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## ASSESSMENT OF FENCE SYSTEMS USING FUZZY MODELING

*The article deals with the use of fuzzy modeling for time estimate of wire fence systems resistance. The resulting time can be used then in quantitative analytical methods for assessing the effectiveness of a technical protection system. The values of the fence system time resistance are very difficult to detect. Neither the technical standards give an exhaustive answer to questions related to time resistance of mechanical barriers. Some experiments were carried out with the aim to determine the time required for penetration of the selected wire fence obstacles. On the basis of the experiment results fuzzy rules were designed allowing, in conjunction with a suitable software tool, precise estimation of the wire fence barriers time resistance.*

**Keywords:** Fuzzy modeling, fence system, resistance, perimeter protection.

### 1. Technical standard requirements for breaching resistance of mechanical barriers

Currently, there are not comprehensively defined times regarding the breach of mechanical barriers for all categories of tools. For example, the standard for opening fillings (EN 1627), such as windows, doors, grilles or shutters, does not state the resistance time corresponding to the categories of all tools, but only for some of them. The standard designed for safety storage units (EN 1143-1) uses more complex approach where the time of breach resistance of appropriate security class is dependent on the intended use of tools, and thus it can be calculated for many tools categories. In the case of breakthrough time of security plastic film and security glazing the standards do not specify time units, but only the number of hits with different instruments to which a relevant passive element should resist (e.g. EN 356). In the case of building constructions by the means of perimeter protection no technical standard defines their breakthrough resistance [1].

It cannot be determined, on the basis of technical standards, their breach resistance expressed in time units. It follows that for many passive protection elements can only verify / certify their conformity of these elements properties. It is, therefore, necessary to search for new ways how to acquire these resistance time data in practice.

### 2. Description and results of the experiment measuring the breach resistance of wire fence systems

The company F.S.C. BEZPECNOSTNI PORADENSTVI, a.s. in cooperation with the University of Zilina implemented the project "Methodology for physical protection assessment of critical infrastructure elements against terrorist attack and other types of attacks" in the period 2012-2013. The project was financially supported by the Programme Prevention, preparedness and consequence management of terrorism and other security related risks of the European Commission - DG freedom, justice and security.

One of the project objectives was to develop a methodology for testing barriers which were installed at the perimeter and to answer the question concerning the attacker's delay during the breach of a wire fence system made from interlocking or welding of individual structural wires. It makes sense to deal with the breach resistance only in the case if the surrounding measures represent for a potential attacker a larger obstacle than the penetration fence.

Proposed structure of the groups and tools selection into each group was inspired by the technical standard [2]. The choice of instruments was selected from the catalogue of tools [3] which contained 83 pieces of tools. When selecting the typical representatives of tools, the following issues were monitored: availability, method of operation, noise generated by their use, aggressive action, the possibility of further use when the attacker approaches the target. Selected instruments were categorized into 5 groups. The final list of instruments is given in Table 1 [4].

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Overview of the tools in groups before tests performing

Table 1

| Group | Group Identification   | Tool                |                     |                 |
|-------|------------------------|---------------------|---------------------|-----------------|
| 1     | Manpower               | Crowbar             | Rock                | Manpower        |
| 2     | Mechanical tools       | Handsaw             | Pliers              | Hammer          |
| 3     | Lever mechanical tools | Lever shears        | Car jack (screw)    | Clamp           |
| 4     | Cordless power tools   | Cordless grinder    | Cordless saw        | Cordless shears |
| 5     | Electric or gas tools  | Handheld gas burner | 230 V grinder 125mm | 230 V - jigsaw  |

Four types of fencing were tested. Fence component can be described by the strength of the used wire and the area of netting mesh. The aim of the tests for the test engineer was to make the hole for crawling through the fence component which was set up in accordance with the technical standards for the opening fillings [2], see Table 2. The test engineers, working on the tests, were well experienced in fencing systems testing and they had experience in the use of given tools.

Description of the holes for crawling through Table 2

|            | Rectangle   | Ellipse   |
|------------|---|---|
| Shape      |  |  |
| Dimensions | 400 mm ± 2 mm x 250 mm  | 400 mm ± 2 mm x 300 mm  |

For the methodology verification 60 breakthrough resistance tests were carried out. It means that 15 selected tools were used for all 4 types of fencing. The overview of fence characteristics is given in Table 3. Fence components were produced from galvanized steel wire.

Used tools had different effectiveness on the tested samples. The measured values, therefore, do not lie exactly on the straight line. For the estimation of searched dependence parameters linear regression analysis was used. The course of time resistance of fence depending on the tools used and the values of the regression analysis are shown in Fig. 1.

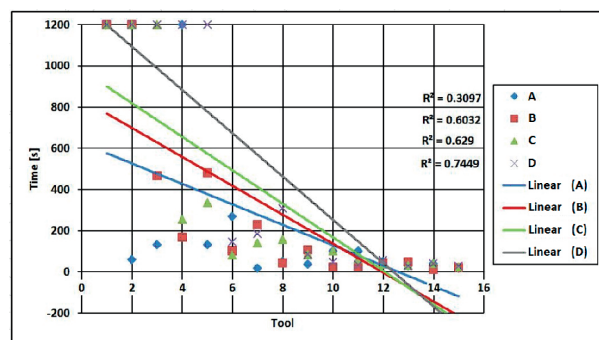


Fig. 1 Linear regression analysis of time resistance depending on verified samples on the used tool

The results proved that decision to divide tools into five groups was correct. Tools groups were modified according to the test results. Negative symptom was the noise made by some tool, which limited the possibilities of its use for fence breach.

The methodology evaluation and results were discussed with the chairman of the technical committee CEN / TC388 perimeter protection. The chairman of the technical commission accepted the proposal for a methodology as a working paper which the technical committee would deal with.

The classification of tools into groups was adjusted on the basis of test results. Tools were arranged in descending order by the sum of times of the breach resistance of the tested fence components and they were assigned with a coefficient according to interrelations (1)

$$c_i = 5000 - \sum(A_r, B_r, C_r, D_r). \tag{1}$$

The value of tool coefficient is a dimensionless number where  $(A_r, B_r, C_r, D_r)$  are values for time resistance of tool dependence in test samples and  $i$  is the tool serial number.

### 3. Proposal for the assessment of fencing systems using fuzzy modeling

For the determination of the breach resistance of similar mechanical barriers in a non-destructive manner it is appropriate to create a model. The breach resistance of a fence component can be described as a socio-technical system created by man - by a tool - by a mechanical barrier. The influence of the external environment is not taken into consideration in the model, whereas the experimental tests were carried out on a summer day in sunny weather when the air temperature did not exceed 30°C.

The fence resistance can be expressed by relation (2)

$$R = f(O, F, T) \tag{2}$$

- R - resistance of fence component
- O - offender
- F - fence
- T - tool.

An attacker may be described as a someone who is motivated for his action, has the necessary knowledge and skills for tool using and has adequate physical skills to carry out the attack (relation 3)

$$O = f(M, K, P) \tag{3}$$

O - offender  
 M - motivation  
 K - knowledge of tool use  
 P - physical skills.

The fence basic data describes its structure characterized by mesh size and wire diameter (relation 4).

$$F = f(A, D) \tag{4}$$

F - fence  
 A - meshes size  
 D - wire diameter.

The used tool is identified by a coefficient (relation 5) which was determined by the results of experimental use and expresses the total success time of the tool used by testing samples.

$$T = c \tag{5}$$

T - tool  
 c - tool coefficient.

In the test, the attackers were represented by test engineers who had many years of experience with tested fences and used tools. Their motivation was to verify in person how durable the fences, which they use each day, were. The fence resistance function for fuzzy model creations was simplified to relationship (6).

$$R = f(E, T) \tag{6}$$

and which has, after the replacement, the final form according to relation (7)

$$R = f(A, D, c). \tag{7}$$

For creation of a fuzzy model properties of approximate reasoning were used, as presented in [5] and [6]. The general fuzzy controller, shown in Fig. 2, is formed on the basis of knowledge, inferential mechanism and defuzzification.

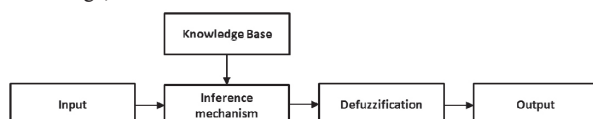


Fig. 2 General fuzzy controller

Knowledge base consists of a fuzzy model using approximate reasoning which in the real process describes the relationship between the conditions, observation and conclusion using the IF-THEN rules. Linguistic variable represents the properties of the input variables, e.g. “small”, “large”, etc. A function value can be assigned to linguistic variables in the context of the problem which should be solved. The context indicates the range limit of minimum and maximum of function values. One rule expresses local knowledge about the relationship among conditions, observation and conclusion. A set of rules creates general knowledge. IF-THEN rules may have a form, i.e.:

Condition: IF the speed is *medium* AND the obstacle is *close*  
 THEN intervention - *hit the brake*.

Observation: speed *slow* AND obstacle is *close*.

Conclusion: intervention - *hit the brake*.

The conclusion can be made by comparing the observation with the input condition.

The inference mechanism consists of logical deduction based on the observation perception. The resulting output fuzzy set enters into defuzzification. Defuzzification method of evaluation expressions DEE (Defuzzification of Evaluative Expressions) gives on the output a value which represents the size of any intervention. Type “small” means that the fuzzy set corresponding to the shape of the extension of pure evaluation term with atomic term like a small and similarly type “great”. If the fuzzy set is “medium”, the defuzzification method is method COG (relation 8)

$$COG(A) = \frac{\sum_{i=1}^n A(u_i) \cdot u_i}{\sum_{i=1}^n A(u_i)} \tag{8}$$

COG(A) - focus of fuzzy set A

A(u<sub>i</sub>) - membership function

u<sub>i</sub> - value.

It follows that it is sufficient to know the regulatory strategy and accordingly it is possible to design a fuzzy controller. For the application of fuzzy control is used following approach:

- 1) There are set the dependent and independent variables (intervence).
- 2) We decide on the type of fuzzy controller and method of approximate deduction.
- 3) We assemble the knowledge base - based on expert information, by which is described control strategy by means of language descriptions.
- 4) For all variables there is determined the context in which it is specified interval of meaningful values, of which the variables can take.

On the basis of the procedure there was determined form of function rule for determination of the breakthrough resistance (relation 9).

$$R_n = IF X_1 \text{ is } A_n \text{ AND } X_2 \text{ is } A_n \text{ AND } X_3 \text{ is } A_n \text{ THEN } Y \text{ is } B_n \tag{9}$$

$R_n$  - resistance of fence component/panel  
 $X_1$  - input variables independently  
 $A_n$  - characteristics independently variables  
 $Y$  - output dependent variables  
 $B_n$  - characteristics dependent variables.

For the verbal description of the wire fence resistance quantitative characteristics of the fence and tools were used.

Distribution of the values into the qualitative groups was carried out uniformly in the range of possible values. The overlap of individual groups did not allow creating sharp intervals which could border each group. This causes inaccurate values located near the left or right boundary of the interval. Distribution of independent and dependent variables in the qualitative groups of linguistic variables is shown in Table 3.

Distribution of values and assigning linguistic variables

Table 3

| Input value             | Indication | Description         | Spread       | Tool                 | Indication | c     |
|-------------------------|------------|---------------------|--------------|----------------------|------------|-------|
| Mesh [mm <sup>2</sup> ] | MS         | Small               | 0-3 500      | Rock                 | VMU        | 200   |
|                         | MM         | Medium              | 2 500-6 500  | Manpower             | VMU        | 1 342 |
|                         | MB         | Big                 | 5 500-9 500  | car jack (screw)     | MU         | 2 002 |
|                         | MVB        | Very Big            | 8 500-12 000 | Crowbar              | MU         | 2 178 |
| Wire [mm]               | WS         | Small               | 0-2.8        | Clamp                | MU         | 2 854 |
|                         | WM         | Medium              | 2.2-5.2      | Hammer               | SU         | 4 405 |
|                         | WB         | Big                 | 4.7-7.8      | Handsaw              | SU         | 4 429 |
|                         | WVB        | Very Big            | 7.2-10       | Pliers               | SU         | 4 446 |
| Tool                    | TVS        | Very Small Effect   | 0-1 400      | handheld gas burner  | VU         | 4 692 |
|                         | TS         | Small Effectiveness | 900-2 800    | cordless saw         | VU         | 4 730 |
|                         | TM         | Medium Efficiency   | 2 200-4 200  | cordless shears      | VU         | 4 782 |
|                         | TB         | Big Efficiency      | 3 600-5 000  | lever scissors       | VU         | 4 812 |
| Output value            | Indication | Description         | Spread       | 230V - grinder 125mm | VU         | 4 869 |
| Resistance [min]        | RS         | Small               | 0-3          | cordless grinder     | VU         | 4 874 |
|                         | RM         | Medium              | 2-5          | 230V - jigsaw        | VU         | 4 914 |
|                         | RB         | Big                 | 4.6-20       |                      |            |       |

Overview of IF-THEN rules

Table 4

| Rule Num. | IF               |                  |                  | THEN                  |
|-----------|------------------|------------------|------------------|-----------------------|
|           | Mesh $X_1 = A_n$ | Wire $X_2 = A_n$ | Tool $X_3 = A_n$ | Resistance $Y=B_n$    |
| 1         | if mesh is MS    | and wire is WM   | and tool is TVS  | then resistance is RB |
| 2         | if mesh is MS    | and wire is WM   | and tool is TS   | then resistance is RM |
| 3         | if mesh is MS    | and wire is WM   | and tool is TM   | then resistance is RM |
| 4         | if mesh is MS    | and wire is WM   | and tool is TB   | then resistance is RS |
| 5         | if mesh is MM    | and wire is WM   | and tool is TVS  | then resistance is RB |
| 6         | if mesh is MM    | and wire is WM   | and tool is TS   | then resistance is RM |
| 7         | if mesh is MM    | and wire is WM   | and tool is TM   | then resistance is RM |
| 8         | if mesh is MM    | and wire is WM   | and tool is TB   | then resistance is RS |
| 9         | if mesh is MM    | and wire is WB   | and tool is TVS  | then resistance is RB |
| 10        | if mesh is MM    | and wire is WB   | and tool is TS   | then resistance is RM |
| 11        | if mesh is MM    | and wire is WB   | and tool is TM   | then resistance is RM |
| 12        | if mesh is MM    | and wire is WB   | and tool is TB   | then resistance is RS |
| 13        | if mesh is MVB   | and wire is WVB  | and tool is TVS  | then resistance is RB |
| 14        | if mesh is MVB   | and wire is WVB  | and tool is TS   | then resistance is RB |
| 15        | if mesh is MVB   | and wire is WVB  | and tool is TM   | then resistance is RB |
| 16        | if mesh is MVB   | and wire is WVB  | and tool is TB   | then resistance is RS |

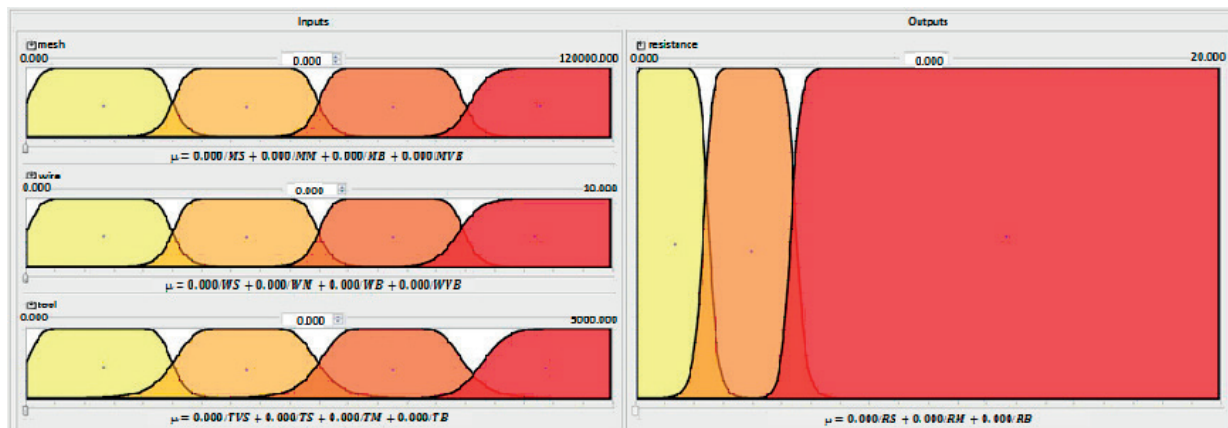


Fig. 3 Distribution of range of values into qualitative groups

Using the general rule set out in relation 9, the knowledge base was created. Based on a combination of number of input variables, 64 rules are needed to be able to create the model. According to the result of the measurement the model was created using 16 fundamental rules. The list of rules, which make the knowledge base is shown in Table 4.

The software tool „qtfuzzylite-4.0b1401 fuzzylite-4.0b1401“ was used for processing rules and model creation [7]. There is a print screen of the software desktop in Fig. 3. On the left side are the input variables and on the right side are deduced values of the dependent variable.

The resulting model allows qualified determination of the time resistance level for a wire fences on the strength from 2.5 mm to 8 mm, the mesh size from 2 574 mm<sup>2</sup> to 11 000 mm<sup>2</sup> and when using a defined set of tools. The results show the information about the level of result in qualitative resistance groups.

The accuracy of the fuzzy model is evaluated as the ratio of the values assigned to the resistance classes from measurements and values included in resistance classes in the model. Due to the nonlinearity of values, as is apparent from Fig. 1, the theoretical accuracy of the model is 92%. The accuracy of the model with respect to the values of the measurement is 88%. The accuracy of the model for different types of tested fencing samples is for type A = 80%, type B = 93% type C = 80% type D = 100%.

For example, for a fence, wherein the mesh size is 50x80 mm, wire thickness is 6 mm and the test is done with the tools from group 3, it is possible, when using the model described, to obtain

the objectivized values of breakthrough resistance. Case study results are presented in Table 5.

The evaluated sample, due to its characteristics, belongs to the fence group “C”. The obtained results are accurate to within 80% to 88%. In the color-coded columns are values of membership function of the results to the group of breakthrough resistance.

The proposed procedure described in this article enables to designers of security systems to refine the calculations relating attacker’s delay, for example, by using the instrument EASI (Estimate of Adversary Sequence Interruption) [8] and [9]. EASI method evaluates the probability of interruption of attack depending on the level and range of perimeter, sheathing and object protection, place of using detection systems, the quality of communication means and the ability of fast-deployment unit to take up defensive positions.

#### 4. Acknowledgements

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#### Case study results

Table 5

| Group | Test sample<br>Tool     | c     | Estimated time<br>[min] | Degree of membership to the set |      |      |
|-------|-------------------------|-------|-------------------------|---------------------------------|------|------|
|       |                         |       |                         | <2                              | 2-5  | 5<   |
| 3     | Handsaw                 | 4 429 | 1.34                    | 1.00                            | 0.01 | 0.00 |
|       | Pair of pliers          | 4 446 | 1.33                    | 1.00                            | 0.01 | 0.00 |
|       | Hand gas incisor/cutter | 4 692 | 1.30                    | 1.00                            | 0.01 | 0.00 |

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