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The 'linguistic pattern' method for a workstation layout analysis

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The 'Linguistic Pattern' approach to the facilities and panels layout is presented. This approach is based on Zadeh's possibility theory and the Łukasiewicz multivalued implication formula. The idea of the approach is presented on the basis of a simple exemplary problem of an automobile display arrangement. The general idea of a computer algorithm is presented and some potential benefits of the proposed approach are discussed.

1. Introduction

In the review work of Karwowski and Evans (1986) the potential application of the fuzzy set theory concepts in studies on production engineering is discussed. One of the domains of this application distinguished by the authors concerns facilities planning, which includes problems of facilities layout design. The authors notice that many variables or relationships relevant to the models existing in the above problems 'are initially specified in an imprecise and vague manner and later these are simplified for ease of analysis in an attempt to eliminate or reduce fuzziness. For example, the distance between planned facilities may be expressed as being short, medium or long. In some instances, it may be even beneficial in a design process to develop and utilize such verbal descriptors of the distance magnitude, rather that using strict values as approximations for the desired magnitudes.' One possible 'fuzzy' approach which makes the above concepts operational is presented in the work of Grobelny (1987 a).

This paper presents, on the basis of cited works, formalization of the 'linguistic' approach to the problem of panel and workstation layout design. This problem, very important in ergonomics, seems to be especially suited to linguistic modelling.

In § 2, some basic concepts of fuzzy methodologies are given. An exemplary panel arrangement problem is presented in § 3.* On the basis of this problem the idea of a fuzzy representation of input data is explained. In § 4 a concept of linguistic pattern and restriction representation is introduced. Measures of the pattern fulfilment are exemplified in relation to an exemplary panel arrangement problem. Section 5 presents the general concept of a computer algorithm based on introduced ideas. The course of the algorithm is shown in relation to the exemplary problem. In the last section the problem of the predominance of the proposed approach over Richard Muther's AEIOUX scale and other related approaches in an ergonomic design is discussed.

2. Basic terms of the fuzzy set theory (Grobelny 1987)

The notion of the grade of membership constitutes the basic term introduced by Zadeh (1973). In the common theory of sets, a given object belongs or does not belong to a given set. In the two-valued logic a given term is classified as true or false. The

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introduction of the grade of membership makes it possible to widen both the notion of belonging to a set and the principles of classical logic. Intuitively, a fuzzy set can be understood as a class of objects in which there is no sharp boundary between objects belonging or not belonging to that class. Formally, if $X=\{x\}$ is a set of objects, then the fuzzy set A in X is said to have a membership function in which the range of the values is $[0,1]$, i.e.

$$A: X \to [0, 1] \tag{1}$$

whereas

$$A=\{A(x), x\} \quad \text{for all} \quad x \in X, \tag{2}$$

so eventually fuzzy set A is a set of ordered pairs of the form in eqn. (2). Function $A(x)$ determines the grade of membership (belonging) of an element x in the set A.

By analogy to the classical theory of sets, the notions of an intersection of fuzzy sets and a sum are introduced. Let A and B be fuzzy sets of the membership functions $A(x)$ and $B(x)$, respectively, then the sets $C=A\cap B$ and $D=A\cup B$ can be defined by means of their membership functions as follows:

$$C(x)=\min(A(x), B(x))\, \forall x \in X \tag{3}$$

$$D(x)=\sup(A(x), B(x))\, \forall x \in X \tag{4}$$

Fuzzy sets can provide a convenient tool to represent some simple linguistic variables concerning the levels and the intensity of certain features (Zadeh 1973, Karwowski and Evans 1986).

Equations (3) and (4) in the case of operating with sets representing linguistic variables are represented by the conjunctions 'and' and 'or'.

In the theory of fuzzy sets much attention is paid to the problems of the estimation of truth and procedures of inference (Zadeh 1978). The truth value of a given statement 'p' in respect to the criterion 'r' can be defined as 'consistency'. Let $p=$'A is F', $r=$'A is G', where A is the name of a variable, F and G denote fuzzy sets (determining the 'level of intensity' in the space X), then

$$\left.\begin{aligned} \text{Cons}(A \text{ is } F, A \text{ is } G) &= \text{POSS}(A \text{ is } F/A \text{ is } G) \\ &= \sup_{x\in X}(F(x) \wedge G(x)) \end{aligned}\right\} \tag{5}$$

where $\wedge$ denotes a minimum operator.

But POSS–possibility is the category introduced by Zadeh (1978), the numerical value of which is calculated from the last element of eqn. (5) and the intuitive interpretation of which, in the case under discussion, lies in the examination of the 'grade of closeness' of sets F and G, or the possibility that the variable A (which we know) equals G and at the same time is F (or if $A=F$ satisfies the critierion G).

The truthfulness of the implication $A\Rightarrow B$, denoted by $|A\Rightarrow B|$ (where $|A|$ means the grade of truth of the expression A, $|B|$ means the grade of truth of the expression B) is calculated from

$$|A\Rightarrow B| = \min(1, 1-|A|+|B|). \tag{6}$$

This fact corresponds to the definition of implication in the infinite valued logic by Łukasiewicz (Zadeh 1978).

3. The example problem and non-sharp values representation

The following simple example will illustrate the basis of our approach.

Example problem: automobile display

Given. A 10 × 20 cm panel. Locate four instruments in this panel. There must be a space of at least 1 cm between the instruments.

Instrument	Size (cm)	Restrictions
(1) Fuel level	2·5 diameter semicircle	Base must be horizontal
(2) Engine rev/min	1 × 4 rectangle	4 cm must be vertical
(3) Oil pressure	2·5 diameter semicircle	Base must be horizontal
(4) Speed	3 × 5 rectangle	5 cm must be horizontal. Should be at display centre.

Relationships

Components	1	2	3	4
1	—	D	E/2	D
2			C	A/1
3			—	D
4				—

Desired relationships	Reasons
A = very important to be close	1 = maximum frequency of looking
B = important to be close	2 = similar shape displays
C = closeness OK	
D = unimportant to be close	
E = keep apart	

It is easy to notice that in a problem so defined, requirements and features occur which are by nature 'non-sharp' or 'inexact'. First of all, they are closeness ratings A–E. The constraint concerned the space 'at least 1 cm' between instruments is also non-sharp. However, this 'non-sharpness' is reduced in the 'classical' approaches, for example giving numerical weights to the proper linguistic terms. The quality criterion of a given layout is usually a numerical function. Most often it is the sum of products of 'closeness ratings' multiplied by distance. Therefore a solution which minimizes this function is the best.

Sharing the opinions contained in the cited work of Karwowski and Evans (1986), we outline in the sequel based on the above example a certain approach to solving the problem discussed. The chief point of this approach is to make possible the numerical calculations—under the stipulation that there are non-sharp data and constraints – without the necessity of reducing the imprecision.

Generalizing the considerations concerning the above example we shall try to analyse the potential profits flowing from such an approach.

In the preceding section we have paid attention to the following fact: the fuzzy sets are proper instruments to represent non-sharp or inexact terms as well as the linguistic variables. Generally, one may say that the linguistic variable is one whose values are words or expressions similar to the natural language. The reader will find more details concerning this subject in the work of Zadeh (1973), for instance. In our example the relations between components undoubtedly have the character of a linguistic variable.

The linguistic scale itself (set of expressions) of closeness ratings is an unfortunate choice from the point of view of its semantic consistency. Wilhelm *et al.* (1985) noticed that in the set of A–E terms (similar to the 'traditional' schema of A, E, I, O. U, X) exists a peculiar mixture of terms concerning **importance** and **closeness**. To avoid misunderstanding and inconsistency the cited authors consider both categories as separate variables. Such an approach leads to complications in the scope of data gathering (a new category), and that is why we have decided to act differently here. On the analysis of the A–E expressions, it is easy to conclude that they concern the degree of mutual relationship within each pair of components. This relationship can be 'positive'—in this case it is advisable to obtain the maximum closeness of a given pair in the layout. The mark A ('very important to be close') ascribed to the pair 2–4 in our example expresses such a positive relationship. The relationship can also be 'negative'. In the example problem it is seen in the mark of the pair 1–3 with the help of closeness rate E ('keep apart'). The reasons why the relationships are evaluated as 'positive' or 'negative' have an ergonomic character. They are results of 'the rules of an ergonomic panel arrangement' discussed in detail, for example, in the work of Bonney and Williams (1977). Levels of relationships A–E between components of a display in our example are a result of applying the 'frequency of use' principle, together with consideration of 'separation of components for avoidance of mistakes'. The 'positive' A–D relationships are the consequence of the 'frequency of use' principle. The assessment 'keep apart' results from the use of the 'separation' rule. To avoid the semantic inconsistency of the A–E scale already mentioned, and at the same time to retain the possibility of expressing the 'positive' and 'negative' relationships between components, one may assume that the assessments of relationships are realizations of the linguistic variable called (for instance) LINK-VALUE. The realizations determine the level— positive or negative —of relationships between components. This level can be represented on the scale analogical to A–E, as PB 'positive big', PM–'positive medium', PS–'positive small', ZE–'zero', N–'negative'. One may also assume that both the character of expressions and their quantity are defined by experts.

Maybe in some cases the 'symmetrical' scale with specified 'negative' levels (NS–negative small, NM–negative medium, NB–negative big), by analogy to the 'positive' ones, will be a more adequate model of relationships. The applied expressions (independently of the method of constructing the scale) can be represented as the fuzzy sets in the appropriate spaces. The space of the linguistic variable LINK-VALUE representation (and consequently of the fuzzy sets representing realization of this variable, e.g. PB–'positive big', PS–'positive small') can, in general, be of two kinds. It can be a 'natural' physical space or an 'artificial' space—not related to any physical value. For our example of automobile display arrangement, the 'frequency of looking' space describing the rate of observations of a given pair of instruments in a total quantity of panel observations can form the 'natural' space for the positive LINK-VALUES representation.

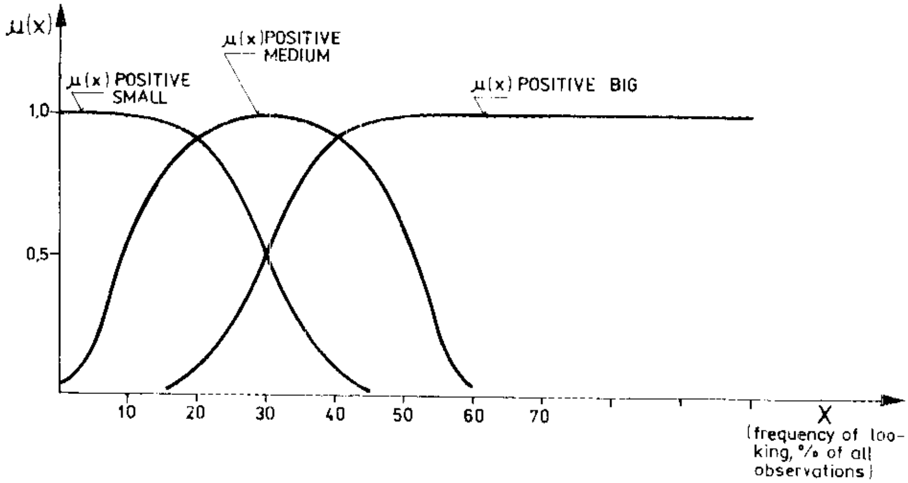


Figure 1. Examples of membership functions for linguistic expressions in the 'frequency of looking' space.

Such a space is physically measurable, It is possible by way of experiment to measure 'frequency of looking' for each pair of display components in standard cars; Fig. 1 shows membership functions representing a few typical linguistic expressions for the 'frequency of looking' level of any pair of instruments. The shapes of functions were chosen arbitrarily. In practice the shape of function should reflect experts' experience, knowledge and preferences referring to their way of interpreting the given linguistic expressions. Freksa (1982) has introduced methods of a statistical search for the membership function determination in such situations. Since it is a 'separate' problem in applying the fuzzy set methodology, it is not the subject of our interest here. However, it is worthwhile emphasizing the fundamental role of the above problems in exploring the practical use of the fuzzy set theory.

Let us assume that the membership functions from Fig. 1 represent the 'adjusted views' of a team of experts on the interpretation of expressions of the automobile display components relationships level. Let us assume as well that the frequency of looking from engine rev/min to speed (and vice versa) makes 40% of all the observations of display. This assumption can be understood twofold (see Zadeh 1973). Firstly, one may say that such a frequency belongs to the fuzzy set representing the POSITIVE BIG expression with the grade of 0·8; to the set representing POSITIVE MEDIUM with grade 0·8; and to the set POSITIVE SMALL with grade 0·1. Secondly, one may say that the degree of truth is 0·8 for the statement: 'the value of 40% is POSITIVE BIG', 0·9 for the statement 'the value of 40% is POSITIVE MEDIUM', and at the end, the degree of truth is 0·1 for the statement: 'the value of 40% is POSITIVE SMALL'.

Representation of linguistic expressions can also be made in 'artificial' spaces, that is, not related to any physical dimension, for example, numerical intervals. Such an approach permits the application of the fuzzy set theory for linguistically stated values which have no physical representations (unmeasurable) or are difficult to measure. It is easy to notice that in our example the relationship 'negative' (fuel level–oil pressure) has such a character. If the rule of 'similar components separation' is interpreted in details it may be stated as follows: 'components of similar shape should be kept apart in the arrangement'. The 'similarity of component shapes' itself is a vague variable. As a matter of fact a man in his everyday practice uses a degree of similarity expressed as 'very similar', 'more or less similar', 'dissimilar', etc., rather than a sharp division into two classes, similar dissimilar. According to our former assumptions we identify, in our example, the shape similarity with the negative link value. Figure 2 shows a membership function representing link value 'NEGATIVE' in the artificial space of representation. An interval of real numbers [0, 10] was taken as the universe of discourse. By analogy with Fig. 1, other possible expressions of the 'negative link value' level were introduced.

We must underline that separate elements like the [0, 10] interval (see Fig. 2) have no physical interpretation to correspond with the respective values from Fig. 1. As will be seen later, a space of representation such as on Fig. 2 is useful because it allows one to make numerical calculations for the fuzzy values. (To be sure in our case the space Y in Fig. 2 can be interpreted as a 'degree of similarity' of both components, if it is assumed that a man is able to use such a scale to compare objects. However, it is not necessary.)

Up to now we have shown how the basic input data from our example can be interpreted in fuzzy set categories. General evaluation of panel components arrangement depends on their natural spatial relationships, i.e. on the distance between each pair of concrete elements, precisely, whether they are FAR or NOT TOO FAR or maybe they are ADJACENT. The above qualifications are fuzzy in their nature. They can be presented as appropriate fuzzy sets in the space of distance or in a certain artificial space.

Assuming that the distance between two instruments in our panel is the Cartesian (straight-line) distance between their closest points, measured in centimetres, it is possible to define the basic linguistic qualifications of distance as in Fig. 3. If any pair of components is placed at a distance of 6 cm, one may say that this distance belongs to the VERY SMALL—the set with a grade of 0·5—and to MEDIUM—the set with grade 0·8. One may also say that the degree of truth of a statement: '6 cm is a VERY SMALL distance' is 0·5 and for '6 cm is a MEDIUM distance' is 0·8. Additionally, we have introduced (see Table 1) definitions of expressions (from Figs 1–3) in the form of discrete numerical dependences, because it will be easier to use discrete variables in

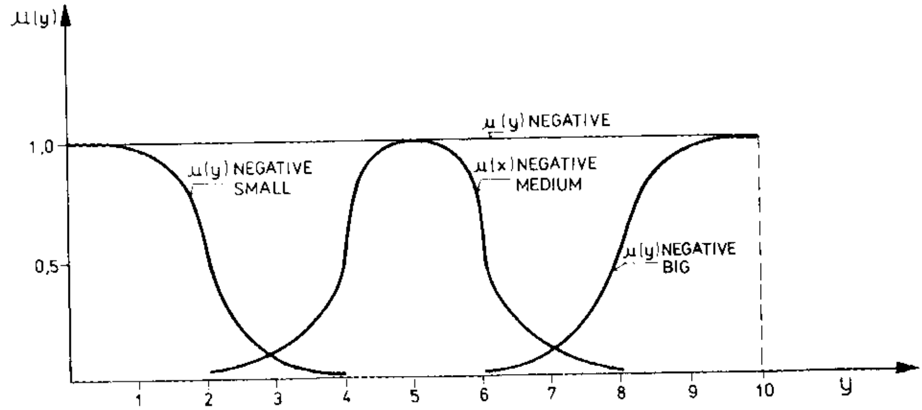


Figure 2. Examples of membership functions for some expressions in a 'negative', artificial space.

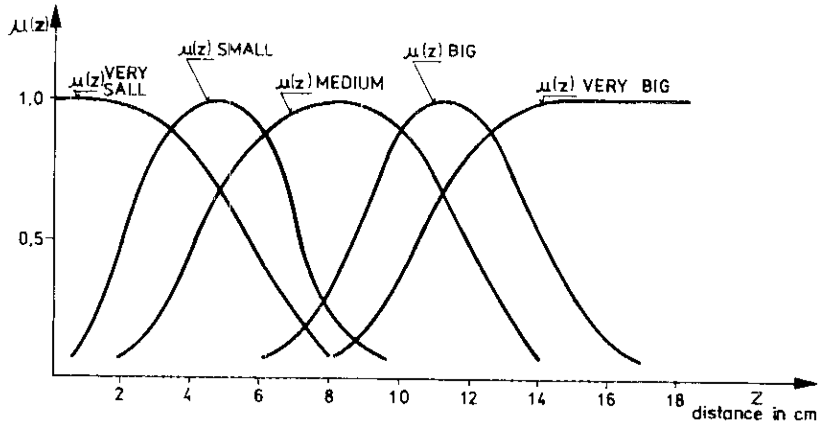


Figure 3. Membership functions of exemplary expressions in 'distance' space.

calculations. That way we managed to project the basic non-sharp variables describing our design problem. The fuzzy sets make the form of this projection. In the sequel we shall propose how to take advantage of this type of description to evaluate the quality of a display arrangement without reduction of fuzziness.

4. Linguistic pattern and restrictions

Rational requirements concerning the proper layout of our panel might be put as follows. 'Taking into consideration restrictions, the components should be displaced in such a way as to allow the instruments of strong "positive" relationships to be as close to each other as possible. The instruments of the "negative" relationships should be placed as far from each other as possible.'

x–frequency of looking (%) y–artificial space z distance (cm)	0 0 0	10 1 2	20 2 4	30 3 6	40 4 8	50 5 10	60 6 12	70 7 14	80 8 16	90 9 18	100 10 20
$\mu(x)_{\text{positive small}}$	1·0	0·9	0·8	0·5	0·1	0·0	0·0	0·0	0·0	0·0	0·0
$\mu(x)_{\text{positive medium}}$	0·1	0·5	0·8	1·0	0·8	0·5	0·1	0·0	0·0	0·0	0·0
$\mu(x)_{\text{positive big}}$	0·0	0·0	0·1	0·5	0·8	0·9	1·0	1·0	1·0	1·0	1·0
$\mu(x)_{\text{zero, not positive}}$	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
$\mu(y)_{\text{negative}}$	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0	1·0
$\mu(y)_{\text{negative small}}$	1·0	1·0	0·5	0·1	0·0	0·0	0·0	0·0	0·0	0·0	0·0
$\mu(y)_{\text{negative medium}}$	0·0	0·0	0·1	0·3	0·5	1·0	0·5	0·3	0·1	0·0	0·0
$\mu(y)_{\text{negative big}}$	0·0	0·0	0·0	0·0	0·0	0·0	0·1	0·3	0·5	1·0	1·0
$\mu(y)_{\text{not negative (zero)}}$	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0
$\mu(z)_{\text{very small}}$	1·0	1·0	0·8	0·5	0·1	0·0	0·0	0·0	0·0	0·0	0·0
$\mu(z)_{\text{small}}$	0·1	0·5	1·0	1·0	0·5	0·1	0·0	0·0	0·0	0·0	0·0
$\mu(z)_{\text{medium}}$	0·0	0·1	0·5	0·8	1·0	0·8	0·5	0·1	0·0	0·0	0·0
$\mu(z)_{\text{big}}$	0·0	0·0	0·0	0·1	0·5	1·0	1·0	0·5	0·1	0·0	0·0
$\mu(z)_{\text{very big}}$	0·0	0·0	0·0	0·0	0·1	0·5	0·8	1·0	1·0	1·0	1·0

Table 1. Numerical values of membership functions for Figs 1–3.

A small modification of the above statement will allow us to obtain sentences we call 'linguistic patterns'. These sentences will enable numerical evaluation of any arrangement by comparing this arrangement with the 'patterns'. If L means a linguistic variable—'Link value', and D a variable—'Distance'—we can put 'rational layout requirements' as follows.

(1) If 'Link value for a given pair of components (ij) is positive bit 'THEN' the distance between them is very small.'
(2) If 'Link value for a given pair of components (ij) is negative 'THEN' the distance between them is very big.'
(3) All restrictions are fulfilled

Or in a shorter form:

(1) If 'L_{ij} = positive big' THEN 'D_{ij} = very small';
(2) If 'L_{ij} = negative' THEN 'D_{ij} = very big';
(3) all restrictions are fulfilled.

To use the 'linguistic patterns' means to evaluate a 'truth value' which shows how a given arrangement fulfils those 'patterns'. It can be done according to formulas given in Section 2 (possibility measure calculation (5), truth value in multivalued implication formula (6)). To make it easy to understand the idea of this procedure we shall refer again to our example of automobile display. First of all, we shall write down relationships of link values in the categories defined by us as fuzzy ones.

Components		2	3	4
$L_{ij} =$	1	ZERO	NEGATIVE	ZERO
	2	—	POSITIVE SMALL	POSITIVE BIG
	3	—	—	ZERO

Redefined relationships (link values) for the automobile display arrangement

According to these expressions we shall evaluate the exemplary display shown in Fig. 4. First of all, we check the degree of 'truth value' of the pattern 1 requirements fulfilment. First of all, for each pair of instruments we verify (a) to what a grade its link value (relationship) fulfils left-hand side expression of the pattern i.e. 'L_{ij} = positive big'; (b) to what a grade the distance between components fulfils right-hand-side expression of the pattern, i.e. 'D_{ij} = very small' and (c) to what grade pair ij fulfils the requirements of pattern 1. For both cases (a) and (b) we use as a measure POSSIBILITY (5) and for case (c) Łukasiewicz's formula (6).

Let us consider a pair of instruments 1–2: fuel level, engine rev/min.

We find in the matrix of redefined link values: L_{12} = ZERO, according to formula (5) we calculate now $|A|$ = POSS (L_{12} is POSITIVE BIG) = POSS (ZERO is POSITIVE BIG) = $\sup_{x \in X}(\mu(x)_{\text{ZERO}} \wedge \mu(x)_{\text{POSITIVE BIG}}) = \max\{(0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}1), (0{\cdot}0 \wedge 0{\cdot}5), (0{\cdot}0 \wedge 0{\cdot}8), (0{\cdot}0 \wedge 0{\cdot}9), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0)\} = 0{\cdot}0$. Of course, the succeeding values of the function $\mu(x)_{\text{ZERO}}$ and $\mu(x)_{\text{POSITIVE BIG}}$ we have taken from Table 1. The results obtained above can be interpreted as follows. The 'truth value' for the statement 'ZERO is POSITIVE BIG' is 0 or—'the consistency of the expressions ZERO and POSITIVE BIG (under the definitions as on Figs. 1–3 and on Table 1) is 0.

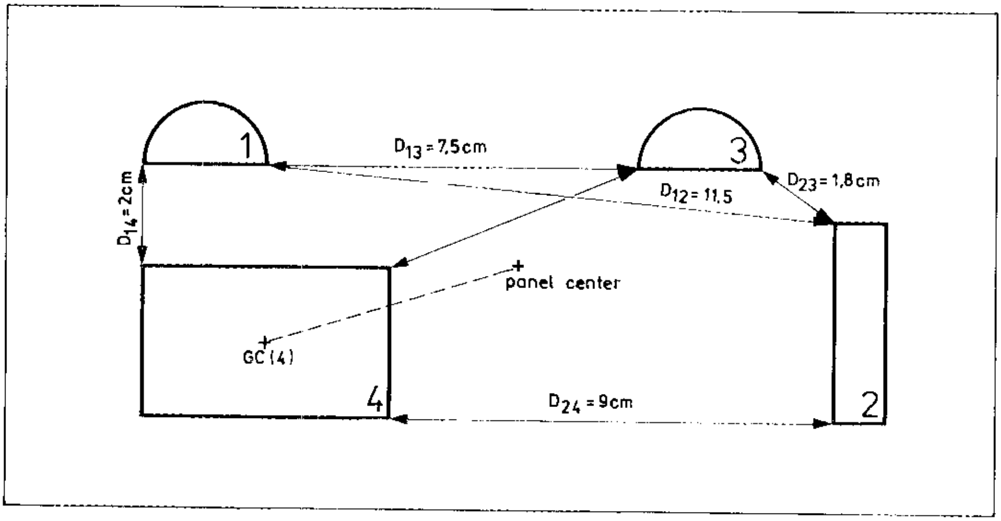


Figure 4. An exemplary layout of the display.

For the above instruments (1–2) we evaluate the truthfulness of the right-hand side of the 'pattern' 1 in a similar way (with the help of Fig. 4). According to the 'pattern 1' we must answer to what a grade a distance between fuel level (1) and engine rev (min/2) is 'very small'.

Using formula (5) we can calculate: $|B| = \mathrm{POSS}(D_{12} = \mathrm{VERY\ SMALL}) = \mathrm{POSS}(11{\cdot}3\,\mathrm{cm} = \mathrm{VERY\ SMALL}) = \max_z\{\mu(z)_{11\cdot5\,\mathrm{cm}} \wedge \mu(z)_{\mathrm{VERY\ SMALL}}\} = \max\{(0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}8), (1{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}0)\} = 0{\cdot}0$.

Interpretation of this result is, of course, similar to the previous result connected with the left-hand side.

The way of defining the membership function for the numerical value of distance, i.e. 11·5 cm needs some comment. The above value, in our calculations (and in the whole approach) is treated as a singleton, i.e. a fuzzy set with the value of the membership function equal only 1 in this, definite point and zero beyond this point. Because of the calculations on discrete spaces (see table 1), we have taken the nearest point of discrete space (i.e. 12) as a representation of a precise measurement of 11·5. (For the equal distances from points of the discrete space we will take the left one.)

Since the 'truth values' obtained so far concern the levels of the left- and right-hand sides of pattern 1 requirements fulfilment by a pair 1–2 in the arrangement given in Fig. 4 therefore, using formula (6), it is possible now to estimate the level of fulfilment of requirements formulated by this pattern as a whole. Using (6) we can write:

$$Q^1_{12} = \min(1,\ 1 - 0 + 0) = 1.$$

This result can be interpreted as follows: the pair of components 1–2 in the exemplary layout (Fig. 4) fulfils the requirements of pattern 1 completely. In other words, the truth value of the pattern 1 requirements fulfilment by pair 1–2 (in the exemplary arrangement) is 1. This result accords with an intuition and it was easy to foresee. It is intuitively obvious that the degree of link ZERO attached to pairs 1 and 2 (see redefined relationships) means that in general it does not matter in what kind of mutual configuration these elements are in the arrangement. The same results will be obtained for the pairs 1 4 and 3–4, which in the redefined relationships matrix receive values ZERO.

The remaining pairs will be appraised in a similar way. Let us take into account the pair 2–4. According to the described procedure we receive:

$$|A| = \text{POSS } (L_{24} = \text{POSITIVE BIG}) = \text{POSS } (\text{POSITIVE BIG is POSITIVE BIG})$$

$$= \max_x \{\mu(x)_{\text{POSITIVE BIG}} \wedge \mu(x)_{\text{POSITIVE BIG}}\} = 1{\cdot}0$$

$$|B| = \text{POSS } (D_{24} = \text{VERY SMALL}) = \text{POSS } (9\,\text{cm} = \text{VERY SMALL})$$

$$= \max_z \{\mu(z)_{9\,\text{cm}} \wedge \mu(z)_{\text{VERY SMALL}}\} = 0{\cdot}1$$

and finally:

$$Q^1_{24} = \min (1,\ 1 - 1 + 0{\cdot}1) = 0{\cdot}1.$$

(8 cm was taken (see Table 1) as an approximate measure of 9 cm).

This result can be interpreted as follows: the degree of pattern 1 requirement fulfilment by pair 2–4 (in the arrangement from Fig. 4) is 0·1.

A similar approach will allow us to calculate the magnitudes of Q^1_{ij} coefficient for remaining instrument pairs. Finally we receive:

$$Q^1_{12} = 1$$

$$Q^1_{13} = 1$$

$$Q^1_{14} = 1$$

$$Q^1_{23} = 1$$

$$Q^1_{24} = 0{\cdot}1$$

$$Q^1_{34} = 1$$

Because a link value for components 1–3 is 'negative' and it is not interpreted as a fuzzy set in space x (frequency of looking) to calculate Q^1_{13} we have used a set NOT POSITIVE (Table 1) as a logical representation of the expression NEGATIVE in space X.

Now we have the problem of how to estimate the degree of pattern 1 requirement fulfilment by the whole arrangement from Fig. 4. According to the idea of Łukasiewicz, formula magnitudes of Q^1_{ij} shows the degrees of truth of the fulfilment of these requirements by each pair of instruments, so it will be reasonable to calculate a 'mean degree of truth' for the whole arrangement. This 'mean truth degree' reflects the 'fitting' of the arrangement to the requirements of the pattern. If Q stands for the truth degree we can calculate:

$$Q^1 = \tfrac{1}{6} \sum_{\substack{i,j \\ i>j}} Q^1_{ij} = \frac{5{\cdot}1}{6} = 0{\cdot}85$$

The above result means that the arrangement introduced in Fig. 4 fulfils the requirements of pattern 1 with the mean truth value $= 0{\cdot}85$.

In a similar way it is possible to calculate the fitting of our exemplary arrangement to requirements defined by pattern (2). Because only one pair of components in our example has received 'negative' link value (1–3) therefore, the remaining pairs can be represented, in the space 'negative link values' by the expression 'not negative'.

That is why it is enough to make calculations for pair 1–3. The remaining entirely fulfil (with degree 1) pattern (2). At first we calculate the truth values of requirement fulfilment for left- and right-hand sides of pattern 2 by pair 1–3:

$$|A| = \text{POSS (NEGATIVE} = \text{NEGATIVE)} = 1$$

$$|B| = \text{POSS } (\text{D}_{13} = \text{VERY BIG}) = \text{POSS } (7{\cdot}5\,\text{cm} = \text{VERY BIG})$$

$$= \max_z \{\mu(z)_{7\cdot 5\,cm} \wedge \mu(z)_{\text{VERY SMALL}}\}$$

$$= \max \{(0{\cdot}0 \wedge 0{\cdot}0),\ (0{\cdot}0 \wedge 0{\cdot}0),\ (0{\cdot}0 \wedge 0{\cdot}0),\ (0{\cdot}0 \wedge 0{\cdot}0),\ (1{\cdot}0 \wedge 0{\cdot}1),\ (0{\cdot}0 \wedge 0{\cdot}5), (0{\cdot}0 \wedge 0{\cdot}8), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0)\} = 0{\cdot}1$$

And then the truth value for pattern 2 fulfilment will be the following:

$$Q_{13}^2 = \min\,(1,\ 1 - 1 + 0{\cdot}1) = 0{\cdot}1$$

But the general appraisal of the arrangement in respect of pattern 2 will be identical with the appraisal of Q^1, i.e. $Q^2 = 0{\cdot}85$.

We emphasize here that both values of Q_{ij}^1 and Q_i^2 depend on the way of defining the membership function (see Figs. 1–3, Table 1).

Let us for example assume that we have interpreted the expression VERY BIG from Table 1 in a quite different manner. Let the membership function of this expression be as follows.

z (cm)	0	2	4	6	8	10	12	14	16	18	20
$\mu(z)_{\text{VERY BIG}}$	0·0	0·0	0·0	0·1	0·5	0·9	1·0	1·0	1·0	1·0	1·0

A consequence of such a change will be another value of $Q_{13}^2 = \min(1, 1 - 1 + 0{\cdot}5) = 0{\cdot}5$. Of course, the value of the general coefficient Q^2 will also be different.

Taking into consideration both criteria jointly (i.e. in regard of fulfilment of both patterns) we shall give the evaluation of the arrangement in Fig. 4 by a calculation of the mean $Q = (Q_1^1 + Q_1^2)/2$. For our data $Q = 0{\cdot}85$ (of course, without regard to the change of definition of expression VERY BIG).

Restrictions are the third element of the arrangement evaluation. In our example of the automobile panel there are the following restrictions:

(*a*) The bases of components 1 and 2 must be horizontal, 3 cm for the component 4, and 4 cm for the component 2 should be vertical.
(*b*) Speed (component 4) should be at the display centre.
(*c*) There must be a space of at least 1 cm between instruments.

In consideration of restriction fulfilment, the arrangement evaluation can be treated in two ways. Firstly, one can accept as permissible only those solutions which fulfil all the restrictions. Under this assumption our exemplary arrangement in Fig. 4 is not permissible (instrument 4 is not in the centre of a panel). Secondly, the restrictions can be treated just as criteria, and then a proper degree of restriction fulfilment can be calculated. Such an index can be constructed in the general case, similarly to Q^1 and Q^2. Restrictions can also be treated as specific linguistic patterns. It can be particularly

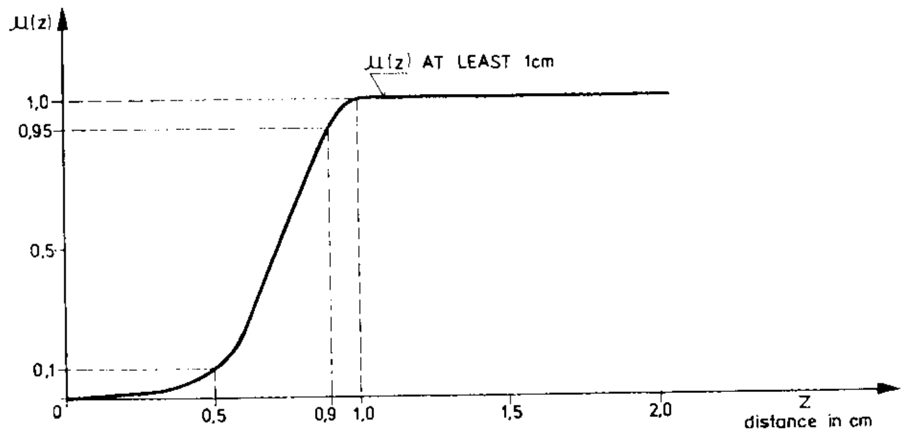


Figure 5. The restriction 'at least 1 cm' in the form of membership function.

convenient for restrictions of a vague character. In our example restriction (*c*) can be treated as a vague one. It would have been unreasonable, for instance, to classify the 9·9 mm distance as not fulfilling the 'at least 1 cm' condition, but distance 1 cm as a distance fulfilling this condition, unless this restriction is for technological reasons and it is not physically possible to set up the instruments at a shorter distance. If we take into consideration only the ergonomic requirements regarding spatial separation of instruments it seems to be reasonable to show the 'at least 1 cm' expression as a fuzzy set in the space of a distance as it is shown in Fig. 5. So it can be possible to say, for example, about the distance of the 0·9 cm that it fulfils the 'at least 1 cm restriction' to 0·95 of a degree and the distance of 0·5 cm to 0·1 of a degree.

The 'linguistic pattern' satisfying restriction (*c*) can have the following shape:

$$c' \quad D_{ij} = \text{'at least 1 cm'}$$

The fulfilment degree of this requirement can be calculated as

$$Q_{ij}^{3} = \text{POSS}\ (D_{ij} = \text{at least 1 cm}) = \max_{z} \left\{ \mu(z) \wedge \underset{D_{ij}\ \text{at least 1 cm}}{\mu(z)} \right\}$$

and if D_{ij} is a precise measure of a distance in cm, (5) reduces itself to a value of the function from Fig. 5 for the measured distance, i.e.

$$Q_{ij}^{c'} = \underset{\text{at least 1 cm}}{\mu(z)} \quad \text{for} \quad z = D_{ij}\,(\text{in cm}).$$

It is worthwhile emphasizing that (*c*′) in contradistinction to patterns (1) and (2) is an unconditional clause, and it concerns equally each pair of instruments. It is easy to check that in Fig. 4 all pairs of components fulfil requirement (*c*′) to degree = 1.

In a similar way one may treat restriction (*b*). If there is no obstacle of a technological nature the conception of a 'display centre' can be represented as a fuzzy set defined for a distance from a gravity centre of component 4 (speed) to the panel centre, e.g. as in Fig. 6. According to this idea, instrument 4, being at a distance of 1 cm (more precisely, having the gravity centre at a distance of 1 cm) from the centre fulfils

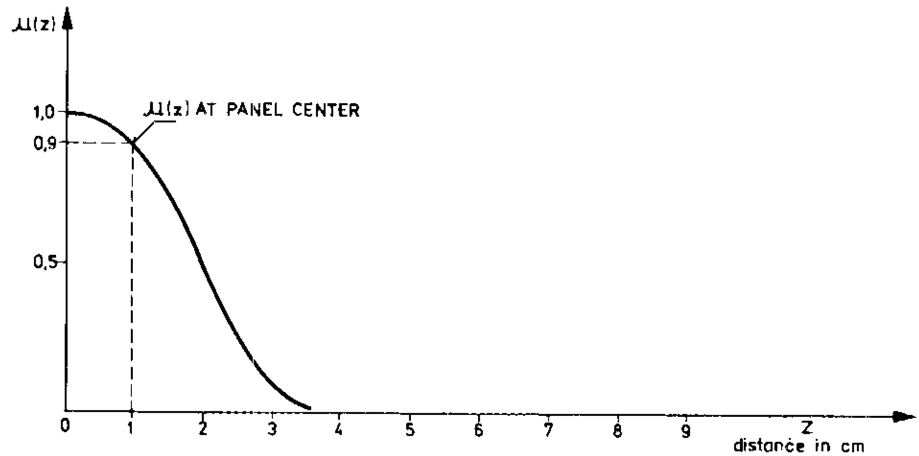


Figure 6. The restriction 'at a panel centre' as a fuzzy set (membership function).

the requirement AT A PANEL CENTRE to 0·9 of a degree. Restriction (b) can have a shape of the following pattern:

$$b' \qquad G-C(4)=\text{'at a panel centre'}$$

$G-C(4)$ means a distance of the gravity centre of speed (4) from a panel centre.

Truth evaluation according to (b') can be done only for instrument (4). The way of appraisal is identical with the above defined for pattern (c'). And so:

$$Q_4^{b'} = \text{POSS } (G-C(4)=\text{at a panel centre}) = \underset{\text{at a p.c.}}{\mu(z)} \quad \text{for } z=G-C(4) \text{ (in cm).}$$

It is worthwhile emphasizing that pattern (b') is a result of using the importance principle to search for the best layout. In many practical cases (Wierwille (1980)) this principle is understood as a requirement to lay out the main devices (from the point of view of the process realized on the work-stand) in the panel centre or in general in the most 'convenient' place. It is necessary to emphasize that the 'importance' of a device (being a vague expression) is not usually connected with the links between devices (devices strongly linked with each other do not have to be important and vice versa). Pattern (b') can be 'extended' for our example so as to represent the importance principle for all the instruments.

The shape of such a generalized pattern can be as follows: b'') IF '$I(i)$ = very big' THEN '$G-C$ (i) = at a panel centre' where $I(i)$ is the degree of ith instrument importance.

Because the 'importance' is not an operationally defined value the membership functions of proper expressions can be defined in the artificial space (like the negative link values in Fig. 2).

The truth values of pattern b'' fulfilment can be calculated in two stages using formulas (5) and (6), in a similar way to one described before for patterns (1) and (2). Apart from the way of defining the expression $I(i)$ for our example, it will be essential to calculate the truth value for speed (4) to fulfil b''. Assuming that $I(4)$ = 'very big' and $G-C$ (4) = 5·6 cm (Fig. 4) we shall receive $Q_4^6 = \min(1, 1-1+0) = 0$ because $|A| = 1$ and POSS (very big is very big) = 1;

$$|B| = 0 \quad \text{because} \quad \underset{\text{at a p.c.}}{\mu(5{\cdot}6)} = 0 \quad \text{(from Fig. 6).}$$

The restrictions (*a*) concerning the orientation of certain sides of instruments have a precise character in our case. One may also expect that there are situations where the orientation can be represented by a fuzzy membership function, for example in the space of declination angles from the horizontal line. Certainly, the reader is now able to define 'reasonable' membership functions for the variable orientation, stated for example as a 'vertical or horizontal' one on the base of the previously discussed examples.

As to what concerns our example and the solution from Fig. 4, we shall assume that instrument orientations different from those on Fig. 4 nullify the solution, and that the 'horizontal' and 'vertical' orientations are exact (non-fuzzy).

In such a formulation restriction (*a*) is not treated as a pattern. The arrangement in Fig. 4 is nevertheless permissible in regard to these restrictions. The truth values according to the patterns (1), (2), (c') and (b') are as follows:

$$Q^1 = 0{\cdot}85, \quad Q^2 = 0{\cdot}85, \quad Q^{c'} = 1, \quad Q^{b'} = 0.$$

The general truth value of the solution from the point of view of all the patterns can be treated in the most simple case as a mean degree of truth per pattern. Then:

$$Q = \frac{Q^1 + Q^2 + Q^{c'} + Q^{b'}}{4} = 0{\cdot}675$$

This result means that the arrangement in Fig. 4 is 'fitted' to patterns $1, 2, c', b'$ to the degree of 0·675; *or* the truth value for the fact that our solution fulfils the requirements of these patterns is 0·675.

5. Problems of optimalization and an algorithmic approach

The proposals introduced allow us to estimate a given arrangement in regard to pattern requirements and restrictions. It is obvious that a permissible arrangement, for which the general index $Q = 1$ is the optimum arrangement, fulfils the pattern requirements to degree 1. But it is less obvious to know how to find such an arrangement. Algorithms enabling searching for sub-optimum and optimum solutions of this problem in an 'automatic' manner, with the help of a computer, were introduced in the works of Grobelny (1987 a, b). Construction-type algorithms were proposed, based on the ideas of the classical approaches of Hiller and Connors (1966) and of Gavett and Plyter (1966). Unfortunately, the 'automation' of the search of solutions forces us to set a finite number of permissible, fixed locations. This means artificial restriction of the real situation of a designer, who usually solves problems similar to our task of automobile panel arrangement. The complicated character of this type of task, and the practically unlimited quantity of possible locations for each instrument tend to require the use of computers rather as a kind of 'assistants' aiding the designer than as automats to optimize solutions. The results of Scriabin and Vergin's research (1976), which prove that this kind of task can be solved as well by a man as by computer algorithms, give an additional argument for such an approach. The only condition is to receive information about the effects of his work by a man. It seems that ideas introduced in this work can serve to build such computer-aided methods for a panel arrangement design. In this kind of method, the computer ought to be a tool to calculate and to represent the graphic project, while the man should take the final location decisions on the basis of computer information. The idea of this is realized by the visual-based methods (Bonney and Williams (1977)) but the linguistic patterns give a chance to formulate requirements and restrictions in a very flexible and individual way.

In addition, the 'truth value' categories allows us to put into practice the idea of a given arrangement distance from the 'absolute solution' ($Q=1$) assessment. According to the research of Trybus and Hopkins (1980) it is very important to know the possible 'absolute' when finding an optimal layout, indeed, it is one of the crucial factors in achieving good results by designers.

One can imagine a number of different realizations of computer systems performing processes of an arrangement based on the above considerations and on the presented idea of 'linguistic patterns'. We shall introduce now a general outline of one of such possibilities. The course of this approach can be treated as a certain kind of result flowing from the 'maximal truth theorem' proved in the work of Grobely (1987 a). This approach has got a character of 'constructive'-type method.

To make it easy, let us assume that we use three criteria in the form of 'linguistic patterns':

(*a*) IF 'L_{ij} = positive big' THEN 'D_{ij} = very small'

(*b*) IF 'L_{ij} = negative' THEN 'D_{ij} = very big'

(*c*) IF '$I_{(i)}$ = very big' THEN '$GC(i)$ = at a panel centre'

As is easy to see, they are criteria 1 and 2 and the restriction b''. The remaining restrictions we shall treat as 'sharp' non-fuzzy ones, which when not fulfilled, disqualify a given project. The cited 'maximal truth theorem' states that in the set of statements 'IF A_i THEN B_i' type the maximal truth value $Q=1/n\sum_{i=1}^{n}Q_i$ [where $Q_i=\min(1, 1-|A_i|+|B_i|)$] is achieved when statements are construed in such a way that $\forall_i|A_i|>|A_{i+1}|$ and $\forall_i|B_i|>|B_{i+1}|$. In other words—left-hand sides and right-hand sides of statements are in decreasing order according to their truth values.

In this situation, the following approach will be reasonable.

(1) Calculate truth values of the patterns (a), (b) left-hand sides fulfilment for all instrument pairs ($i,j=1,2,n$) ($j>i$). For all i calculate truth values of the pattern (*c*) left-hand side fulfilment. Put calculated truth values into the matrices A_{ij} B_{ij} and into the vector C_i.

(2) Calculate for all i,j $(i<j)G_{ij}^1=A_{ij}+C_i+C_j$ and for all the k,l $(k,l=1,2,\ldots,n)$ $G_{kl}^2=B_{kl}+C_k+C_l$. If $\max_{i,j}(G_{ij}^1)>\max_{k,l}(G_{kl}^2)$, choose a pair ij of a maximum G_{ij}^1, otherwise k, l of max G_{kl}^2

(3) (*a*) If i,j were chosen, put this pair as close to each other as possible and in such a way as to maximize the truth value of the criterion C fulfilment and to keep the restrictions.

(*b*) If k, l were chosen, put this pair as far from each other as possible so as to maximize the truth value of the criterion c fulfilment and to keep the restrictions.

(4) For the set of all instruments not laid out: ($p,q\in N$)

$$G_p^1=\sum_{\substack{p\in N\\ s\in L\\ s>p}}A_{ps}+\sum_{\substack{p\in N\\ s\in L\\ s<p}}A_{sp}+C_p$$

and

$$G_q^2=\sum_{\substack{q\in N\\ s\in L\\ s>q}}B_{qs}+\sum_{\substack{q\in N\\ s\in L\\ s<q}}B_{sq}+C_q,$$

where N = a set of not arranged instruments, L = a set of arranged instruments.

If $\max_p(G_p^1) > \max_q(G_q^2)$ choose the element p for which G_p^1 is maximum, otherwise choose q, maximizing G_q^2.

(5) (*a*) If p was chosen, find a place for this element adjacent to already located elements. It is necessary for the general truth value of patterns (a), (b) and (c) fulfilment (a mean truth) for all the arranged elements together with p to be as high as possible 'if necessary, displace the instruments that are already in place).

(*b*) If q was chosen find a place far away from already located elements, similar to the previous (5 (*a*)) step.

(6) If all the instruments are located that is the end, else go to (4).

It is clear that for bigger tasks the realization of such an algorithm will require a computer. However, it cannot act 'automatically'. Steps (3) and (4) need active participation of a designer and his decisions in regard to the final instrument location. Yet our proposal does not mean that it is impossible to create 'automatic' algorithms. If one divides the whole space of location into certain equal modules (so as to enable the biggest instrument to be contained in the module), it is possible to adopt the classical methods to search for the optimum or sub-optimum solutions. As we have said before, the introduction of a modular net is a considerable restriction, and modern methods and algorithms usually avoid such an approach.

To make the idea of the introduced outline of an 'algorithm' more clear we use it to search for a solution of our automobile display problem. We shall of course use data from the matrix L_{ij} of redefined relationships and the fuzzy sets interpretation from Table 1.

Additionally, we assume that $I_{(i)}$ = 'very big' for $i=4$ (speed) and $I_{(i)}$ = 'ZERO' for $i \neq 4$ in regard to the form of linguistic pattern (*c*).

In our first step we shall calculate values of matrices A_{ij}, B_{ij} and vector C_i elements. Let us for example calculate the A_{23} element. Because A_{23} is the truth value of the pattern (*a*) left-side fulfilment by the expression L_{23} from matrix L_{ij}, by using definitions from Table 1 we can calculate:

$$A_{23} = \text{POSS (POSITIVE SMALL is POSITIVE BIG)}$$

$$= \max\{\mu(x)_{\text{POSITIVE SMALL}} \wedge \mu(x)_{\text{POSITIVE BIG}}\} = \max\{(1{\cdot}0 \wedge 0{\cdot}0), (0{\cdot}9 \wedge 0{\cdot}0),$$

$$(0{\cdot}8 \wedge 0{\cdot}1), (0{\cdot}5 \wedge 0{\cdot}5), (0{\cdot}1 \wedge 0{\cdot}8), (0{\cdot}0 \wedge 0{\cdot}9), (0{\cdot}0 \wedge 1{\cdot}0),$$
$$(0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 1{\cdot}0), (0{\cdot}0 \wedge 0{\cdot}1), (0{\cdot}0 \wedge 0{\cdot}1)\} = 0{\cdot}5$$

The final A_{ij} matrix is:

$$A_{ij} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 2 & 3 & 4 \end{array} \\ \begin{bmatrix} 0 & 0 & 0 \\ & 0{\cdot}5 & 1 \\ & & 0 \end{bmatrix} \end{array}$$

Analogically, replacing expressions other than 'negative' by 'not negative' we receive:

$$B_{ij} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array} \begin{array}{c} \begin{array}{ccc} 2 & 3 & 4 \end{array} \\ \begin{bmatrix} 0 & 1 & 0 \\ & 0 & 0 \\ & & 0 \end{bmatrix} \end{array}$$

and

$$\begin{matrix} & 1 & 2 & 3 & 4 \\ I_i = & [0 & 0 & 0 & 1] \end{matrix}$$

In step 2 we calculate G_{ij}^1 and G_{kl}^2 values. For example: $G_{24}^1 = A_{24} + C_2 + C_4 = 1 + 0 + 1 = 2$. The final G appraisals are as follows:

$$G^1 = \begin{bmatrix} 0 & 0 & 1 \\ & 0{\cdot}5 & 2, \\ & & 1 \end{bmatrix} G^2 = \begin{bmatrix} 0 & 1 & 1 \\ & 0 & 1 \\ & & 1 \end{bmatrix}$$

Because $\max G^1 > \max G^2$ we choose for location pair G_{24}.

According to step 3 (*a*) we shall try to locate the chosen pair of elements on the project plane. Both instruments ought to be placed as close to each other as possible. At the same time we maximize the truth of patterns (*A*), (*B*) (*C*) fulfilment. In a simple case of computer algorithm implementation a computer-aided lay-out designmay consist in 'displacement' of models of objects on the monitor screen. The computer 'gives' at any time the truth value of patterns (*A*), (*B*), (*C*) fulfilment and it 'verifies' restriction fulfilment.

The computer may also calculate and indicate the direction of displacement which gives the highest rise of general truth value of pattern fulfilment for each step.

It is quite easy for our simple example to make here such an analysis 'by hand' and to find the arrangement for pair 2–4, which fulfils the assumed criteria to degree 1·0. Taking into account our definitions of fuzzy expressions (Table 1) it can be an arrangement shown in Fig. 7 (*a*).

According to step (4), we receive:

$$G_1^1 = A_{12} + A_{14} + C_1 = 0 + 0 + 0 = 0$$

$$G_3^1 = A_{34} + A_{23} + C_3 = 0 + 0{\cdot}5 + 0 = 0{\cdot}5$$

$$G_1^2 = B_{12} + B_{14} + C_1 = 0 + 0 + '' = 0$$

$$G_3^1 = B_{34} + B_{23} + C_3 = 0 + 0 + 0 = 0$$

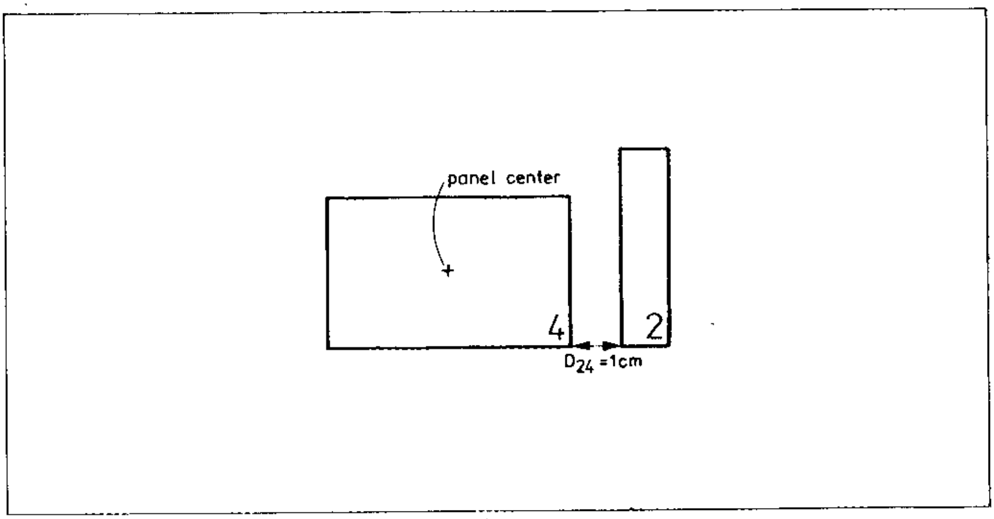
We take element 3 and we place it 'near' the 2 4 (according to 5 (*a*)), e.g. as in Fig. 7 (*b*).

The reader can easily check that the partial arrangement from Fig. 6 (*b*) fulfils criteria (A), (B) and (C) to the degree 1 (under the condition of acceptation definitions of fuzzy sets given in Table 1). Because one element is left we go back to step (4) and we reckon:

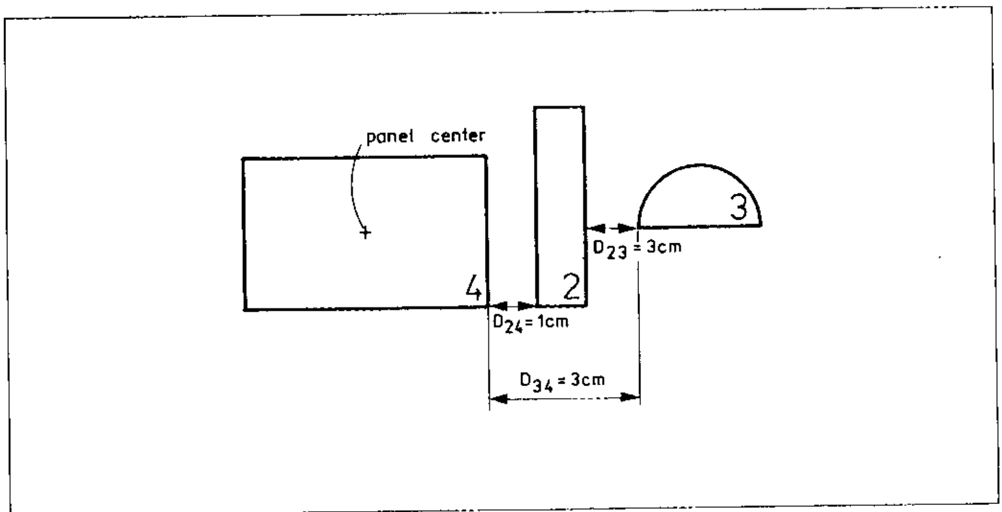
$$G_1^1 = A_{12} + A_{13} + A_{14} + C_1 = 0$$

$$G_1^2 = B_{12} + B_{13} + B_{14} + C_1 = 1$$

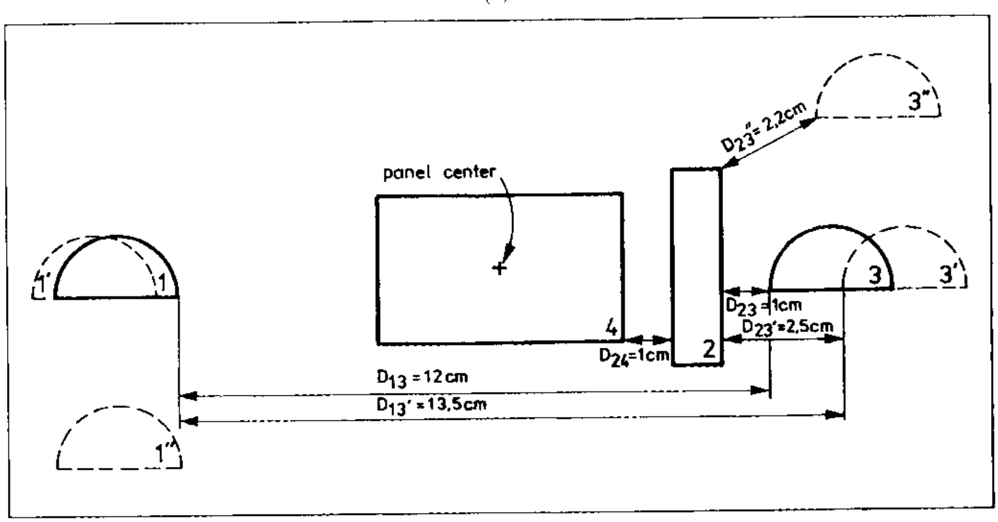
As $G_1^2 > G_1^1$ we place element 1 according to step 5 (*b*) 'far away' from already located elements. Figure 7 (*c*) shows such possible placements of instrument 1. Unfortunately, on the base of distance definition from Table 1, the distance between elements 1 and 3 does not allow us to obtain 'complete fitting' of such an arrangement to the requirements of patterns (*A*), (*B*) and (*C*). On the base of input data the computer should here 'prompt' the direction of instrument 1 displacement, which enables us to improve the general 'fitting degree' (truth of pattern fulfilment). It is easy to find that there are



(a)



(b)



(c)

Figure 7. (*a*) The possible arrangement of the panel after the first three steps of the algorithm. (*b*) The panel arrangement after first pass of the algorithm. (*c*) Some possible 'optimal' arrangements (comments in text).

many possibilities in this scope. Figure 7 (*c*) shows for example a few possible optimum (according to our definitions) arrangements of the pair 1–3 (dashed lines). It can be arrangements containing 1′–3′, 1″–3″ but also 1″–3′ and 1′–3″.

It is proper to add here that to obtain these solutions it is necessary to enclose in the computer program possibilities of displacing elements located before. The possibility of indicating optimum directions of displacement for each element in every stage of the projects process (step 5 of the algorithm) would have been desirable.

6. Final remarks

Any new approach or algorithm in the fields of industrial engineering or ergonomics induces the following question: what is the advantage of a new approach over the methods existing in a given field? One could treat the established Muther's scale as an existing 'classical' model of a fuzzy data representation. To prove the predominance of the Linguistic Pattern method over Muther-type propositions, one should use both methods in a variety of practical situations and compare the results. However, some theoretical, potential premises, testifying to an advantage of the fuzzy approach in ergonomic problems, can be induced from our considerations in previous sections.

Here are the most important.

(1) The use of categories of logical truth gives additional information about the distance of any given solution from the 'fully true' solution (i.e. from a certain 'absolute'). In the Muther-type numerical approaches, only relative comparison of two arrangements is possible. As was shown in the work of Trybus and Hopkins (1980), it is very important for a designer to know such a 'best' solution when solving a layout problem.

(2) One can show simply that our Linguistic Pattern approach is more general than the classical numerical representations in the sense that the ABCDE scale from our example can be treated as a special case of possible fuzzy representations of input data. The fuzzy representation of this data enables us to use the sharp intervals as models of this scale. This corresponds with a numerical representation in classical approaches.

(3) The fuzzy representation of linguistic expressions enables us to model the experts' knowledge about ergonomic requirements. For example, concerning the model of an expression 'AT LEAST 1 cm' (Fig. 5) one can easily notice that a membership function in such a case can be estimated from empirical experiments searching for the relation linking minimal distance between instruments and errors in task performance by a man. 'Classical' conventions enable only the 'sharp' representation of such the requirement (i.e. they define a sharp boundary, 1 cm in our example, between values which fulfil or do not fulfil this requirement), which is usually not the case with ergonomic data.

(4) A general form of a linguistic pattern allows for flexible formulation of the given model criteria and requirements in a way close to the linguistic description of a situation. This may be of particular importance while constructing interactive computer models for ergonomic workstation layout design. Freksa (1982) has shown experimentally that, in general, it is more convenient for a man to use inaccurate, linguistic terms rather then precise, numerical values – because the 'cognitive distance' between natural principles of the brain-work and non-sharp notions is (probably) smaller than in the case of numerical quantities.

There are also a list of problems which should be resolved when using a fuzzy-type approach in actual situations. The most important seems to be a way of fuzzy representation of the expert's knowledge. In spite of practical research in this field (for example Freksa (1982), Karwowski and Mital (1986)), commonly accepted standards of collection of the required data and construction of a fuzzy representation of the linguistic variables do not exist. Perhaps these standards are 'context-dependent'. In such a situation intensive and multidirectional studies are required to find such standards for specific ergonomic fields. Fortunately, in some of them such studies were undertaken (Karwowski and Mital (1986)).

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L'approche 'Modèle linguistique' à la disposition des installations et des panneaux est présentée. Cette approche se fonde sur la théorie des possibilitiés de Zadeh et sur la formule d'implication à valuer multiple de Łukasiewicz. Le concept de cette approche est présenté sur la base d'un simple problème représentatif de la disposition d'une présentation automobile. Le concept gèngéral d'un algirithme informatisé est présenté et l'article examine quelques uns des avantages éventuels de l'approche présentée.

Es wird eine Methode vorgestellt, die Anordnung von Anlangen und Bedienungsfeldern auf Grund von 'linguistischen Mustern' zu entwerfen. Diese Methode stützt sich auf die Möglichkeitstheorie von Zadeh und auf die mehrwertige Implikationsformel von Łukasiewicz. Der Grundgedanke der Methode wird anhand eines Beispielproblems vorgestellt, das die Anordnung eines Kraftfahrzeug-Armaturenbretts behandelt. Ferner wird das Konzept eines Rechner-Algorithmus vorgestellt, und schließlich werden einige potentielle Vorteile der vorgeschlagenen Methode besprochen.