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A decision-making module for aiding ship system automation design: A knowledge-based approach

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ABSTRACT

The use of elements of artificial intelligence, including knowledge-based systems, becomes more and more widespread in aiding design problem solutions. The authors have been working on problems of control systems for many years. A design process involves many decision problems connected with, for example, a choice of a subsystem structure, subunits or particular elements selection. Because of such regards, it was decided to extend knowledge-based system with a module for support of such decision making.

In this paper, an elaborated module for decision-making support is considered. The basic theoretical assumptions concerning the accepted method of multiattribute decision making based on pairwise comparison in categories of hierarchical decision process (AHP) is presented. Accepted knowledge representation in AHP method and pairwise comparison method and methods of expert knowledge acquisition are discussed. The module functioning is illustrated by an example of choice of temperature sensors in a system of fuel transport to Diesel engine of a main propulsion unit of a ship.

1. Introduction

The design of ship system automation belongs to poorly formalised tasks. Attempts are made to solve design issues with the use of artificial intelligence, especially expert systems (Arendt, 2004; Kowalski, Arendt, Meler-Kapcia, & Zieliński, 2001; Lee, 1997; Lee & Lee, 1999; Park & Storch, 2002).

The authors deal with problems connected with design of ship control systems (Arendt, 2004; Arendt & van Uden, 2005; Kowalski et al., 2001). Stages of preliminary design are considered encompassing bidding design and commission design and main design encompassing technical project.

The proposed database system (Kowalski et al., 2001) allows for

- Collecting input information on the ship being designed and devices selected for its engine room and placing the information in a database.
- Searching the database for existing designs in order to find the automation solutions, which are identical or similar.
- Choice of a solution based on an actual database of system automation and elements – the system informs the user of any existing solutions or lack of thereof,
- Calling a user (designer) for a decision in case of a lack of existing solutions or if variant (non-equivalent) solutions exist.
- Presentation on the screen (schematic, descriptive or indicative) of obtained partial solutions: for instance, solutions concerning individual objects or power-station subsystems, for the user to accept.
- Taking into account the requirements of a relevant classification societies and international conventions in the course of reasoning (looking for solutions).
- Generating output design documentation in the form of technical descriptions of automation: comparisons and other text documents, schematics and designs (graphical), and data (databases) to be used by other systems.
- Preparing data and leading simulation investigations into system automation that are being designed (Arendt, 2004).

In designing ship system automation, one encounters many decision problems connected, for example, with a choice of structure subsystem, subunits choice or individual elements choice. Because of these problems, we decided to extend knowledge-based system for a module, which helps to aid decision making during the design process.

There exist many decision models, which can be applied in design aid. Considering database system creation, we decided to apply an AHP method with pairwise comparisons because of the following features:

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- Simple knowledge acquisition.
- "Good knowledge representation" – fulfilling most postulates in this area (Niesenfeld, 1989; Reichgelt, 1991).
- Good substantiation of this model in psychological sciences.
- Existing verification of this decision model using known and measurable outputs.

In this paper, we present assumptions concerning knowledge representation and applied decision models, and applied algorithms. The functionality of the decision-making support module is demonstrated using an example of sensor selection in a fuel transport system in a ship main propulsion engines.

2. Multiattribute decision making based on pairwise comparison method in terms of AHP

The method of hierarchical decision process (analytic hierarchy process) was introduced by Saaty (1980). It consists in creating a decision table and weight vector based on pairwise comparison method. The ranking computation is carried out by a simple additive weight method.

The construction of a decision table relies on a finite number of variants (objects) ranked by pairwise comparisons according to a scale, $S = \{1/9, \ldots, 1/2, 1, 2, \ldots, 9\}$. To each pair of objects, an expert (decision maker) arbitrarily assigns a number from the set S. Assuming that there are n objects, $F_1, F_2, \ldots, F_n$, to each pair (F_i, F_j), $i, j = 1, \ldots, n$ assigned is a number $r_{ij} \in S$ according to subjective preferences of an expert (for instance Saaty, 1980). Then, the results are placed in a comparison matrix $\boldsymbol{R}$:

$$\mathbf{R} = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nn} \end{pmatrix}. \tag{1}$$

Saaty's idea relies on approximating the matrix $\boldsymbol{R}$ with the following matrix of quotients:

$$\mathbf{S} = \begin{pmatrix} \alpha_1/\alpha_1 & \alpha_1/\alpha_2 & \cdots & \alpha_1/\alpha_n \\ \alpha_2/\alpha_1 & \alpha_2/\alpha_2 & \cdots & \alpha_2/\alpha_n \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_n/\alpha_1 & \alpha_n/\alpha_2 & \cdots & \alpha_n/\alpha_n \end{pmatrix}. \tag{2}$$

In other words, a matrix $\boldsymbol{R}$, created by an expert, is a matrix with inconsistent estimates. Our goal is to find a matrix $\boldsymbol{S}$ with consistent estimates, which are presented in the form of quotients $s_{ij} = \alpha_i/\alpha_j,\ i,j = 1,2,\ldots,n$. By obtaining the matrix $\boldsymbol{S}$, we also obtain a vector associated with the considered problem as follows:

$$\mathbf{s} = (\alpha_1, \ldots, \alpha_n)^T. \tag{3}$$

Normalizing the vector $\boldsymbol{s}$ we obtain a vector:

$$\mathbf{s}^* = (\alpha_1^*, \ldots, \alpha_n^*)^T, \tag{4}$$

where

$$\alpha_i^* = \alpha_i \Big/ \sum_{i=1}^{n} \alpha_i, \quad i = 1, \ldots, n. \tag{5}$$

The vector $\boldsymbol{s}$ is, in this case, a vector of ordering of variants connected with a certain attribute (a column of decision matrix). In order to create the entire decision matrix, this procedure is repeated for all attributes.

In what follows, the asterisk, "*", is omitted, and the vector $\boldsymbol{s}$ is assumed to be normalized according to Eqs. (4) and (5).

In order to find a vector $\boldsymbol{s}$, three main methods are used: maximal eigenvalue method (Saaty, 1980; Saaty & Vargas, 1984), least squares method (Crowford & Williams, 1985; Saaty & Vargas, 1984) and logarithmic least squares method (Crowford & Williams, 1985; Saaty & Vargas, 1984).

Let us assume that in decision-making process considered, we have n objects: $F_1, F_2, \ldots, F_n$. Our task is to compare them according to m criteria $C_1, C_2, \ldots, C_m$. Our decision-making task can be decomposed into the following subproblems: Criteria ranking (creation of the weight vector) and alternative ranking for the criteria $i, j = 1, 2, \ldots, n$ (creation of the decision matrix). Moreover, assume that using the method described above we obtained the following, normalized vector of weights for criteria: $\mathbf{w} = (w_1, \ldots, w_n)^T$ and the following objects ranking solutions according to a criterion C_i, $i = 1, 2, \ldots, m$: $\mathbf{s}_i = (\alpha_{i1}, \ldots, \alpha_{in})^T$. Then, in AHP, we obtain the following global ranking by the use of simple additive method:

$$\alpha_i = \sum_{j=1}^{m} w_j \alpha_{ij}, \quad i = 1, 2, \ldots, n. \tag{6}$$

3. A module supporting design decision making

A module-supporting-design-related decision making in knowledge-based system for ship system automation was elaborated Kowalski et al. (2001). The performance of this module was tested on an example of decision-making problems concerning selection of temperature sensors in fuel transport system to Diesel engines of a ship's main propulsion. The structure of a module aiding automated choice of control elements for ship subsystems is shown in Fig. 1 (Arendt & van Uden, 2005).

The most important procedures realized by the module contain

- Searching the database for objects that meet given criteria.
- For the objects that have been found creating their pairwise comparisons matrices for expert knowledge acquisition.
- After introducing notes concerning these objects verifying their correctness.
- Writing verified data on the disc.
- Utilizing the knowledge accumulated by the user in the form of calculating ranking vectors and their aggregation according to accepted attributes.
- Generating reports.

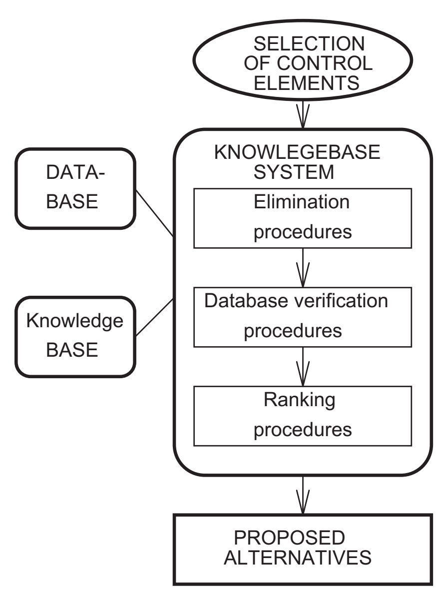

Fig. 1. Module structure in knowledge-based system for supporting decision making in a design process.