mail: devedzic@galeb.etf.bg.ac.yu

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Abstract. The paper describes I-Promise, an expert system for configuration design of complex protective materials. Configuration problem of I-Promise is a part of conceptual design of complex protective materials; hence the context of conceptual design and configuration problems is briefly described before the detailed description of I-Promise, its problem domain, its design, and its application. Due to the complexity and sequential nature of its task, I-Promise is designed as a series of three specialized expert systems. I-Promise is a real-world system, built on top of the information system of an enterprise that produces and delivers complex protective materials.

Keywords. Complex protective materials, expert system, conceptual design, configuration, case-based reasoning.

1. Introduction

In manufacturing, design is the process of transforming the customer's requirements into a set of specifications, drawings, plans, and other descriptions, suitable for conducting production operations and/or other practical activities in creating the corresponding artifact. Oakland (1989) defines the following phases in the design process, regardless of the kind and nature of design:

- conceptual design;
- detailed design;
- process and equipment design;
- prototype manufacturing.

Conceptual design means requirements identification and development of the product's specification. In many cases, conceptual design involves the product's *configuration design*. Such design has the following features (Brown, 1998; Franke, 1998):

- the artifact being configured is assembled from instances of a fixed set of well defined component types;
- components interact with each other in predefined ways.

This paper describes an application of expert systems in conceptual design of complex configuration tasks (or just 'configuration', for short). The industry considered is manufacturing of protective materials, and the system is deployed in "Tipoplastika" Holding Co., Gornji Milanovac, Yugoslavia. Complex protective materials are used for wrapping and packing of various products. In practice, complex protective materials combine a number of basic materials (such as different kinds of paper, PE foils, PP foils, PET foils, AL foils, etc.), in order to achieve desired protective features (e.g., water-proofing, oxygen-proofing, aroma preservation, and the like). It is a classic configuration task, but it is simultaneously extremely complex and involves a lot of heuristics. Hence we used expert system technology for designing complex protective materials. Specifically, our approach to such a configuration has two steps. In the first step, we consider the possibility of configuring the protective material starting from already used combinations of basic materials. If that's not feasible, in the second step we try to generate an entirely new combination. Only the first step is described in this paper. The second step is the subject of our ongoing research.

2. Problem domain

Solving configuration problems in conceptual design is important in many branches of manufacturing. There are several critical issues here:

- customers can represent their requirements in a number of ways, hence flexible problem-solving strategies are necessary;
- constraints as to what parts can go together in the assembly can be very complex;
- the kind of activities that must be performed in order to get to a valid configuration;
- the schedule of the activities.

Manufacturing of complex protective materials also bears additional, specific problems in conceptual configuration design. Combinations of basic materials can be standard and non-standard. Standard combination is the one that has been already used before. Non-standard combination is the one that has never been used before. The obvious advantage of standard configurations is avoiding technological problems that usually feature first-time manufacturing processes. Hence in practice the configurer always tries to satisfy the customers' requirements by a standard combination. If that's not possible, a non-standard combination is used.

3. Problem statement

The problem we have focused on was how to properly configure a complex protective material starting from a standard combination of basic materials. This problem has the following steps:

- specify the customer's requirements as accurately as possible, allowing the customer to most effectively articulate his business needs;
- select a standard solution that most closely corresponds to the customer's needs;
- consider different commercial and technological constraints in the context of the selected solution, and make the necessary commitments.

4. Previous work

The authors are not aware of any previous attempt to automate conceptual configuration design of complex protective materials by means of intelligent systems techniques. However, in our work we have used experience and advice of authors and configuration designers from other application domains.

Approaches to performing configuration tasks differ in the methodologies and techniques they use (Faltings & Freuder, 1998; Sabin & Weigel, 1998). When configuration tools use intelligent technologies, they support different reasoning possibilities and knowledge representation techniques. Effectively, one or more intelligent systems can be used for solving configuration problems (Đurić & Velašević, 1998; Soininen, Tihonen, Mannisto & Sulonen, 1998; Wielinga & Schreiber, 1997).

4.1. Rule-based reasoning systems

This rather traditional approach has been used extensively, and is quite appropriate in exact, technical domains. Rule-based knowledge representation formalism allows for expressing the necessary configuration knowledge as relatively static, consistent, and context-independent. A typical example is the expert system for conceptual design of injection molding parts, developed by Kwai-Sang & Wong (1996). They have used the Kappa-PC shell, and their system has two main modules, one for material design (ESMAT), and one for mould design (MOLT).

4.2. Model-based reasoning systems

The rationale behind using model-based reasoning in performing configuration tasks is grounded in their essentially synthetic nature. Such systems can analyze the entire space of possible solutions. Experience with working in a specific domain can be useful for applying such systems, but the idea is to design them to be applicable even in domains in which they were not applied before.

One of the most important subsets of these systems is based on *description logic (DL)*. For example, the DL-based expert system called CLASSIC, developed in AT&A, configures large telecommunications systems (McGuiness & Wright, 1998).

Another subset of model-based reasoning systems are *resource-based systems* (Heinrich & Jungst, 1991; Sabin & Weigel, 1998), in which different resources enable the interaction between the system, its components, and its environment. Each technical entity is featured by certain kinds and amounts of resources.

Mittal & Frayman (1989), Mittal & Falkenhainer (1990), Rissland & Skalak (1989) and other authors have pursued *constraint-based approach* to configuration design. Each component is defined by a set of features and a set of ports for interaction with other components (Sabin & Weigel, 1998). Constraints limit the ways in which different components may be combined in order to achieve a correct configuration. For example, Siemens AG has used this approach and a configuration tool called Cocos (Configuration by Constraint Satisfaction) to develop its Lava automatic configurer of complex telephony systems (Fleischanderl, Friedrich, Haselbock & Stuptner, 1998).

4.3. Case-based reasoning systems

Case-based reasoning (CBR) approach to configuration problems is completely different from those mentioned above. Here, the necessary knowledge is stored mostly in the examples (cases) that have been configured before. The current configuration problem is solved by finding the most similar previous case in the case base, and then adapting it to the requirements of the current problem. The rationale behind this problem-solving method is that similar cases have similar solutions (Maher & de Silva Garza, 1997).

4.4. Multi-phase and hybrid-AI configuration systems

Pugh (1981) has been the first one to describe multi-phase conceptual design. Mistree, Lewis, & Stonis (1994) have presented 3-phase conceptual design of aircraft. They have applied the Pugh method in the first phase and constraint-satisfaction with different levels of correctness in the other two phases. The initial concept is generated by means of improvisation, not by case-based reasoning. Netten & Vingerhoeds (1997) have also implemented a 3-phase approach to conceptual design of fiber reinforced composite panels.

Several authors have combined different reasoning techniques in configuration tasks. In most of cases, CBR has been combined with another technique (such as model-based reasoning, description logic, and constraint satisfaction), used to adapt the cases (Branting, 1998; Marling, Petot & Sterling, 1998; Oakland, 1989; Price & Pegler, 1995; Rong, Saldanha & Lowther, 1998).

5. Proposed solution

In conceptual design, the solution space and the level of abstraction gradually decrease (Soininen, Tihonen, Mannisto & Sulonen, 1998; Wielinga & Schreiber, 1997). In our case, the solution is based on:

- a standard combination of basic materials;
- comparative evaluation of general protective features of the complex material with respect to the customer's requirements;
- comparative evaluation of those protective features of the complex material that can be measured, with respect to the customer's requirements;
- comparative evaluation of commercial requirements and conditions, with respect to the customer's requirements.

We have designed and developed the system called *I-Promise* (Intelligent PROtective Material SElection) to meet these issues. Its design has been largely affected by the following considerations.

5.1. Formalizing customer's requirements

The first problem of configuring complex protective material (both in case of standard and non-standard combinations of basic materials) is how to formalize the customer's requirements. Customers often express their needs informally, but the configuration system requires more rigorous and a more stable format. The system can present the customer a list of conditions that they must satisfy in expressing their needs, but such a solution is rather system-oriented. It either requires specific domain knowledge from the customer, or help from domain expert who can interpret the customer's needs expressed informally, which is highly error prone. It is better to design the configuration system to be customer-oriented, providing interactive guidance that will assist the customer in expressing his requirements accurately and in a desired form.

In that sense, our solution starts from acquiring the customer's technological requirements at an abstract, customer-oriented level, Figure 1. Through a graphical interface supplied with appropriate menus and choice lists, containing a large number of basic materials, typical protective features, measures, quality parameters, and the like, the customer enters his first choice of requirements.

The first choice is typically rough and incomplete, but it makes possible to the customer to get a basic idea of what the final product's features can be and to articulate his needs in a guided and controlled way. By having a direct insight into real-world protective materials, their production and sales codes, their technological features, their costs, and their quality, the customer gets easily accustomed to the manufacturer's offer. For example, if the customer selects his specific requirements in terms of water-proofing, oil-proofing, and so on, the interface will offer a list of typical concrete standard combinations, such as PA30m/PE18m/PE50m (see Table 1 for a quick, rough, first-time familiarization with some of frequently used basic protective and packing materials). By clicking each one of them, the customer gets a high-level description of what they mean and what they are good for. The idea is that he eventually makes an incomplete selection of his requirements and possible combinations ("I might want something like this"). It gives I-Promise the initial, realistic concept of the final product, i.e. the first picture upon which it will configure and refine the complex protective material with desired features.

Table 1 - Typical basic protective materials

Symbol	Meaning
PA	Polyamide
PE	Polyethylene
AL	Aluminum foil
PET	Polyester
PP	Polypropylene
Copolymer	Copolymer

The customer's initial choices get automatically converted into a form that I-Promise uses internally. For example, the concrete combination PA30m/PE18m/PE50m would be formally represented as PA/PE/PE, which is meaningful for the system, but too general and too abstract for the customer.

5.2. Prototype design and conceptual design

From the requirements specification - formally represented features and behavior of the protected material to be configured - the system can then reason about standard combinations and eventually recommend a configuration at an abstract, customer-oriented level. I-Promise first builds a prototype (see Figure 1). It is not a concrete configuration yet - it is rather a rough sketch of it, making possible for the system to analyze its feasibility and constraints. By building a prototype first, I-Promise greatly reduces the solution space and makes the next step - the conceptual design - much easier.

In the conceptual design, there are generally several standard solutions that can be used to instantiate the prototype design, all of which have been used in similar previous cases. The system tries to select the one that best reflects the customer's requirements. The result is a recommendation of the final product concept, including the basic materials to be combined, the relevant measures, and quality standards to be expected.

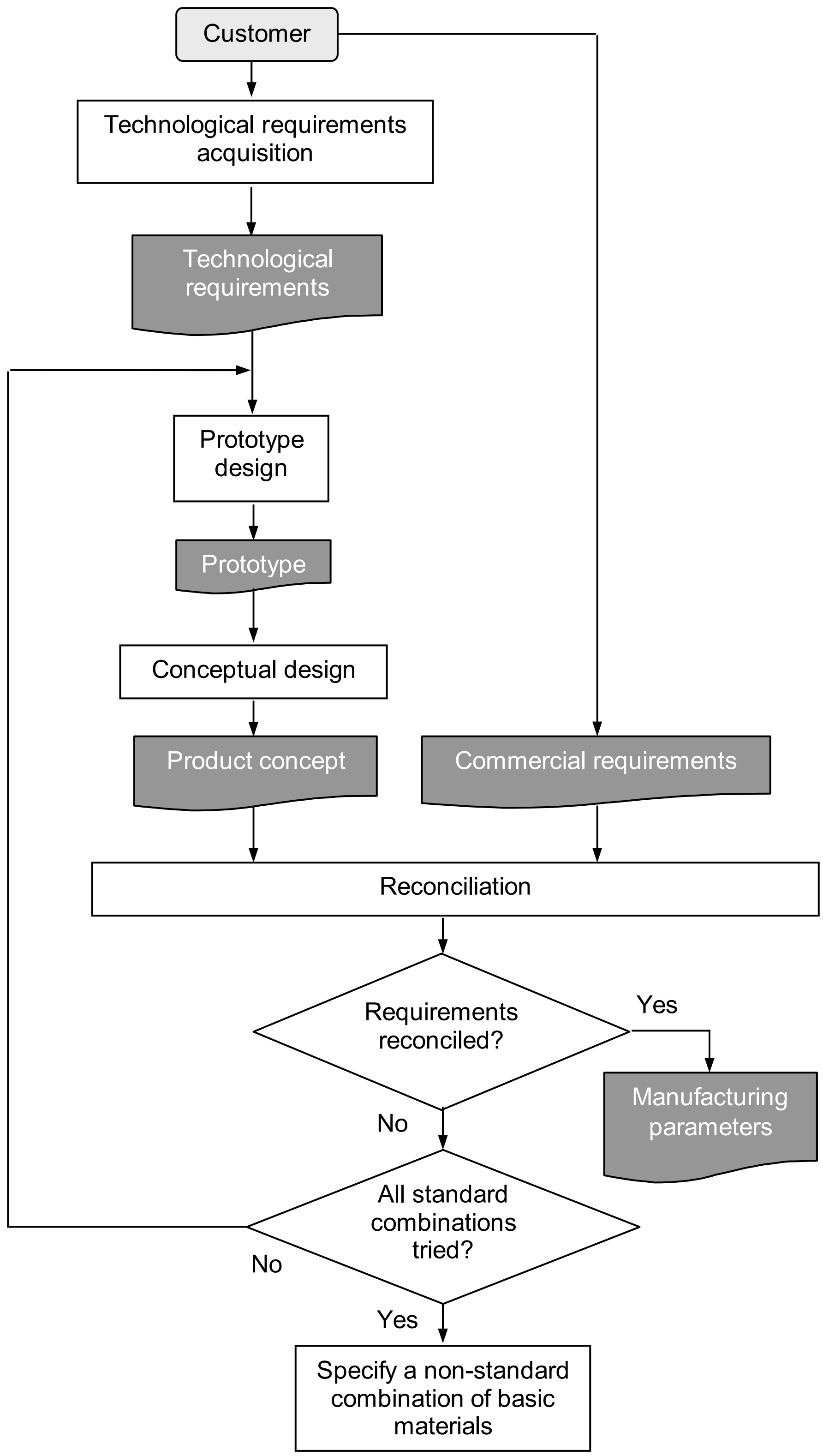

Figure 1 - Conceptual configuration design of complex protective materials

5.3. Reconciliation with commercial requirements

The recommended product concept might need to be modified according to the cost and realistic delivery date. In such a case, I-Promise will try to find an alternative standard solution that satisfies both technological and commercial requirements, as well as the required delivery date. If that is not possible either, the system will try to make a non-standard configuration.

5.4. Output and environment

After possibly iterating a couple of times through the design and reconciliation processes, I-Promise eventually outputs the product's manufacturing parameters and a completed production order form.

I-Promise was built on top of our enterprise-wide information system. The information system stores in its database (among the other things) stock and inventory data about basic materials, features of standard configurations, production orders, and so on. It is from that information system that I-Promise gets data about previous orders, costs, orders of basic materials that are out of stock, how busy the production machines are, what their planned activities are, and what are expected delivery times. All these data are necessary in order to reason about the current order.

6. Design details

The processes depicted in Figure 1 involve numerous and often incomplete input data, heuristic reasoning and selection from multiple alternatives, and also possibly conflicting sets of requirements. This creates a good ground for applying expert system technology. In fact, I-Promise is designed as a series of several expert systems, Figure 2. The link to the enterprise's information system is also shown.

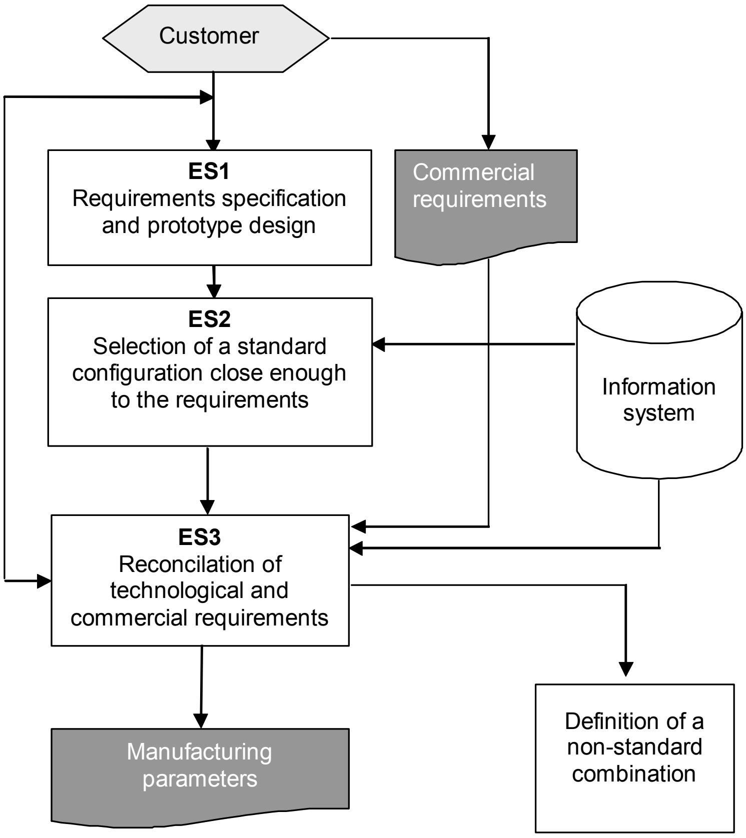

Figure 2 - Detailed design of I-Promise

6.1. I-Promise-1

Acquisition of technological requirements and prototype design create a logically closed system. It is designed as a separate expert system that we call I-Promise-1. In Figure 2, it is depicted as ES1. Its tasks include:

- specification of the customer's requirements;
- specification of the desired features of the protective material;
- abstract recommendation of the combination of basic materials;
- reduction of the space of possible combinations.

Generally, there are several categories of packing for which I-Promise-1 configures complex protective materials:

- vacuum packing
- snack packing
- candy, chocolate, and bubble-gum packing
- dessert-bar packing
- fat and oil packing
- cakes and waffle packing
- dehydrated food packing

- frozen food packing
- coffee, spice, grains, and powder-type product packing
- packing of pharmaceuticals and medical creams/lotions/balms and instruments
- packing of plant-protection chemicals
- wheat and vegetables packing

For each of the above categories, there are several typical combinations of basic materials. These combinations are stored in the I-Promise-1 knowledge base in an abstract form, without physical parameters. For example, typical combinations (Ci) for vacuum packing are:

- C1 - PA/PE
- C2 - PA/Copolymer
- C3 - PA/PE/PE
- C4 - PA/PP
- C5 - PET/AL/PE
- C6 - PET/AL/PP

Important features (Fi) for this category of packing include:

- F1 - Water-steam-proofing
- F2 - Oxygen-proofing
- F3 - Oil-and-fat-proofing
- F4 - Light-proofing
- F5 - Aroma and smell preservation
- F6 - Suitability for thermal forming and packing
- F7 - Suitability for high-temperature sterilization
- F8 - Low-temperature-proofing

Each of these features can take one of the following five descriptive values:

- 1 - LOW
- 2 - MEDIUM
- 3 - GOOD
- 4 - HIGH
- N/A (cannot be measured)

Using the above symbols (Ci, Fi) and descriptive values, Table 2 represents the knowledge of vacuum packing built into I-Promise-1. Table 2 is essentially a decision table, and representing its knowledge in the form of production rules is straightforward - I-Promise-1 is designed as a rule-based system. For example, from the C4-row of Table 2 we can read:

IF IF

F1 = 4, and	Water-steam-proofing = HIGH, and
F2 = 3, and	Oxygen-proofing = GOOD, and
F3 = 4, and	Oil-and-fat-proofing = HIGH, and
F4 = 1, and	Light-proofing = LOW, and
F5 = 3, and	Aroma and smell preservation = GOOD, and
F6 = 3, and	Suitability for thermal forming and packing = GOOD, and
F7 = 3, and	Suitability for high-temperature sterilization = GOOD, and
F8 = 4	Low-temperature-proofing = LOW
THEN	THEN
Suggest C4	Suggest combination PA/PP

Table 2 - Decision table for vacuum packing

	F1	F2	F3	F4	F5	F6	F7	F8
C1	3	3	3	1	3	3	1	4
C2	3	3	4	1	3	3	4	1
C3	3	3	3	1	3	3	3	4
C4	4	3	4	1	3	3	3	4
C5	4	4	3	4	4	1	1	4
C6	4	4	4	4	4	1	4	4

I-Promise-1 does not combine different materials in order to provide desired features of the complex protective material; it only uses expert knowledge about possible combinations. That knowledge includes all the factors relevant for possible combinations.

I-Promise-1's flowchart is shown in Figure 3. After obtaining a recommendation, the customer can iterate through the process if necessary, in order to refine the recommendation or obtain an alternative one.

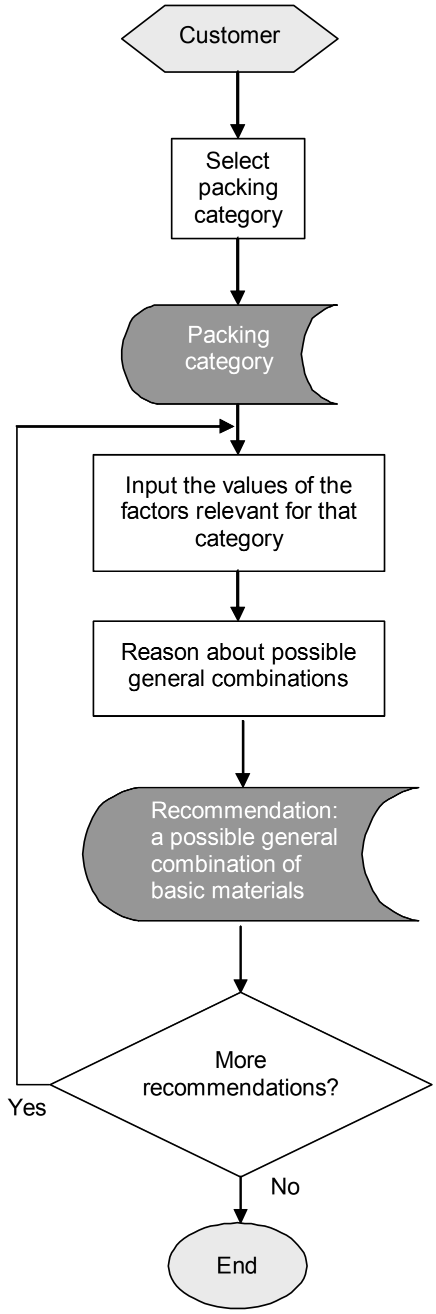

Figure 3 - I-Promise-1's flowchart

6.2. I-Promise-2

The second expert system, which we call I-Promise-2 (ES2 in Figure 2) instantiates the recommendation obtained from I-Promise-1 by assigning realistic values to the parameters of the combination from the recommendation. The result is a configuration of the complex protective material the customer needs. The flowchart of I-Promise-2 is shown in Figure 4. I-Promise-2:

- further refines the general recommendation obtained from I-Promise-1 by applying quality assurance standards (essentially by taking into account the required standard values of all the measurable parameters from the general combination of basic materials, as prescribed by quality assurance procedures);

- selects the previously configured case closest to the customer's requirements, starting from the refined recommendation obtained from I-Promise-1 and the case base maintained by the enterprise's information system (see the example shown by Table 3);
- selects and outputs an appropriate previous production order that corresponds to the recommendation obtained from I-Promise-1.

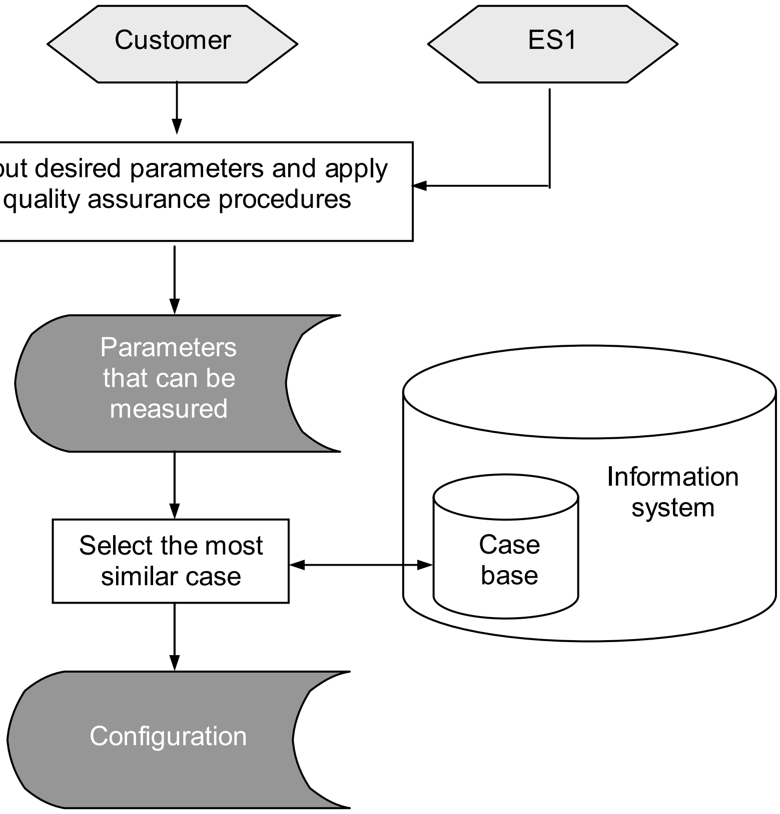

Figure 4 - I-Promise-2's flowchart

Table 3 - A concrete complex protective material (PA30/PE18/PE50)

Feature No.	Feature	Importance	Unit	Required value
1	Water-steam-proofing		$ml/m^2/day$ (pressure difference 1 bar)	18
2	Oxygen-proofing		#	35
3	Break resistance		N/mm^2	44 34
4	Welding quality		N/mm^2	25 26

I-Promise-2 is developed as a CBR expert system, following the recommendations and experience of Price & Pegler (1995). It was a natural design decision, given the need to select a previously configured case from the corresponding database. The case base contains a large set of previous configurations and production orders, and similarity-based criteria (not identity-based ones) are used to guide the search and selection process. That was the reason to design a CBR expert system instead of using ordinary database search. Each case instance is represented as in Figure 5, where most of the fields, in fact, point to different tables in the database.

```
CASE INSTANCE production-order
        date = …;
        product-code = …;                  // final product (complex material)
        general-combination-code = …;      // such as PA/PE/PE
        graphical-design-code = …;
        packing-category-code = …;         // e.g., snack packing
SOLUTION
        specific-combination-code = …;     // combination in the final product,
                                           // such as PA30m/PE18m/PE50m
        feature-code = …;                  // final product's distinct feature,
                                           // such as high-temperature resistance
END
```

Figure 5 - Case instances that I-Promise-2 reasons about

From the customer's perspective, I-Promise-2 is just two forms on the screen. In the input form, the general combination obtained from I-Promise-1 is shown and the customer selects among concrete parameter values the system offers. The output form then shows the resulting instantiated configuration, the corresponding production order completed earlier for a similar case, the feasible parameter values, and the percentage of satisfying the customer's requirements in the configuration.

6.3. I-Promise-3

When I-Promise-2 outputs a concrete configuration, it is necessary to reconcile it with the costs and realistic due dates (see Figure 1). That's the job of the third expert system, I-Promise-3 (ES3 in Figure 2). I-Promise-3 is a kind of a negotiation expert system. Both the enterprise and the customer generally have their own ideas about the cost and the due dates. When the enterprise offers its price and a due date, I-Promise-3:

- compares the enterprise's offer with the price and the due dates the customer can accept;
- if necessary, performs heuristic analysis of differences in the enterprises offer and the customer's commercial requirements;
- if possible, modifies the enterprise's offer and comes up with a new offer to the customer.

Figure 6 shows the flowchart of these activities of I-Promise-3.

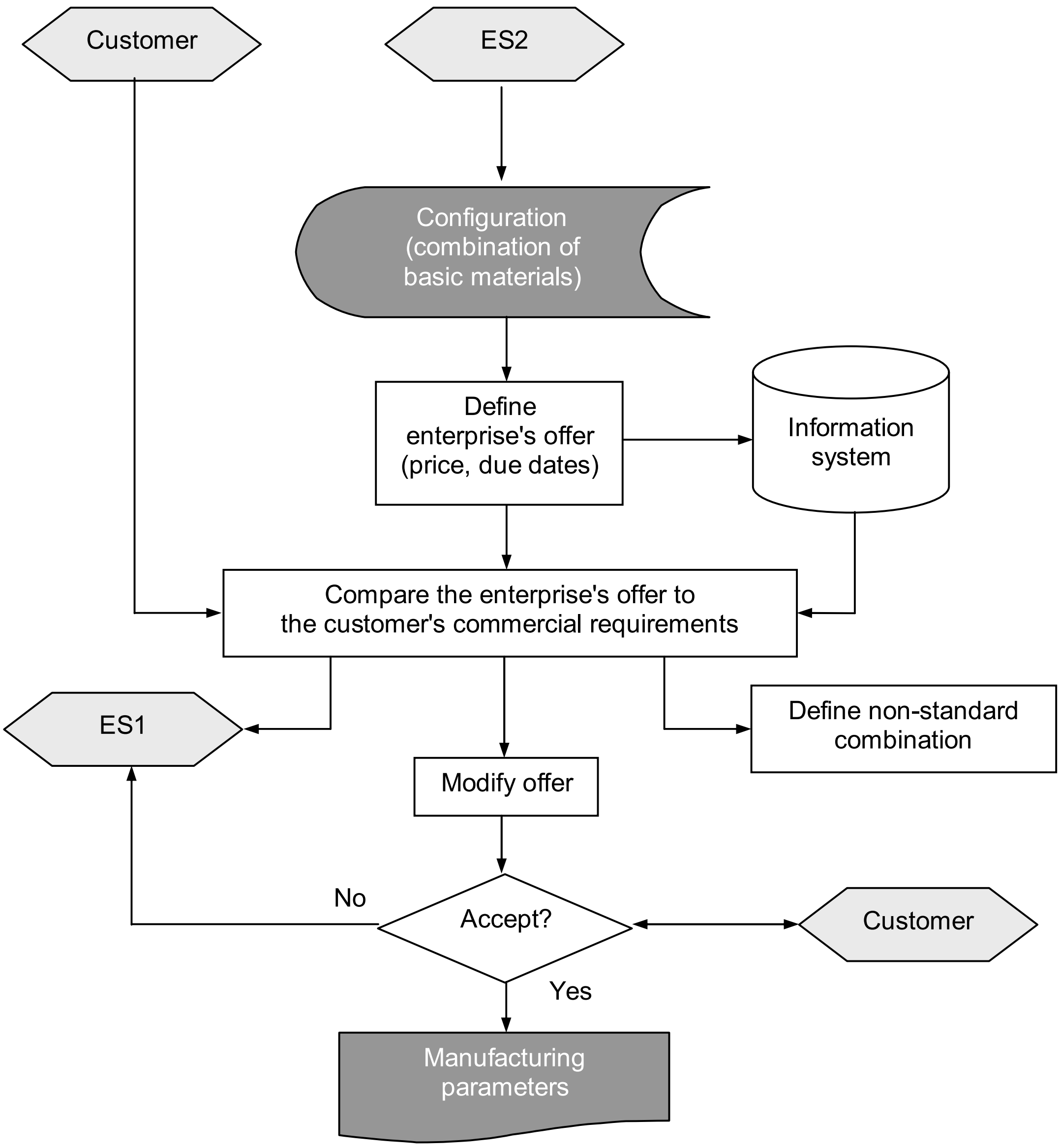

Figure 6 - I-Promise-3's flowchart

When the enterprise offers its price and a due date, there are four scenarios:

- The customer accepts the offer. Based on the configuration output by I-Promise-2, I-Promise-3 specifies the manufacturing parameters directly and creates the production order.
- The price in the enterprise's offer is not acceptable for the customer. I-Promise-3 computes the difference between the price offered and the price the customer is ready to pay. If the difference is small, I-Promise-3 slightly modifies the technological requirements accordingly and initiates another run of I-Promise-2 in order to select another standard combination.
- The due dates in the enterprise's offer are not acceptable for the customer. In that case, I-Promise-3 first tries to make the necessary price adjustments to compensate for the customer's tighter requirements in terms of the due dates. If the customer is not ready to

accept the adjusted price, I-Promise-3 calls I-Promise-2 to select another standard combination (if possible) that will fit the customer's commercial requirements. If that fails as well, an expert is called up to help define a non-standard combination.

- Neither the price nor the due dates in the enterprise's offer are acceptable for the customer. I-Promise-3 will run I-Promise-1 in order to redefine the technological requirements and possibly select another general standard combination. If the customer is not ready to accept changes in requirements, an expert is called up to help define a non-standard combination.

I-Promise-3's input module collects the necessary input data for performing its task from three sources, specified in Table 4. I-Promise-3 is designed as a rule-based system.

Table 4 - I-Promise-3's input

Source	Data
Customer	Amount required Graphical design Other features of the final product that might effect the price and the due dates
I-Promise-2	Proposed configuration of basic materials
Enterprise information system	Enterprise's cost/price offer Enterprise's due dates offer

Note that commercial requirements must be assigned priorities in order to compare the enterprise's offer to the customer's needs and capabilities, and to possibly modify the requirements. The priorities determine the sequence of actions that I-Promise-3 performs.

7. Conclusions

I-Promise approach essentially covers two categories of the configuration task. The first one is configuration starting from existing similar cases; the second one requires using another technique. The goal is to solve as many configuration problems as possible by using existing similar configurations from the case base. The obvious benefits are:

- reduction of potential technological difficulties that new solutions often bring up;
- cost minimization;
- decreased design time;
- open end for using another design technique if necessary.

The approach is suitable for enterprises and companies whose information systems cover standard business activities, but must occasionally perform expert-level configuration tasks as part of completing their contracts. In a number of enterprises, such tasks are poorly formalized and usually let to individual expert judgments and manual configuration, assisted only by a number of catalogues of appropriate configuration components. I-Promise mitigates these problems by introducing a formal, heuristic, and intelligent support for using previous solutions to similar configuration problems. It improves the enterprise's business procedures, brings higher efficiency in completing configuration tasks, and makes the enterprise less dependent on human domain experts.

It is generally possible to develop a procedural program to automate configuration tasks such as those performed by I-Promise. However, potential complexity and modification difficulties of such a program, its poor scalability, as well as its lack of a heuristic component, have made us decide for using expert systems and case-based reasoning in our design. Likewise, case-based configuration problems can be partially automated by ordinary database technology, but such a solution in practice often brings the need to search a large number of old production orders without clear-cut search criteria. This is yet another reason in favor of a solution that uses intelligent technologies.

Our next steps in further development and improvement of I-Promise will include automating specification of non-standard configurations of complex protective materials. Since that problem is much more complex than those covered by I-Promise so far, we envision the need to use a hybrid intelligent system for that purpose.

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Biographies (Vitae)

Mirko Đurić is the Manager of the Department of Advanced Technologies and Programs, "Tipoplastika" Holding Co., Gornji Milanovac, Serbia, Yugoslavia. "Tipoplastika" Holding Co. is the largest manufacturer of complex protective materials in South-Eastern Europe. He has received his degrees from The School of Electrical Engineering, University of Belgrade, Yugoslavia (BS, 1982; MS, 1991). He is currently pursuing his PhD thesis in the field of intelligent systems. His 20-years experience in research, design and development of information systems are a valuable background for developing his current interests in artificial intelligence techniques and their application to information technologies.

Vladan Devedžić is an associate professor of computer science at the Department of Information Systems, FON - School of Business Administration, University of Belgrade, Yugoslavia. He has received all of his degrees from The School of Electrical Engineering, University of Belgrade, Yugoslavia (BS, 1982; MS, 1988; PhD, 1993). His main research interests include software engineering, intelligent systems, knowledge representation, ontologies, intelligent reasoning, and applications artificial intelligence techniques to education and medicine. So far, he has authored and co-authored about 160 research papers published in international and national journals and conferences. His major long-term professional goal is a continuous effort to bring close together the ideas from the broad fields of intelligent systems and software engineering. He has developed several practical intelligent systems and tools, and actively participates as a consultant to several ongoing projects in industry.