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Multi-attribute Decision-making in Economics of Fire Protection

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The economic decisions concerning fire safety of built property may involve alternative solutions (alternatives) of fire protection measures, comparison of buildings with different fire safety levels, choice among construction products with different properties of performance in fire. The need to choose among alternatives may be faced by various interested parties: fire safety regulators (authorities on national level), insurers, architects (building designers), manufacturers of fire protection measures, property owners and buyers. The problem of choice will often involve the need to consider simultaneously several characteristics (attributes) of alternatives, and those related to fire safety will be accompanied by economic and non-economic ones. Such a choice can be formalised as a problem of multi-attribute selection (MAS), a filed known also as multi-criteria decision making (MCDM).

The present paper aims to formulate and solve several problems of multi-attribute selection by taking into account attributes related to fire safety. The problems are considered in an attempt to facilitate decision-making on three levels: the level of a property buyer/renter, the level of a property owner, and the level of an architect (building designer). It is shown that a different level of decision making requires to apply attributes of different nature. The well-developed field of fire safety offers a range of quantitative and qualitative indicators describing fire performance of building materials, construction and fire protection products as well as entire buildings. These indicators are introduced, with relative ease, into MAS problems.

The attributes of economic nature fit naturally in the MAS problems involving fire safety. They can be introduced passively and accompany fire-related attributes as well as other non-economic attributes. However, economic aspects of MAS problems can be used in a more subtle way, namely, by introducing elements of formal expression of risk posed by fires. Monetary losses caused by fires are among the elements of a risk profile. An expected value of these losses can be used as an MAS attribute.

Keywords: *multi-criteria decision making (MCDM), analytical hierarchy process (AHP), fire, sprinklers, fire risk index, risk profile.*

Introduction

Society has responded to the hazard of fire in build property in many ways. They include fire brigades, insurance, building regulations, education on fire hazards, controls on construction products and the design of buildings to resist the effects of fire (e.g., Vaidogas, Juocevicius, 2008a). The level of fire safety and protection in buildings reflects the general economic, social and cultural features of society.

The regulatory control of fire protection measures has mainly been achieved through a framework of prescriptive design requirements (SFPE, 2002; Hasofer et al., 2007). These requirements generally relate to the provision of compartments with prescribed levels of fire resistance, the selection of building materials, the provision of escape facilities. The prescriptive requirements do not take sufficient account of the effectiveness of active fire protection measures such as sprinklers, ventilation systems and fire alarms. Prescriptive requirements, if enforced rigidly, can lead to costly over-design, particularly for some large and complex buildings (Ramachandran, 1998).

A viable substitute for prescriptive approach is fire risk indexing and fire risk assessment (SFPE, 2002; Rasbach et al., 2004; Hasofer et al., 2007; Sakenaite, Vaidogas, 2010). This risk-based approach can produce alternative fire protection strategies, including combinations of passive and active measures which can provide equivalent levels of safety for life and property. From among such strategies, a property owner may select one which is economically optimum in terms of the costs and benefits involved.

Selecting the most cost-effective fire protection strategy would be a simple task for an economist with experience of practical applications. It may, however, be a complex and confusing exercise for a fire safety engineer or property owner (manager) confronted with several options that satisfy acceptable safety levels for life and property. Selected fire protection options should then be considered in combination with insurance options.

Economic decisions about fire safety in buildings can be made by a wide range of interested parties (Ramachandran, 1998):

- authorities on national level;
- insurers;
- building designers (architects);
- manufacturers of fire protection systems;
- property owners and buyers.

The decision can be simply enforced by the requirements specified in fire regulations, codes, and standards. In this case, the decision will be relatively simple. For instance, the building owner will have no choice as to install sprinklers. However, the restrictions imposed by legal requirements on the one hand and diversity of fire safety solutions on the other hand may lead to the necessity to choose among several alternative solutions. This leads to the need to consider simultaneously many, sometimes conflicting, attributes of alternative solutions and then to choose the best one by applying methods of the multi-attribute selection (MAS). The field of MAS is also known as multi-criteria decision making (MCDM), multi-attribute decision analysis (MADA), and multi-attribute utility theory (Figuera et al., 2005).

There exists some knowledge on the subject of safety-related applications of MAS. Measures of reliability and risk have been incorporated into the decision matrix of MAS problem by Vaidogas (2003, 2006, 2007), Vaidogas and Hayashi (2007), Vaidogas and Juocevicius (2008ab, 2009), Zavadskas and Vaidogas (2008, 2009). In one instance, components of the decision matrix of MAS was constructed using components of fire risk (Zavadskas, Vaidogas, 2009).

Methods of MAS were applied to solve specific fire safety problems in the areas of forest fire management (Iliadis, 2005; Diaz-Balteiro, Romero, 2008; Ananda, Herath, 2009) and territorial fire fighting planning (see the surveys by Behzadian et al., 2010, Farahani et al., 2010 and references therein). A MAS method known as the analytic hierarchy process (AHP) was used for the attribute ranking (weighting) in the development of the so-called Edinburgh method which, in turn, was used to develop a fire risk index (Rasbach et al., 2004). Zhao et al. (2004) used a stochastic version of AHP to rank fire safety attributes. To the best of our knowledge, the only application of MAS, which has incorporated fire safety attributes into a multi-attribute evaluation of buildings, was proposed by Wong et al. (2008ab). They included characteristics (indicators) of fire detection and alarm systems among a large number of indicators of an intelligent building and then applied two MAS methods, AHP and a related method called the analytic network process (ANP), to rank these indicators. However, Wong et al. did not formulate and solve the general problem of MAS based on a decision matrix and did not explicitly consider fire safety to be a goal of an operation of intelligent building.

There exists vast literature devoted to economics of fire safety (see, e.g., Ramachandran, 1998). Some authors consider in detail the economic aspects of fire safety systems and their findings come close to the problems of MAS; however, they did not apply MAS formally (e.g., Brown, 2005; Buttry et al., 2007). On the other hand, there are numerous publications devoted to an application MAS to decision-making concerning buildings, building systems and construction in general (e.g., Norris, Marshall, 1995; Zavadskas et al., 2008; Zavadskas et al., 2008; 2009abc; Park et al., 2009; Turskis, 2008; Turskis et al., 2009; Liaudanskiene et al., 2009). As fire safety systems are widely used in buildings and fire is the dominating hazard in most of them, this body of knowledge is natural environment to incorporate characteristics of fire safety systems into MAS problems.

This paper presents an attempt to formulate and solve several MAS problems which include the attributes related to fire safety and which can be of interest to parties on several levels of decision-making. The MAS problems are formulated from the viewpoint of property owner, property buyer, and architect (designer).

Economics of fire protection in multi-attribute decisions of property owner's

Types of decisions

Among the potential decision-makers, building owners and, sometimes, building renters are interested parties who have to carry the direct costs of providing passive and active fire protection measures. These measures can be required by fire safety regulations, codes and standards or, alternatively, can be applied voluntarily as a result of self-discipline (self-regulation).

It is obvious that decisions related to the choice of specific fire protection measures will require economic analysis, such as life-cycle costing and expenditures on insurance against fire (Dewar, 2001; Brown, 2005). However, these measures are characterised also by non-economic attributes, for instance, performance, effectiveness, and reliability (Rasbach et al., 2004). After all, fire protection measures are safety-related, risk-reducing building systems which can not be described by economic attributes alone.

In many cases, the decision-maker will be faced with the possibility or necessity to choose among several fire protection measures by taking into account not only economic attributes of them. Typical situations of choice can include the following alternatives:

1. to install some fire protection measure(s) or not to install any measure(s);
2. to install only one specific protection measure or several measures, for instance, sprinklers or automatic detectors alone, or both sprinklers and detectors;
3. to choose among several types of a specific safety measure, for example, among several sprinkler types (dry-pipe sprinklers, wet-pipe sprinkles, etc.);
4. to choose among several producers (importers) of specific equipment used as a fire protection measure;
5. to choose among more complicated alternatives which can include specific combinations of fire protection measures as well as the alternative of “doing nothing” (not installing any fire protection if this is allowed by regulations) mentioned in the first alternative.

Each of these situations is amenable to a formal expression as a MAS problem. Economic attributes and attributes expressing standard technical characteristics of fire protection measures can be a natural part of this problem. However, the MAS problem should also include attributes which directly or indirectly express the risk posed by potential fire. Fire protective measures are installed to reduce this risk and eventually their effectiveness should be measured in terms of risk reduction.

Example: choice among fire protection measures

A hospital administration is choosing fire protection system for retrofitting one of its buildings. It wants to improve fire safety in the building where patents with impaired movement capabilities stay. This physical condition can result in the problems with evacuation of patents and, in part, personnel in case of fire. The administration seeks to reach the maximum level of fire safety, but at the same time it does not want to appear as being uneconomic in its choice of fire protection. Furthermore, the administration does not want to impair the continuous operation of the hospital building.

The alternatives used in the problem represent four alternative variants of installing two fire protection measures. For simplicity, the alternatives are referred to as A, B, C, and D:

A: smoke detectors and alarm in corridors only; no sprinklers;

B: smoke detectors and alarm in the total space of building; no sprinklers;

C: smoke detectors, alarm and automatic sprinklers in corridors only;

D: smoke detectors, alarm and automatic sprinklers covering the total space of building.

These four alternatives will be used in the MAS decision matrix shown in the shaded area of Table 1.

Table 1

The decision matrix (shaded cells) composed for the choice among fire protection systems in hospital

Alternative safety system	Cost of system[1], a_1	Fire safety index $a_2 \equiv I_{FSES}$	Effectiveness		Operation impairment, a_5
			Probable number of victims, a_3	Value of dama-ged property[2], a_4	
	Attribute weights				
	$w_1 = 0.35$	$w_2 = 0.25$	$w_3 = 0.15$	$w_4 = 0.10$	$w_5 = 0.15$
A	9.9 LTL/m^2	46	4	10 %	1 weeks
B	114 LTL/m^2	57	2	10 %	3 weeks
C	26.4 LTL/m^2	73	1	8.5 %	6 weeks
D	304 LTL/m^2	78	0	7 %	10 weeks

(1) Approximate material and labour cost per floor (in thousands) retrieved from http://lantana.lt/lt/iranga [Accessed 10 May, 2010]
(2) When sprinklers are installed, the property loss can be reduced by 70% (the case of partially sprinklered corridors, alternative C) to 85% (the case of fully sprinklered floors, alternative D) (Melinek, 1993)

The hospital administration selects five attributes a1, a2, … , a5 for evaluating the fire safety systems. The economics is taken into account by the first budged requirements of each system (attribute a1). The fire safety is expressed quantitatively by the fire safety index IFSES (attribute a2). This index is widely used for the evaluating and ranking of hospitals in terms of fire safety (e.g., SFPE, 2002; Rasbach et al., 2004). As IFSES does not take a direct account of possible fire damage to people and property, two additional attributes are introduced to express the fire system effectiveness: the expected number of victims, a3, and the relative estimate of the value of property damaged by fire despite or in consequence of protective system operation, a4. The values of a3 and a4 can be estimated by means of a coupled modelling of building evacuation and spread of fire in it (Hostikka et al., 2007; Machado Tavares, Galea, 2009).

Finally, the desired smooth operation of the hospital building during the system installation is expressed by the attribute a5. Values of this attribute can be obtained by a detailed consideration of timing and technology of installation of fire protective measures.

The difference in significance of the attributes a1 to a5 is expressed by assigning the common weight of 0.5 to economy-related attributes a1 and a5 and the equal common weight 0.5 to the safety-related attributes a2 to a4 (the significance of economy is equated with significance of safety). A further division of these fifty-fifty weights is presented in Table 1 by the weights w1 to w5. The relatively large weight of the safety index a2 is due to the ability of this quantity to reflect various factor influencing fire safety. The values of wi (i = 1, 2, … , 5) were assigned subjectively. If necessary, a number of formal, albeit not fully subjectivity-free, methods can be used for specifying wi (Triantaphyllou, 2000; Wong et al., 2008ab; Zavadskas et al., 2010).

The AHP method was applied to rank the alternatives A to D. The eigenvector of relative importance or value of A, B, C, and D is (0.441, 0.215, 0.200, 0.139). This yields the following ranking of alternatives Ḍ□Ç□A□B. The commercial AHP software code Expert ChoiceTM was used to work this problem (Expert Choice Inc., 2010).

Fire safety in multi-attribute decisions of property buyers

Fire safety measures in building-related MAS

The five problems listed in the previous section consist in a selection among fire protection measures on a detailed level of characteristics of these safety systems. A provision of these measures influences the fire safety of the entire building. As fire is the main physical hazard threatening most of built property, the property buyer may be interested in attributes expressing the fire safety when he/she makes choice on a more general level, namely, among several buildings.

Fire safety attributes should depend on the main factors influencing the risk of fire. They can be used along with economic attributes as well as non-economic attributes which are not directly related to fire safety.

A list of the attributes that most decision makers find important in building decisions was suggested by Norris and Marshall (1995) and is presented in Table 1. The list contains 15 attribute groups which can be classed as follows:

I. Attributes of economic nature can constitute the first class (attribute groups 1 and 2, Table 1).

II. Attributes belonging to the second class express the functionality and environment of building alternatives (attribute groups 3 to 13, Table 1).

III. The third class of attributes is related to specific characteristics of building alternatives, namely, reliability and security (attribute groups 14 and 15, Table 1).

Reliability has a clearly defined aspect of safety. For instance, unreliable elevators can fail and cause accidents involving harm to occupants and visitors. Reliability is also related to fire safety, because building equipment failures can cause ignitions which in turn can escalate into fires. However, reliability alone is insufficient to express the risk of fire. In our opinion, the attribute list from Table 1 should be supplemented by at least two attribute groups (attributes) which take into account the hazard of fire: fire safety and proximity of the fire brigade with respect to the building under analysis.

Table 2

Attributes for building-related decisions introduced by Norris and Marshall (1995) and supplemented by attributes related to fire safety

No	Attribute group	Attributes within the groups
1	Economics	Cost budget requirements, life-cycle costs, net savings, return
2	Operation and maintenance	Ease and staff requirements of operation and maintenance, cost of running and maintenance
3	Occupancy availability	Time to being available for new occupancy
4	Building function	Layout, space (for office, shipping and etc.), plant
5	Aesthetics	Attractiveness of design inside and outside
6	Environmental impacts	Energy consumed, soil pollution concentration, etc.
7	Flexibility in functional use and disposition	Retrofitting costs, demolition costs
8	Location	Acceptance of clients, customers, staff
9	Technology	Telecommunications and computer infrastructure, equipment
10	Sound and visual environment	Aural privacy and ambient noise, light and glare, view to the outside
11	Thermal environment and air quality	Air quality, occupant control of conditions, temperature, humidity, ventilation
12	Transportation	Efficiency and ease of movement of people to the site and on site
13	Durability	Random lifetime and design working life (performance requirement)
14	Reliability	Survival (failure) probabilities of building structures and utilities
15	Security	Protection during and outside normal hours of workers and visitors inside and outside the building on site
16	Fire safety	Fire safety indices, risk of fire
17	Fire brigade	Fire brigade arrival time, distance to fire brigade

"Fire safety" can be expressed either by fire risk indices and/or by risk of fire. The fire risk indices are relatively simple-to-calculate quantities and depend on various characteristics of the building which are relevant to fire safety (e. g., SFPE, 2002; Rasbach et al., 2004). The risk of fire is expressed by a risk profile (likelihood-outcome pairs). In a more concentrated form, the risk profile can be expressed by the vector of expected severities se (Yung, 2008):

where sei is the ith expected severity (e.g., expected property losses, expected number of victims, etc.); m is the number of components of severity vector s; n is the number of fire scenarios; lr is the likelihood of the scenario r; and sir is the severity i related to the fire scenario r. Components of the vector se fit naturally into the framework of MAS and can be used as MAS attributes (Zavadskas, Vaidogas, 2009). Some of these components can be quantities of economic nature and so can be used as economic attributes. For instance, se1 can be direct monetary losses due to fire and se2 can be consequential losses due to loss of production, of trade, of market share.

The estimation of the quantities lr and sir is often a non-trivial task and it is highly probable that fire risk indices and not the formal expression of risk will be preferred by practitioners. Several risk indices are used worldwide for the evaluation of fire safety. However, the choice among them should not pose a problem because the use of individual indices is specific to individual countries and, in some instances, to the type of build property (Šakėnaitė, Vaidogas, 2010). Lithuania does not have the practice of applying fire risk indices.

"Fire safety" is related to economic attributes, because fire protection measures require investments for purchasing and installing sprinkler systems, fire alarms, smoke, flame or thermal (heat) detectors, etc. "Fire safety" is also related to another economic aspect, namely, fire insurance. In many countries, insurance companies offer a significant discount on their premiums for installation of fire protection measures (e. g., SFPE, 2002; Yung, 2008). Thus the MAS attributes used to the quantification of fire safety will be dependent on economic ones.

A natural measure of the attribute "Fire brigade" is the time to the arrival of fire fighters in case of fire or, alternatively, distance to the nearest fire station. In some fire risk indices, this distance is incorporated into the expression of fire risk index and the attribute "Fire brigade" becomes redundant. An example of such an index is the so-called FRAME index (FRAME, 2010).

The inclusion of additional attributes into Table 1 depends on other perceived needs of the decision maker. The list of attributes can be made also for solving specific selection problems. For instance, Wong et al. (2008ab) proposed a list of attributes (intelligent indicators) for the appraisal of intelligent building systems. They can be included in the traditional decision matrix of MAS.

Example: choosing a building for nursing home

A state agency needs, within 6 months, a building for nursing home. It seeks a location of 20-60 minutes from the city centre. It has also requirements for basic utilities which allow functioning of the nursing home and special building functions, such as a suitable layout of rooms and availability of elevators or possibility to install them. The agency is also aware of fires in nursing homes which occurred in previous decades and had heavy death toll. Thus, the high level of fire safety will limit the search along with the location and building function requirements. Having up to 6 months to occupy does not allows to construct a new building and the choice is to be made among existing buildings which can be retrofitted in terms of utility and, if necessary, fire safety.

An MAS analysis can help the agency to choose the building by taking into account the ten attributes a1, a2, … , a10 explained and evaluated in the decision matrix shown in Table 3. These attributes are grouped in three classes I to III listed above. As the fire safety plays an important role in the exploitation of nursing home, the largest common weight was assigned to the class III attributes, whereas the common weights assigned to class I and class II attributes were equal to 0.25. The weights subjectively assigned to individual attributes, wi, are given in Table 3.

Table 3

The decision matrix (shaded cells) used for the choice of a building for a nursing home

Alternative building	Economics (attribute class I)			Function (attribute class II)				Fire safety (attribute class III)		
	Initial building price, mln €	Retrofitting cost, mln€	Annual running cost, mln€	Occupancy availability	Layout	Noise environment	Accessibility	Fire safety index, I_G	Evacuation time estimate	Distance to fire station, km
	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8	a_9	a_{10}
	Attribute weights w_i (i = 1, 2, … , 10)									
	0.1	0.1	0.05	0.1	0.05	0.05	0.05	0.1	0.3	0.1
A	9	0.5	0.1	2 months	Good	Good	Good	1.29	5 min.	0.5
B	7,0	0.8	0.15	3 months	Very good	Very good	Poor	1.18	6 min.	1.0
C	8,7	0.965	0.09	6 months	Excel-lent.	Excel-lent	Excel-lent.	1.09	9 min.	1.2

The numerical values of the economic attributes a1 to a3 given in Table 3 are hypothetical ones and are used only as an example. The main fire related attribute a8 is the so-called Gretener's index denoted here by IG. It is the first of a series of fire risk indices and it was used in many countries since 1960s (Kaiser, 1980). Values of IG are considered to be acceptable when they do not exceed 1.3 (Rasbach et al., 2004). As IG is a universal and comprehensive measure expressing the fire safety of building, this index can be used as MAS attribute. The attributes a9 and a10 are also related to fire safety. They were added as "auxiliary" measures of fire safety because the index IG does not involve explicitly neither evacuation time nor distance to nearest fire station.

The AHP method was applied to rank the alternatives A, B, and C. The eigenvector of relative importance of A, B, and C obtained by this method is (0.427, 0.260, 0.313). This allows to rank the alternatives as follows: A□C□B.

Fire safety indicators in multi-attribute decisions made by architect/designer

Fire-specific attributes

Multi-attribute decisions involving economics and fire safety can be required at an early stage of building design. In most cases, the design will include a provision of passive fire protection measures which are required by fire codes, prescriptive or performance based ones (e. g., SFPE, 2002). The fire codes specify testing, rating, and measuring fire properties of construction products. An example of the prescriptive based design codes (currently in use in many countries) for passive fire protection is the specified fire resistance rating for interior walls (for instance, fire resistance classes 0 and 1 to 4 in UK and seven main Euroclasses A1 to F) (Harper, 2004). We think that characteristics of fire performance of construction products specified in the fire codes fit naturally into MAS and can be used as continuous and categorical MAS attributes.

Decisions concerning construction products involve many, sometimes, conflicting attributes which must be juggled simultaneously (Zavadskas et al., 2008; Zavadskas et al., 2009b). The attributes related to fire safety do not have a priory right to be preferred to economic or performance-related ones. However, MAS provides an excellent format for architect (designer) to embed the performance in fire in the choice among building materials and construction products.

Example: choosing among building partitions

We will modify the example situation proposed by Norris and Marshall (1995), in which an architect is working with clients to select materials for the partitions of a large office building. The clients tell the architect that they want partitions made from materials that are friendly to the environment. However, the clients do not want the building functions to be compromised by the design of partitions or choice of their materials. First of all, they are interested in good performance of partitions in terms of sound insulation and fire safety. The clients go on to say that, while they are willing to spend more money on materials to achieve a "green building", cost is still consideration.

The situation just outlined can be formalised as a MAS problem. The potential number of alternatives in this problem can be large because the construction industry proposes a variety of building partition solutions. To simplify the example, the choice among alternative solutions will be restricted by the four solutions A, B, C, and D consisting of assemblies of building boards and wall linings described in Table 4.

Table 4

Alternative designs of building partitions considered in the selection problem stated in Table 5

Alternative partition	Building board	Wall lining
A	Plasterboard	Hardboard with 2 coats of flat oil paint
B	Plasterboard	Fibre insulating board with skim of plaster
C	Woodwool slabs	Hardboard with 2 coats of flat oil point
D	Woodwool slabs	Non-combustible insulating material

The alternative solutions of partitions are characterised by MAS attributes a1 to a6 evaluated in the decision matrix given in Table 5. The economic attribute a1 is the cost of partition and the attributes related to the fire performance of the partition are represented by the combustibility class of its board, a2, and flashover time of the partition lining, a3. The internal partitions of walls and ceilings should be Class 0 materials wherever possible and must not exceed Class 1 (e.g., Hughes, Ferrett, 2007). Class 1 materials present the slowest speed of flame among four classes. Class 0 material must be Class 1 and must not contribute greatly to the propagation of fire. Thus Class 0 material should be preferred to Class 1 material in a pairwise comparison. The attribute a3 expresses the effect of wall linings on the growth of a fire and occurring of a flashover (a fire in an enclosed room that fosters the buildup of heat).

As in the previous examples, the solution of the MAS problem started from a subjective assignment of the weights wi to the attributes. A common weight of 0.7 was assigned to the economic attribute a1 and the attributes expressing the environmental impact of partition materials, a5 and a6. The weight of 0.1 was assigned to each of the remaining attributes a2 to a4.

The AHP method was applied to rank the alternatives A, B, C, and D. The eigenvector of relative importance of A, B, C, and D obtained by this method is (0.178, 0.575, 0.191, 0.057). This allows to rank the alternatives as follows: B□C□A□D.

Table 5

The decision matrix (shaded cells) used for the choice among building partitions

Alternative partition	Economics, cost[1], LTL/m^2	Fire performance		Sound isola-tion STC[3]	Environmental impact	
		Combustibility class	Flashover time[2]		Embodied ernergy[4], MJ/kg	Recycling potential[5]
	a_1	a_2	a_3	a_4	a_5	a_6
	Attribute weights w_i (i = 1, 2, … , 6)					
	0.4	*0.1*	*0.1*	*0.1*	*0.15*	*0.15*
A	110	Class 0	8 min. 15 s	45	22.1	Low
B	100	Class 0	12 min.	56	18.1	Low
C	120	Class 1	8 min. 15 s	53	22.1	Medium
D	85	Class 1	8 min.	68	39	Medium

[1] Approximate material and labour cost in 2010 prices in Lithuania, retrieved from http://www.statilitas.lt/ [Accessed 10 May, 2010]
[2] The flashover times were extracted from test results of the British Building Research Establishment, http://www.bre.co.uk/ [10 May, 2010]
[3] STC = sound transmission class is an integer rating attenuation of airborne sound by partition (STC is roughly the decibel reduction in noise a partition can provide) (e.g., Ballou, 2002)
[4] Approximate values calculated for the assembly of two partition materials according to Dimoudi and Tompa (2008)
[5] Recycling rating of the building board according to Harris (1999)

Conclusions

The problem of making economic decisions about the fire protection of built property has been considered. The problem was formulated as a task of multi-attribute selection (MAS), a decision-making methodology known also as multi-criteria decision-making (MCDM). Three MAS problems were identified, formulated and solved as examples. The problems differ in the level of detail, in which the alternatives of MAS and their attributes are considered: the problem of selection among buildings, choice among alternative measures of active fire protection and selection among building components (partitions) expected to exhibit some fire resistance. In all these problems, MAS attributes related to fire safety were considered together with economic attributes as well as attributes which describe non-economic performance of alternatives.

The main finding is that MAS attributes related to fire safety can be introduced into MAS problems with relative ease. In addition, the vast field of fire safety engineering has well-developed means used to characterise the performance in fire of both fire protection systems and potential "targets" of fires: building materials, individual construction products, building occupants, and entire buildings. These characteristics vary in nature and span between ignition temperatures and other elementary properties of materials, on one side, and a formal expression of risk assessed by means of rigorous probabilistic risk analysis, on the other. Consequently, fire safety related attributes can be found and introduced into MAS problems formulated on basically different levels of decision-making.

The MAS attributes of economic nature can be used in decision problems in a passive way, namely, by a simple assignment of cost estimates to fire protection measures or property involving such measures. A more subtle introduction of economic characteristics related to fire safety can be done through a formal expression of risk posed by a potential fire. The severity of fire damage is evaluated, among other measures, by monetary losses. The risk can be expressed though the expected monetary losses and these can be used as economic attributes in decision problems which involve fire safety.

This paper did not consider the role of insurance in a decision-making related to fire safety. We are aware that insurance plays an important role in providing fire safety. However, a detailed analysis of fire insurance within the formal framework of MAS lay beyond the scope of the present paper.

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Daugiatisklis pasirinkimas priimant ekonominius gaisrinės saugos sprendimus

Santrauka

Ekonominiai sprendimai, susiję su nekilnojamojo turto gaisrinės saugos užtikrinimu, dažnai turi būti priimami atsižvelgiant į keletą alternatyvių galimybių (alternatyvių sprendimų arba tiesiog alternatyvų). Lyginti galima pastatus su skirtingu gaisrinės saugos laipsniu, gaisrinę saugą užtikrinančias sistemas, statybos pramonės gaminius su skirtingomis laikysenos gaisro metu charakteristikomis. Su būtinybe rinktis iš kelių alternatyvų sprendimų gali susidurti įvairaus lygio sprendimų priėmėjai: gaisrinę saugą reglamentuojančios institucijos, draudikai, architektai ir pastatų konstruktoriai, gaisrinės saugos sistemų gamintojai ir pastatų savininkai. Esant pasirinkimo problemai, dažnai reikia atsižvelgti į keletą alternatyvių sprendimų charakteristikų (kriterijų). Toks pasirinkimas gali būti išreikštas daugiatikslio pasirinkimo (apsisprendimo) uždaviniu.

Šiame straipsnyje siekiama suformuluoti ir išspręsti keletą daugiatikslio pasirinkimo uždavinių, kuriuose atsižvelgiama į kriterijus, susijusius su gaisrine sauga. Pasirinkimo problemos sprendžiamos siekiant palengvinti sprendimų priėmimą trijų kategorijų suinteresuotiesiems asmenims: pastatų pirkėjams, pastatų savininkams (nuomininkams) ir architektams (konstruktoriams). Plačiai plėtota gaisrinės saugos mokslo sritis leidžia rasti ir taikyti įvairius kriterijus sprendžiant daugiatikslio pasirinkimo uždavinius. Tokie kriterijai tinka nusakyti statybinių medžiagų ir gaminių, gaisrinės saugos sistemų ir ištisų pastatų gaisrines charakteristikas. Šiuos kriterijus galima santykinai lengvai įtraukti į daugiatikslio pasirinkimo uždavinius.

Ekonominiai kriterijai yra natūrali daugiatikslio pasirinkimo uždavinių, kuriuose yra atsižvelgiama į gaisrinę saugą, dalis. Juos galima įtraukti pasyviai, naudojant juos kartu su gaisrinės saugos kriterijais ir kitais neekonominiais kriterijais. Tačiau ekonominiai daugiatikslio pasirinkimo aspektai gali būti ir sudėtingesni. Toks pasirinkimas gali būti grindžiamas matematiniu gaisro rizikos įverčiu. Šio įverčio elementai būna gaisro pasekmių sunkumo matai. Vienas iš tokių dydžių yra tiesioginiai gaisro sukeliami piniginiai nuostoliai. Tų nuostolių vidurkis, apskaičiuojamas įvertinant visus galimus gaisro scenarijus, gali būti naudojamas vienu iš pasirinkimo kriterijų.

Asmenys, turintys išlaidų užtikrinant pastatų gaisrinę saugą, yra pastatų savininkai ir kartais ilgalaikiai nuomininkai. Dažnai jie privalo įrengti pasyviąsias ir aktyviąsias gaisrinės saugos priemones. Kad būtų įrengtos tokios priemonės, gali būti reikalaujama pagal įstatymus, projektavimo normas, standartus. Gaisrinės saugos priemonės gali būti įrengiamos ir savo noru, kai pastato savininkas suvokia sunkias potencialaus gaisro pasekmes. Sprendimą įrengti konkrečią gaisrinės saugos sistemą reikia ekonomiškai išanalizuoti. Tačiau gaisrinės saugos sistema yra apibūdinama ir svarbiais neekonominiais kriterijais: gaisro gesinimo parametrais, efektyvumu ir patikimumu. Šie kriterijai yra nemažiau svarbūs už ekonominius kriterijus, nes gaisrinės saugos sistemų vaidmuo labai svarbus siekiant išvengti sunkių, kartais katastrofiškų gaisro padarinių. Kai reikia pasirinkti iš keleto alternatyvių gaisrinės saugos sistemų, gali tekti spręsti tokius uždavinius:

1. Įrengti vieną iš galimų gaisrinės saugos sistemų arba neįrengti nei vienos.
2. Įrengti tik vieną sistemą arba kelias (pvz., tik gaisro aptikimo ir aliarmo sistemą ir (arba) automatinius sprinklerius).
3. Pasirinkti iš kelių vienos sistemos variantų (pvz., kelių tipų automatinių sprinklerių).
4. Pasirinkti iš kelių konkrečios gaisrinės saugos sistemos gamintojų (importuotojų).
5. Pasirinkti iš kelių sudėtingesnių alternatyvių gaisrinės saugos priemonių kombinacijų, įskaitant alternatyvą apskritai neįrengti gaisrinės saugos sistemos.

Kiekvienas iš šių uždavinių gali būti matematiškai išreikštas daugiatikslio pasirinkimo problema. Ekonominiai kriterijai ir techniniai kriterijai, išreiškiantys įprastines technines gaisrinės saugos sistemų savybes, gali būti tokio uždavinio dalis. Tačiau į šį uždavinį reikia įtraukti kriterijus, atspindinčius gaisro riziką. Jos laipsnis priklauso nuo alternatyvių gaisrinės saugos sistemų charakteristikų. Gaisro rizikos matai gali būti gairinės saugos indeksas, evakuacijos laikas, numatomas gaisro metu sunaikinto turto nuošimtis. Daugiatikslio pasirinkimo uždavinyje tokius kriterijus galima naudoti greta ekonominių kriterijų.

Gaisrinės saugos kriterijus galima taikyti, kai reikia pasirinkti iš keleto pastatų, ypač kai tų pastatų eksploatavimas susijęs su padidinta gaisro rizika. Daugiatikslis pasirinkimas iš kelių pastatų yra gerai žinomas ir plačiai aprašytas uždavinys. To uždavinio kriterijai būna trijų rūšių: 1) ekonominiai kriterijai; 2) pastato funkcijas ir aplinką apibūdinantys neekonominiai kriterijai ir 3) specifines pastato savybes išreiškiantys kriterijai (pvz., pastato aplinkos saugumas, sistemų patikimumas). Gaisrinę saugą nusakantys kriterijai gali būti įtraukti į trečiąją kriterijų grupę. Kriterijai, naudojami renkantis iš kelių pastatų, paprastai būna mažiau detalūs, nei kriterijai naudojami renkantis iš kelių gaisrinės saugos sistemų. Todėl pastatą reikės apibūdinti bendresniais gaisrinės saugos kriterijais nei tais, kurių prireiks renkantis, tarkime, sprinklerių sistemą. Daugiatikslio pasirinkimo kriterijai, kurie išreiškia viso pastato gaisrinės saugos laipsnį, yra dviejų tipų: gaisrinės saugos indeksai ir kiekybinis gaisro rizikos įvertis.

Gaisrinės saugos indeksai yra santykinai paprastai skaičiuojami dydžiai. Jų reikšmės priklauso nuo daugelio veiksnių, lemiančių gaisrinę saugą. Jie plačiai naudojami kai kuriose šalyse ir juos paprasta įtraukti į daugiatikslio pasirinkimo uždavinį. Tačiau gaisrinės saugos indeksai nėra pakankamai pagrįsti griežtais moksliniais principais ir jų taikymas grindžiamas susitarimu tarp specialistų ir gaisrinę saugą reguliuojančių institucijų. Jeigu pavienėje šalyje yra įprasta naudoti gaisrinės saugos indeksus, juos bus galima naudoti ir sprendžiant daugiatikslio pasirinkimo uždavinius.

Atliekant daugiatikslį pasirinkimą iš pastatų, pasirinkimo kriterijais galima imti gaisro rizikos komponentus. Gaisro rizika yra išreiškiama galimų gaisro scenarijų tikėtinumais ir šių scenarijų pasekmių sunkumo matais. Gana sudėtingą bendrąją gaisro rizikos išraišką galima supaprastinti, apskaičiuojant vidutinius sunkumo matus, susijusius su visais galimais gaisro scenarijais. Tokius matus galima naudoti daugiatikslio pasirinkimo kriterijais. Tarp vidutinių gaisro sunkumų bus ir ekonominio pobūdžio dydžiai: tiesioginiai ir netiesioginiai piniginiai nuostoliai dėl gaisro. Taigi daugiatikslis pasirinkimas remiantis gaisro rizikos įverčiu turės ir ekonominį aspektą. Tačiau rizikos įvertį gana sudėtinga apskaičiuoti. Rizika grindžiamam pasirinkimui reikalingos specialios žinios.

Detaliausiai ir dažniausiai daugiatikslis pasirinkimas atsižvelgiant į gaisrinę saugą gali būti atliekamas projektuojant pastatus. Architektūriniai ir konstrukciniai sprendimai turi užtikrinti pasyviąją pastato gairinę saugą. Tai pateikta norminiuose dokumentuose. Statybinių medžiagų ir gaminių gaisrinės charakteristikos, reglamentuojamos šiuose dokumentuose, natūraliai tinka būti kaip daugiatikslio pasirinkimo kriterijai. Jų pavyzdžiai yra medžiagų degumo klasės, konstrukcijų atsparumas ugniai, laikas iki intensyvaus degimo pradžios. Priimdamas sprendimus, kokias medžiagas, gaminius ar konstrukcijas pasirinkti, architektas (konstruktorius) turės vertinti ne tik ekonominius ir techninius kriterijus, bet gaisrinę saugą nusakančius kriterijus. Tokius sprendimus palengvins matematiniai daugiatikslio pasirinkimo metodai.

Straipsnyje išspręsti trys daugiatikslio pasirinkimo pavyzdžiai, kuriuose naudojami gaisrinę saugą nusakantys kriterijai. Pirmajame uždavinyje sprendžiama, kokias alternatyvias gaisrinės saugos sistemas įrengti ligoninėje. Antrajame uždavinyje sprendžiamas pastato parinkimas globos namams įrengti. Šio tipo pastatuose yra įvykę labai skaudžių gaisrų, todėl sprendžiant pasirinkimo uždavinį buvo naudoti keli kriterijai, nusakantys gaisrinę saugą. Trečiajame uždavinyje aprašoma, kaip naudoti gaisrinės saugos kriterijus pasirenkant pastato pertvarų variantą. Visuose pavyzdžiuose gairinės saugos kriterijai naudojami kartu su ekonominiais kriterijais. Uždaviniai išspręsti pritaikius daugiatikslio pasirinkimo metodą, kurio angliškas trumpinys – AHP (angl. analytical hierarchy process).

Raktažodžiai: *daugiatikslis apsisprendimas, analitinis hierarchijos procesas, gaisras, sprinkleriai, gaisro rizikos indeksas, rizikos profilis.*

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