PRIMATES – AN EXPERT SYSTEM FOR SELECTING THE OPTIMAL HALL ASSEMBLY METHOD

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Summary: The production of prefabricated structures implies following certain regulations and applying certain work management in order for the process to proceed within the framework of the set requirements (deadline, costs, building and process quality). The application of inappropriate technology and management eliminates the advantages offered by prefabricated construction. Since the process is a complex one and is, from the mathematical point of view, poorly structured, the proposed solution for defining actual possible assembly methods, process flow and effect modeling, as well as selecting the optimal solution, is the application of an expert system as a comprehensive model. An expert system set in this way yields decisive information, essential to assembly management as a part of the construction process.
The paper gives an outline of the possibilities of the PRIMATES designed and tested expert system for the selection of the optimal method of concrete hall assembly.
***Key words:** modeling, expert system, assembly management, concrete assembly halls.*

The industrialization of construction and, as its part, the assembly of prefabricated construction elements, are achieved by designing adequate technical solutions for the building, applying and mastering modern technology, the thorough preparation, design and management of the assembly process. The application of inappropriate technology and management eliminates the advantages offered by prefabricated construction. It is necessary to select the optimal method of assembly, depending on the set requirements.

Apart from the loadbearing system (structure) of a building, elements of the other subsystems are also assembled, however, the accent is placed on the assembly of the structure of buildings where the elements are mainly dominant concerning size and weight, which gives them an important place in the decision about the method of assembly. When planning the management of the production of a prefabricated structure it is necessary to define the characteristics and the course of the process (technology, required machinery, work management), which will yield the specified effects attached to the deadline, costs and quality.

Production systems in the construction industry, just like the system of producing prefabricated concrete structures are complex, real, stochastic and dynamic, with many elements and connections between them. A number of factors have an influence on the functioning of such systems. The factors of influence are intrinsic and extrinsic and their effect on the system is either individual or combined.

Since it is necessary to offer project managers the necessary information for managing a project and making decisions in a zone of reduced risk, and also since these problem situations are poorly structured, a model which successfully presents and solves them was applied. The paper presents the PRIMATES expert system for the optimization of the assembly of concrete halls. The expert system includes experiences about possible methods of assembly (possible cases), corresponding models for presenting the course of assembly and calculating the effects, as well as a model for the selection of the optimal method of assembly.

1 The Assembly of the Concrete Structure of Halls

The presentation of the process, that is the course of the production process of prefabricated building structures is carried out through the assembly method. First of all, it is necessary to know the difference between assembly methods which are connected to the method of assembly of the structure as a whole and technological processes of assembling particular elements.

Possible assembly methods are defined, methods which were created: as a result of experiences acquired in the course of applying assembly methods and as a result of special research on possible assembly methods founded on the basic requirements for the production of prefabricated buildings.

In case we include into our consideration the actual production conditions of prefabricated structures, we get a limited number of truly possible assembly methods for a given constructive system, influence factors (intrinsic and extrinsic) will have different effects on the functioning of the system. By defining the functions of our goal and applying an appropriate model, it is possible to select the optimal method of assembly. The flow chart of the procedure of defining possible assembly methods and selecting the optimal one is displayed in Figure 1 and it represents the basis of the PRIMATES expert system.

This paper, as well as the PRIMATES expert system do not contain the production and transport stages of the prefabricated elements. Instead they contain the part about the method of assembly at the building site.

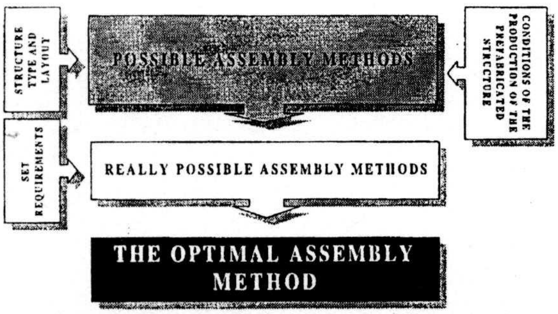

Fig. 1. The procedure of selecting the optimal assembly method

1.1 Possible and Actually Possible Hall Assembly Methods

Concrete assembly hall structures are classified into 14 types (Fig. 2), while the 10 (1,2,3,4,5,6,8,9,11,14) are included in the expert system. The prefabricated elements used in their assembly are further subdivided into 9 types, each type into classes, according to weight and size.

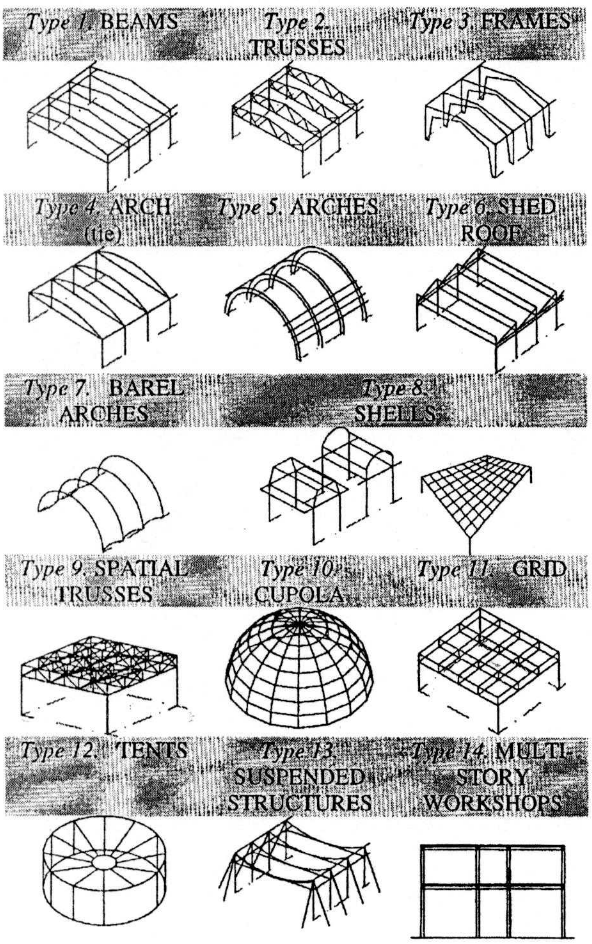

Fig. 2. Types of prefabricated hall structures

Possible assembly methods depend on the following:

- type of hall structure (Fig. 2),
- structure discreteness (type of prefabricated elements).

The composition of possible assembly methods refers to the following:

- type of crane (tower, mobile, hydraulic) and the number of cranes that can be employed,
- method of assembly depending on the order of assembly according to elements,
- the position of the crane relative to the building during assembly,
- assembly management method.

Before considering the method of assembly, possible methods of element production are defined and the optimal one is selected. On the basis of the selected production method of particular elements, the position of the element being assembled is defined according to the assembly plan. Possible radii of the crane during assembly are obtained on the basis of the assembly plan and the technology of assembly which is applicable to the given element.

The combination of possible assembly methods thus factorized defines possible assembly methods for each assembly hall type, that is a number of variations in the assembly method - placing the elements into the structure using certain cranes.

In the real conditions of an actual building site, a relatively small number of actually possible methods stands out of the group of possible assembly methods.

The actual characteristics of a hall, location and the specialization of the technological process, have a dominant influence on the selection of the actually possible assembly methods.

1.2 Modeling Possible Hall Assembly Methods

Possible methods of assembling particular elements and hall types represent an experience gathered from literature and experts in this field. In order to be able to use the gathered knowledge displayed in the tables, along with certain descriptive explanations, a model, that is a series of models in the form of algorithmic structures were adopted. A corresponding algorithm was formed for each possible assembly method, an algorithm which, apart from the assembly method, also contains conditions for its possible application under actual circumstances. A model of an assembly method for hall types 1, 2 and 4, compiled in such a way, is shown in Figure 3.

A set of common algorithm-models describing possible assembly methods was compiled for certain hall types which have the same assembly method.

Both the character of particular elements (C - constructive or F - Façade) and their position (D - down, U - up) were also taken into consideration within detailed algorithm-models of certain assembly methods for the purpose of a more detailed definition of the assembly method.

Along with the rest of the data defining the applicability of a certain method, each solution (possible assembly method) was also given the coefficient k_{kor} (Fig.3) which is included in the calculation of the quantitative indicator of the quality of the process. Each possible assembly method solution has within itself the elements of process quality, namely a value describing the process' degree of reliability. A prominent example of getting the picture of it is the fact that the following may appear in some solutions:

- cranes with a higher degree of capacity utilization represent the so-called heavy assembly, which has requires special attention (longer assembly time), they also represent an increased risk and a possibility of breakdown,
- a greater number of utilized cranes increases the possibility of system breakdown (systems with several sensitive elements).

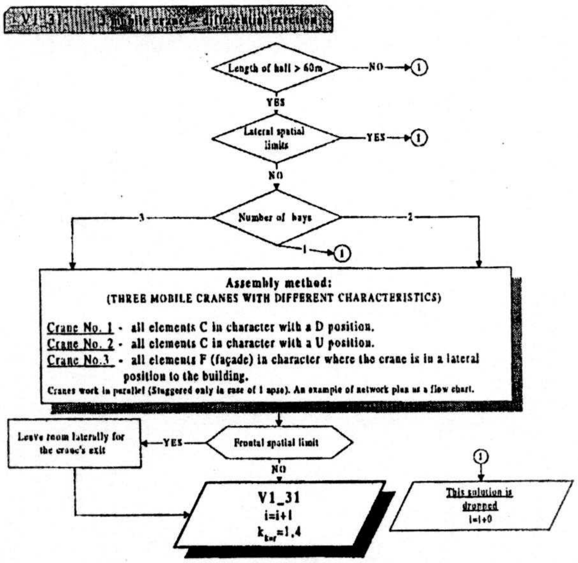

Fig. 3. The flow-chart of a possible hall assembly method for structure types 1, 2 and 4

The quantitative indicator of the process quality is defined as a dimensionless quotient for each variant:

$$\overline{K} = k_{kor} \cdot K$$

$k_{kor} \geq 1.0$ - correction quotient, depends on the variant of the assembly method;

K - depends on the crane selected for assembly;

$$K = \sum_{1}^{nn} \frac{\sum_{1}^{m} \mu_i}{m}$$

μ_i - utilization factor of the crane's carrying capacity for each element;

m - number of elements assembled using a single crane;

nn - number of cranes in a particular variant.

1.3 Optimal Assembly Methods

Based on the presented models and the definition of the actually possible assembly methods, the optimal one is selected among them taking the set requirements into consideration.

The set requirements represent a function of the goal which is defined through construction time, costs and building quality. Concrete requirements may refer to construction time or cost minimization or an optimal ratio between the two. An optimal assembly method is the one from the group of possible methods which meets the set requirements.

2 The PRIMATES Expert System

In the course of designing a building - hall, as well as the making of a project of construction technology and management, the application of the expert system defines possible assembly methods and an optimal one is selected. The expert system allows the selection of the optimal hall assembly method using mobile or tower cranes.

A selection of the optimal assembly method is made for the adopted production and transport methods of the prefabricated elements, and according to the hall's characteristics, working conditions at the building site and set requirements (minimal construction time or minimal costs or the optimal ratio of the two).

The structure of the PRIMATES expert system for the selection of the optimal concrete hall assembly method is displayed in the form of a flow chart in Figure 4.

The contents of the base of knowledge and the base of rules by parts is as follows:

The base of knowledge and the base of rules part 1. The direct base of knowledge and rules (data used by the ES) includes rules which determine possible cranes and their position relative to the building for the assembly of particular hall elements.

The base of knowledge and the base of rules part 2. The indirect base of knowledge (a user accessible database) which gives the user information and recommendations about which crane to select for the assembly of a particular building.

The base of knowledge and the base of rules part 3. This part of the base is direct by nature and includes rules for determining actually possible crane positions relative to the building, depending on the spatial limits around a particular building. For instance lateral spatial limits around a building eliminate lateral crane movement relative to the building during the assembly of particular elements whose character allows such a thing. This base was formed as a system of rules (of an IF...THEN type) which processes data on the limitations set by each element, thus filtering out only the possible crane positions for each element, relative to the building.

The base of knowledge and the base of rules part 4. This is a part of the base which is indirect by nature and which supplies the user with information on the production process, assembly plan and the determination of the assembly radius of a particular type of element. The base contains the following:

1. drawings and descriptions of possible crane positions during the assembly of a particular type of element,
2. drawings and descriptions of possible assembly devices for the assembly of a particular type of element.

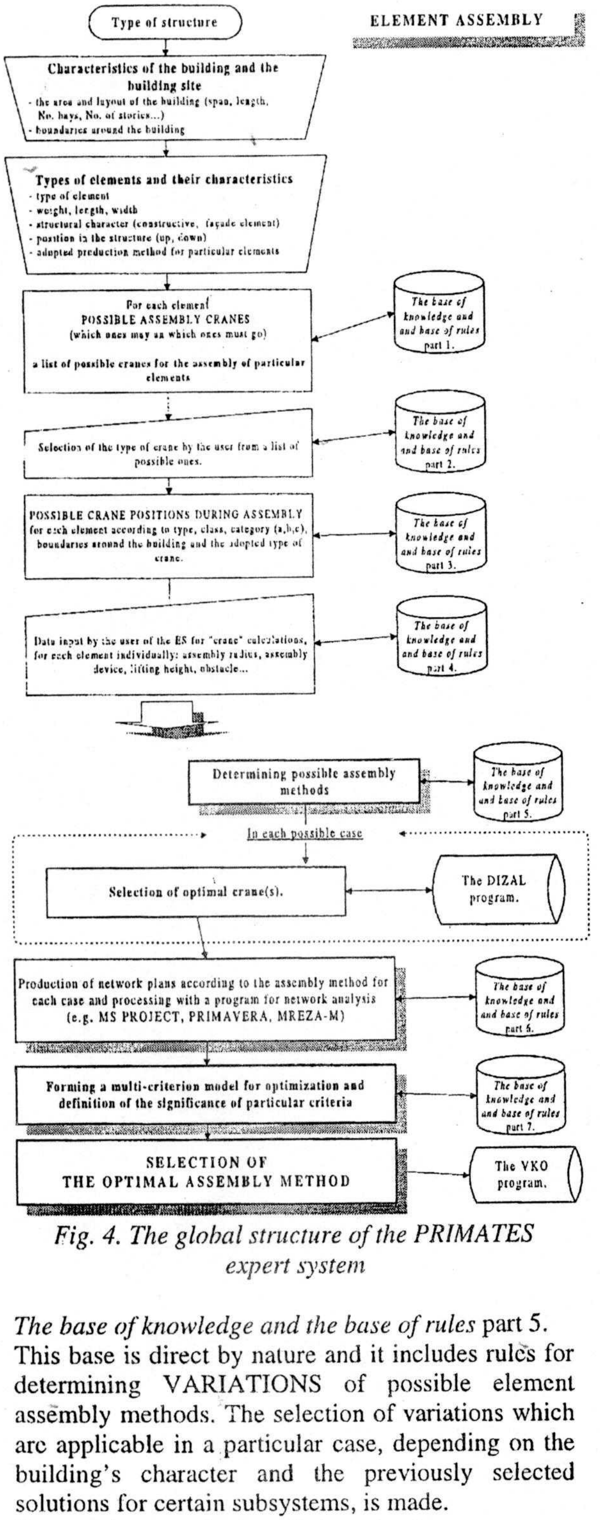

Fig. 4. The global structure of the PRIMATES expert system

The base of knowledge and the base of rules part 5.
This base is direct by nature and it includes rules for determining VARIATIONS of possible element assembly methods. The selection of variations which are applicable in a particular case, depending on the building's character and the previously selected solutions for certain subsystems, is made.
Due to the complexity of the selection process, as well as to different rules concerning different types of structures, such a base is built on the basis of previously compiled rule algorithms for every possible variation of the assembly method. The form of this base (algorithms) for the selection of hall assembly method variations is given in Fig. 3. Algorithmic rules for the selection of possible assembly methods are compiled on the basis of expert knowledge and literature data. Rules are set in such a way as to eliminate inferior solutions (variations which would be dropped later on as unsuitable anyway). The user is also left with the possibility to enter the contents of a new assembly solution, if he or she thinks it would be important for the analysis.
The base of knowledge and the base of rules part 6.
This part of the base is indirect by nature giving the user information on the modeling of the element assembly process using the network planning technique for different solutions:

- assembly with tower cranes,
- assembly with mobile cranes (one crane, two cranes, three cranes),
- combined use of tower and mobile cranes.

A special attention has to be given to the input of data on crane operating costs. Especially important are the running cost of mobile cranes in operation and their idle-time cost.
The base of knowledge and the base of rules part 7.
Another indirect-type base with information for the user about the method of a VKO model formation, from data acquired for each solution, as well as about the selected priority levels of particular criterion functions depending on the adopted decision strategy (selection of the optimal solution). The user is left with the choice between previously specified criteria (min. construction time, min. costs, optimal ratio between the two).

In order to complete all the required calculations and to select an optimal assembly method, computer programs have been written and methods compiled within operation research methods (Table 1).

Table 1. The authors' computer programs and their application (included in expert system)

Name of the program	Application of the program
DIZAL	The calculation of the minimum required characteristics of cranes (mobile, tower, hydraulic) for the assembly of elements individually or in a group and the selection of the optimal one among those available (a base of available cranes divided by types).
MREZA-M	Calculating the course and costs of element assembly at the building site using a network-planning model (critical path method), with a special part concerning a crane's idle-time cost
VKO	Making a ranked list for compromise programming and compromise ranking for set models of multi-criterion optimization

The PRIMATES expert system was written in the surroundings of the MS Visual Basic computer language. Since the ES was made in a Windows environment, communication with the user is achieved through frames for each stage of consulting the system. Data input is organized in three ways:

1. Selection among suggested solution (clicking the mouse button),
2. Using Input Boxes,

3. From previously formed files which may be modified according to the problem being solved.

Some of the input data, information (indirect knowledge base) and output data concerning the PRIMATES expert system, according to the course of consultation, are given in Table 2.

Table 2. Input and output data and information within the PRIMATES ES

Type*	Data
I	information on the ES and the type of data to be prepared
UE/OF	hall type, shape and size, spatial limits around the hall
UE/OF	prefabricated hall element types and characteristics
OE	possible crane types for the assembly of particular elements
UE/OF	selection of the crane type for assembly
OE/OF	possible directions of crane movement during the assembly of each element
I	information, rules and examples on the method of drawing an assembly chart
UE/OF	selected direction of crane movement during the assembly of each element
UE	data on elements required for the calculation and selection of cranes (from the assembly chart)
OE/OF	actual assembly methods (solutions)
OE/OF	data on the selected optimal cranes for every possible solution
I	directions for the preparation and processing of network plans for particular solutions
UE	choice of optimal criteria
UE	data from the network plan for every solution - construction time and costs
OE/OF	ranking list (solutions) of actual possible assembly methods for the adopted criterion

*Type of data: UF - input file data, UE - input data entered in the course of consultation, I - information from the ES, OF - output data for the files, OE - visual output data

The display layout for the expert system is shown in Fig. 5.

An example of the application of the PRIMATES expert system is displayed in figure 5. The example includes a twin-bay hall 81m long and 2x20.4 m wide. The area around the structure is flat and without boundaries. The elements can be manufactured in a factory 50 km away from the building site.

After entering the characteristics of the halls and assembly elements (10 types) four possible modes of assembly have been singled out. In each case the mobile cranes were calculated and selected, as well as the costs and deadlines. Based on the given model, it has been calculated that the optimal assembly method would require 2 different types of cranes, would last 22 days and would cost 44480.00 din.

The presented expert system, PRIMATES, has been tested on a number of occasions on building sites in Yugoslavia.

3 Conclusions

Assembly processes which belong, from the mathematical point of view, amongst the poorly structured problem situations are modeled by the use of expert systems. Certain operation research models may be applied for modeling certain parts of the process, and as such be incorporated in the global model - the expert system.

The application of a model outlined in this way allows the selection of the optimal assembly method which will yield the required effects during the design stage, and also the technology and management planning stage.

Thus set, the expert system allows the processing of various solutions concerning the adopted requirements (a function of criteria) for a particular type of structure, or the fast processing of solutions for different hall types.

The fact that expert systems do not make decisions, but give decisive information to the user, decision maker, has to be stressed above all.

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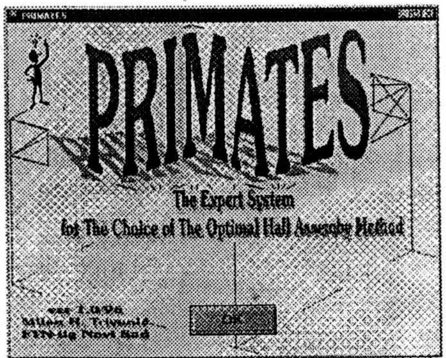

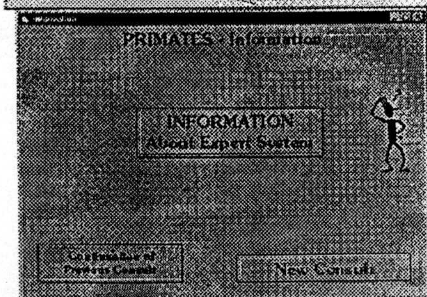

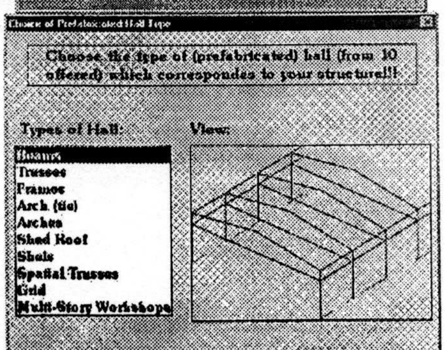

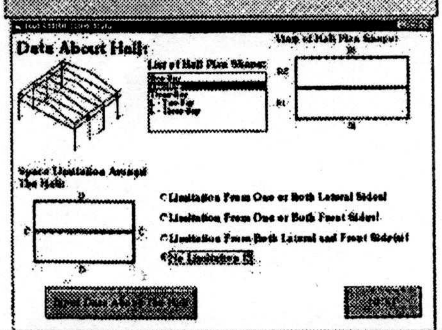

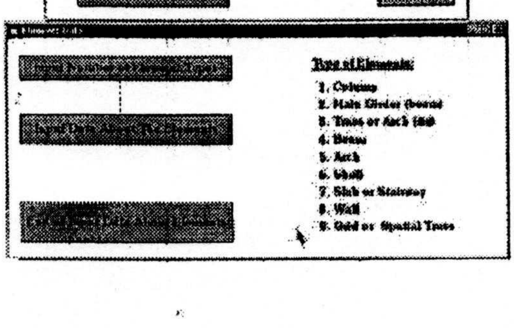

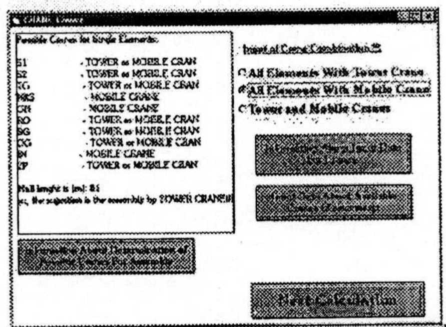

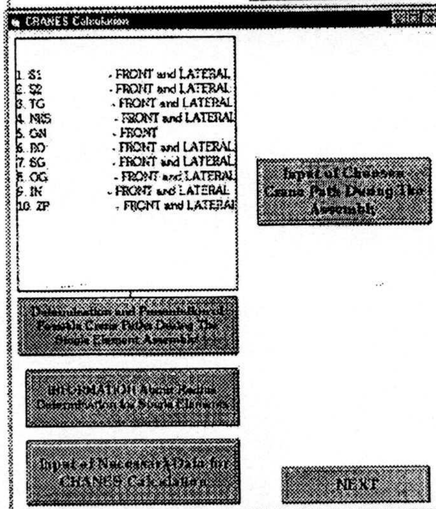

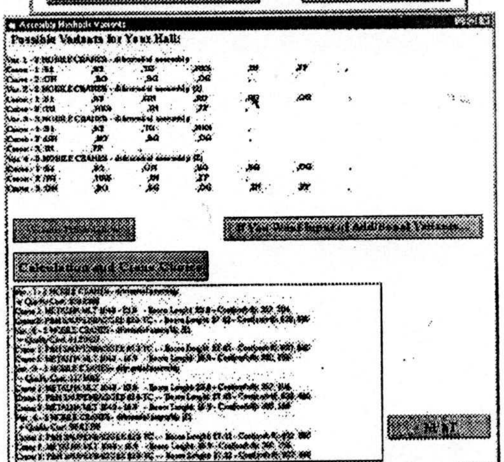

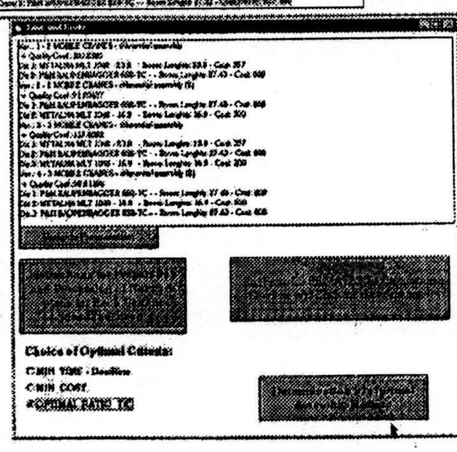

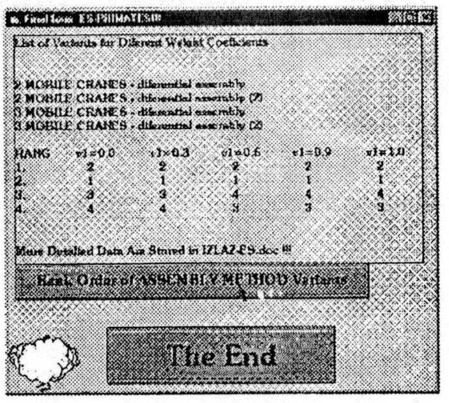

Fig 5. The expert system PRIMATES