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An Elementary Feasibility Analysis Expert System as a Teaching Aid*

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An expert system for elementary feasibility analysis for chemical products is presented in this paper. It is a useful teaching aid to introduce undergraduate students of chemical engineering the fundamentals of techno-economic feasibility analysis. The rule-based expert system is implemented in Exsys, an inexpensive shell which runs on PCs. With 93 rules, it runs relatively fast by backward chaining and nevertheless covers a wide range of considerations. The heuristics cover economic, technological, and some administrative and legal aspects. The system is designed to give the student an opportunity to study the effects of various constraints on feasibility. The system is user-friendly, easy to use, is menu-driven and accepts multiple answers from menus.

INTRODUCTION

AN EXPERT system is a very useful tool that stores and processes expertise-like knowledge in a well organized knowledge base. It serves as a consultant in the specific domain in which it has the expertise. Several books and review papers cover this subject of expert systems in great detail, but the references [1, 2, 3] may be mentioned in relevance to this work. Expert systems in chemical engineering and chemical engineering education is the theme of this paper, hence their background and the present situation are outlined below.

1.1 *Expert systems in chemical engineering*

Expert systems have become quite common in chemical engineering, both at the research level as well as in applications. Many chemical engineering departments including ours at Åbo Akademi teach artificial intelligence and expert systems to chemical engineering sudents. The article [4] includes a good overview on teaching artificial intelligence to chemical engineering students.

The chemical engineering applications of expert systems have been mostly in three categories. The first category is troubleshooting [5] of chemical plants and equipment—primarily diagnostic but also remedial. The other two categories are process control [6], and selection systems. The selection systems include selection of materials of construction, selection of equipment, selection of catalysts [7, 8], selection of correlations for predicting physical and thermodynamic properties [9], etc.

The application presented in this paper does not fall into any of the above three categories, causing it to be a novel application in chemical engineering. This system, however is intended to be more of a teaching aid for chemical engineering students.

1.2 *An aspect of chemical engineering education*

Chemical engineering education in many major universities includes a course on chemical engineering economics. This course, however, does not usually cover the topic of techno-economic feasibility analysis. It is partly because the chemical engineering faculty tends to be more academic, and few of the teachers have worked in industries. It is also for historic reasons, i.e. it has never been taught before. Availability of this kind of an expert system would encourage and facilitate teaching it. With rapidly changing world markets and faster obsolescence of speciality chemicals, techno-economic feasibility has become important for chemical engineers. It allows the students to look at the possibility of producing a chemical product from the entrepreneur's point of view and thus increase their potential as future entrepreneurs. Students would find this skill particularly useful in small-scale and middle-scale industrial environments. The expert system is based on the experience of the former author of this paper, who had the opportunity to be involved in techoeconomic feasibility analyses in a chemical industry.

2. FEASIBILITY ANALYSIS FOR CHEMICAL PRODUCTS

Feasibility analysis is the investigation one goes through before deciding for or against a proposal to manufacture a new product. This is usually done in two stages. The elementary stage aims at a shallow but broad scan of possible problems that may be encountered. This expert system is designed for this first stage of the feasibility analysis. The second stage is an exhaustive, meticulous study taking into account every small detail. The elementary stage has a lot of similarities for a wide range of chemical

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products, and can be taught to undergraduate students.

The basic necessity for the viability of any commercial, industrial venture is its potential to operate profitably. Thus, the first thing that needs to be checked is that the raw material cost does not exceed the selling price of the product. But, even if the two are similar, it is not good enough. Labour costs and depreciation have to be accounted for. The instability of the product market has to be taken into consideration. For studying the feasibility, the selling price should be taken closer to the expected lowest selling price. If raw materials are not available freely, and the price keeps fluctuating, the raw material cost should be calculated at the highest prices of the raw materials.

The difference between the selling price and the raw material cost (hereafter referred to as the margin) required for feasibility depends on several factors: type of chemical, scale (volume) of production, and labour requirements being some of the main factors. Plants for common organic chemicals which are usually produced in large quantities operate at a smaller margin. Specialty chemicals, pharmaceuticals, catalysts produced in small quantities have fairly high margins. A larger margin is required for labour intensive processes.

Profitability is not the only important consideration. Existing process or product patents may not permit setting up a production plant for the chemical under consideration. Product obsolescence also needs to be examined. There are thus, technical, legal and administrative aspects also to be considered.

These heuristics are written down as if-then rules to form the knowledge base for this expert system.

3. THE EXPERT SYSTEM

The discussion regarding the expert system EFA is subdivided into the following three aspects. The shell contains the inference engine of the expert system and some housekeeping routines and the user interface. The knowledge base stores the knowledge or expertise in terms of rules which contain the heuristics for the elementary feasibility analysis. The operation of the system is easy and user-friendly, and is described in the third section.

Knowledge acquisition phase was not required since the first author had gone through feasibility analyses earlier in a chemical industry. Knowledge engineering was thus simply writing the rules in Exsys, and subsequent modifications.

3.1 *The shell Exsys*

Exsys is an expert system development package of Exsys, Inc in Albuquerque (New Mexico, U.S.A.) [10]. the standard version (version 3.2.5) runs on IBM PCs, XTs, ATs or compatibles with 320K RAM, one floppy disk drive, on DOS 2.0 or higher. 64K accommodates about 700 rules with an average of 6 or 7 conditions. Expert systems of 5000 rules can be run on PCs. Exsys also runs on VAX/VMS. Exsys source code is in C which produces small and fast running programs.

Exsys provides for conclusions in terms of choices. The end of a run results in one or more choices. In that sense, it is designed for selection expert systems—systems that would select from alternatives. In this kind of application (the elementary feasibility analysis), a number of advices are listed, and the expert system selects one or more of the advices as the conclusion of a run.

The rules have the usual structure: an IF part, a THEN part, an ELSE part which is optional and then optional NOTES and REFERENCES. The rules resulting in choices have relative probabilities associated with them. A useful feature of Exsys is that it allows assigning multiple values to qualitative variables called qualifiers. (Qualifiers are the subjects of the clauses in the IF, THEN, and ELSE parts of the rules, often including the verb after it.) e.g. the type of a chemical can be both 'inorganic chemical' and 'fertilizer.' The rule editor allows easy additions, deletions, modifications and reordering of rules and its contents and even running the set of rules.

It has options for backward chaining, forward chaining, and other ways of inferencing. The rules, qualifiers, results, input data, etc. can be printed out easily.

However, being a simple tool, it has several limitations. It does not have facilities for implementing frames or objects, and little can be done to structure or group the rules. Exsys has no built-in graphics interfaces. External programs can be called or files can be displayed. It may be noted that such facilities were not really required for this application. The user cannot specify a confidence level to his input data. There is no facility for fuzzy logic.

3.2 *The knowledge base*

The knowledge base contains heuristics completely in the form of rules. No other forms of knowledge representation are used. There are a few mathematical expressions. Exsys is therefore sufficient for this purpose.

The rules have been written for backward chaining. Backward chaining starts with investigating the possibility of the first choice (conclusion) and after determining it, goes on to the next choice. Thus, the order of choices is important. They would determine the order of rules to be triggered. Choices have been ordered so that the more important aspects in the feasibility analysis are considered first.

All the rules are used to cover all the aspects included in the knowledge base. Even if some information is not available, some analysis is done, but sometimes it is quite clear that further analysis is not required to confirm infeasibility, and in such cases, the run is terminated at that point and results are displayed.

The first thing that needs to be confirmed is that the raw material cost does not exceed the selling price. There are rules to see that there is sufficient margin between the raw material cost and the selling price under various circumstances: for low, medium or high volume products, organic, inorganic or other kinds of chemicals, processes that are or are not labour intensive, stability of the product market, availability of the raw material, etc. Since the numbers used in these rules tend to be subjective, and make the difference between a risk-taking and a cautious individual, the numbers put in there by the first author may be taken as only illustrative and not authoritative.

Then there are rules of technical, legal and administrative natures. It is often difficult to distinguish between the above three types, but the following will clarify the point. If you do not have the technology, it may not be an easy task to procure it. Old, inefficient and possibly obsolete technology is more freely offered. Toxicity hazards of the process need to be weighed during the process selection phase. Pollution requirements differ from country to country and the technology may need upgrading in this respect. Waste disposal can be a serious problem, and this too has to be taken into account before the decision for or against producing a chemical is made.

Some consideration is given to the existing marketing infrastructure, if any. If the product is to be marketed mainly abroad, or if the raw material is imported, currency stability also needs to be studied. Tax legislation may be more conducive in some places than others and hence can make a lot of difference. Product and process patents may be obstructive and it is necessary to have some information on this matter. These are some very elementary considerations to be examined and therefore form a part of the first stage of the feasibility analysis.

Exsys provides for associating probabilities with rules that result in choices. In this expert system, they have been used as indicators of relative importance and not as probabilities (see Fig. 2). The choices are used as advices. The system also takes into account the rapidly changing face of Europe. The main feature which considers this is that it has been assumed that it will not be very difficult to market products abroad, or import raw material, or have manufacturing establishments abroad.

The simplest rules look like these:

```
33, IF
        Type of chemical is fertilizer
    THEN
            Nature of chemical is heavy/bulk
        chemical
    ELSE
    —
    NOTE:
            We do not include micronutrients here.
40, IF
        Nature of chemical is fine chemical
    THEN
        Volume of the product is low volume
    ELSE
    NOTE:
```

The more complicated rules look like these:

```
14, IF
        [RMC] > 0.7*[SELLING PRICE]
        Type of chemical is inorganic chemical
        Volume of the product is low volume
        Labour requirement is not high
        Producing this product is still feasible
    THEN
        It is probably not worth the effort—
        Probability: 90/100
    ELSE
    NOTE:
        Exceptional cases include . . .
21, IF
        [RMC] < 0.6*[SELLING PRICE]
        producing this product is still feasible
        raw material availability is sufficient
        annual turnover (expected) is of the
        right order of magnitude
        market survey is done
        tax legislation is not a hindrance
        technology is available indigenously/
        easily
        pollution control or waste disposal or
        toxicity hazards are not problematic
    THEN
        It seems worthwhile from this
        elementary feasibility analysis—
        Probability: 90/100
        A detailed feasibility analysis is
        recommended—Probability: 98/100
    ELSE
    NOTE:
        This looks attractive enough and a
        more thorough feasibility analysis is
        desirable.
```

To facilitate the maintenance of the knowledge base, the rules have been written as simply as possible. There are notes associated with many of them to explain why, how and its limitations and exceptions. All the rules are used and the order in which they get triggered is dictated to a good extent by the order of choices.

The knowledge base has 22 qualifiers, 30 choices (or conclusions), 5 mathematical variables and 93 rules.

The system was validated using several hypothetical test cases. It was found in the earlier stages of development that the system tried to analyse the situation even after a negative answer was rather obvious. This was the only situation which required major changes to be made to stop execution at the right points.

3.3 *Operation of the expert system*

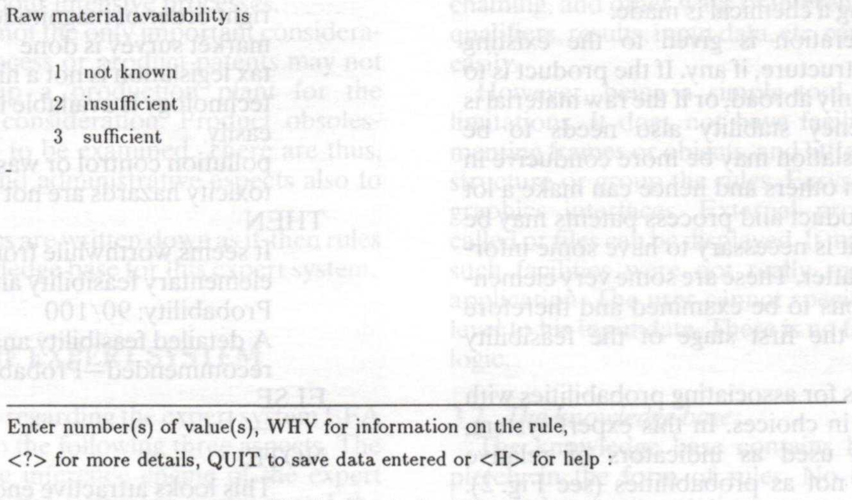
The expert system is quite user friendly, and the operation is very easy. It asks multiple-choice questions to which it can accept more than one answer. Figure 1 shows a typical run-time screen. To avoid inconvenience to the user, 'don't know' is built in as a choice in many cases where the user may not be able to answer categorically. The user can ask 'why' before answering a question to know why it has been asked. The expert system then tells the rule it is trying to test with the information that it would derive from that answer. The rule is displayed on the screen in the same manner as it appears while editing.

The user can ask for a list of known data, and can change one or more of the answers he has given in the end. When the conclusions are presented, one can ask for explanation as to how the conclusion was arrived at, and the expert system displays sequentially the rules that were used, in the same format as in the rule editor. This is not very convenient for the users.

Figure 2 shows a typical results screen. The user can rerun the EFA after making one or more changes in the input data and the expert system provides a choice if the user wants to store the results of the previous run to compare them with those of the new run. Such 'what-if' analyses are very useful for students to get a good feel of the process of feasibility analysis.

4. SUMMARY

This paper illustrated how an expert system can be developed using a simple shell like Exsys as a valuable teaching aid for introducing chemical engineering students to technoeconomic feasibility analysis. Consistent behaviour, not subject to human vagaries and impatience makes it an ideal tool for students to learn from it. Besides being able to process the knowledge, it serves as a very convenient storage of knowledge and expertise, which can continue to grow with time. Such potential exists in ostensibly every area in chemical engineering, and probably most other engineering

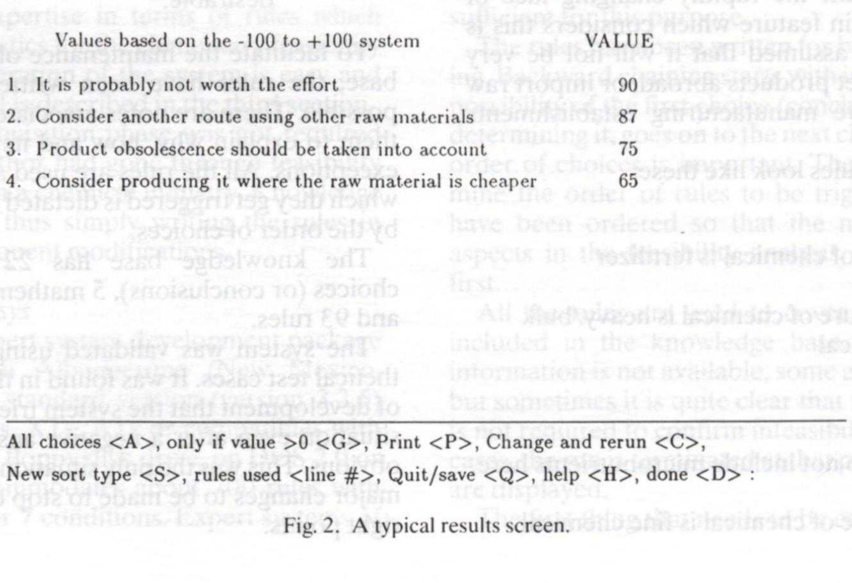


```
Raw material availability is

  1  not known
  2  insufficient
  3  sufficient

Enter number(s) of value(s), WHY for information on the rule,
<?> for more details, QUIT to save data entered or <H> for help :
```

Fig. 1. A typical run-time screen.



```
Values based on the -100 to +100 system                            VALUE

1. It is probably not worth the effort                               90
2. Consider another route using other raw materials                  87
3. Product obsolescence should be taken into account                 75
4. Consider producing it where the raw material is cheaper           65

All choices <A>, only if value >0 <G>, Print <P>, Change and rerun <C>,
New sort type <S>, rules used <line #>, Quit/save <Q>, help <H>, done <D> :
```

Fig. 2. A typical results screen.

fields. With input from engineers who have worked in industry, realistic and practical expert systems for teaching students can be built which would help bridge the gap between industry and academia, and better prepare students for their function in industrial environments. Further work in this area can be suggested.

This system can also serve as a predecessor for building a real expert system for technoeconomic feasibility analysis.

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