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Original article

Expert systems in assessing the construction process safety taking account of the risk of disturbances

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ABSTRACT

The objective of the paper is to present the issue of safety management during the construction process. Threats in the form of disturbances may occur in the preparatory phase, during the execution of the construction project and also during its operational use. The article presents the concept of applying the methodology based, among others, on Learning Bayesian Networks, Artificial Neural Networks and Support Vector Machine, which can be used for building a system for diagnostic and decision-making support at each stage of the construction process. The use of expert systems when it comes to making choices related to construction issues can bring many benefits to decision-makers, as it reduces the risk of taking a wrong decision, and, thus, increases the construction process safety.

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KEYWORDS

construction safety, artificial intelligence, expert system

Introduction

One of the more important aspects of management is to ensure safety during both construction and operation. The construction process includes the preparation of a construction project (documentation and design part) and its execution and also operation. In the preparatory phase there occur errors and omissions committed by designers or civil-service employees as well as factors independent of human activities, including those that could not have been foreseen in this phase and which may exert an indirect influence on safety in the next phase. When a building is being constructed, the risk of direct threats to human life and health increases. Even after it has been placed in service the safety management has to be continued, although it is sometimes a matter of formalities, i.e. adding entries in the building log book [Jakubczyk-Galczynska et al. 2012]. According to [*Slownik terminow*… 2008, p. 14] safety is the state of affairs which gives the feeling of certainty of existence and guarantees its continuation and provides opportunities for its improvement. In practice it means that the feeling of safety is one of the basic needs of every man and, therefore, it is so important to adopt a versatile and interdisciplinary approach in the construction industry.

1. Occurrence of disturbances causes the loss of safety

1.1. Preparatory phase

The initial phase of a construction process exerts a crucial influence on the efficient, timely and safe completion of works [Drzewiecka and Paslawski 2011; Jakubczyk-Galczynska and Siemaszko 2014; Lesniak and Plebankiewicz 2010; Lesniak 2012]. At this stage an important role is fulfilled by the experience and expertise of both designers and official inspectors who take decisions regarding the correctness of the design and its compliance with the regulations (see e.g. [Dz. U. z 2003 r. Nr 47, poz. 401; Dz. U. z 2003 r. Nr 120, poz. 1126; Dz. U. z 2002 r. Nr 108, poz. 953; Dz. U. z 1994 Nr 89, poz. 414 z pozn. zm.]). The project should comprise guidelines for the Health and Safety Protection Plan (PBiOZ, Plan Bezpieczeństwa i Ochrony Zdrowia). It is important to have the guidelines precisely established for a given project. It is absolutely not allowed, although often encountered in practice, to copy guidelines for similar projects. The part to be prepared by the designer should include the following information at a minimum: legal basis for the document, scope of planned works, potential threats that may occur while carrying out the construction works, guidelines for carrying out the works taking account of the specifics of the project, proposal for designating and marking the place where the works are to be carried out, information and warning boards, staff training, guidelines for storing and handling materials and for the equipment used at the building site. The proper planning of the project is conductive to the mitigation of risk during the further phases of the construction project.

1.2. Project execution phase

Having received a building permit or having its notification of construction works accepted the Investor can start preparations for commencing the construction project. It involves the proper and careful organisation of a site compound, which consists in designing (drawing) and describing (description) all elements necessary and required to start construction works. The development of a full version of PBiOZ, which is the site manager's responsibility, should be the first activity. First, the building site has to be fenced to prevent unauthorised access. The minimum height of the fence should be 1.5 m [Dz. U. z 2003 r. Nr 47, poz. 401]. It is necessary to situate an entrance gate for heavy equipment and vehicles and a separate entry for pedestrians to minimise the possibility of running them over. A yellow information board, with the dimensions of 90 × 70 cm, and a notice concerning PBiOZ should be fixed in a visible place on the fence, at a minimum height of 2 m [Dz. U. z 2002 r. Nr 108, poz. 953]. The text on the boards should be legible and durable, made using black letters and digits of a minimum height of 4 cm. This rule is very rarely observed. Usually the font is considerably smaller, the information is incomplete and the text disappears quickly under the influence of weather conditions. The information to be obligatorily placed on the board has been described in [Dz. U. z 2002 r. Nr 108, poz. 953].

At a building site there is an increased risk of accidents, which results from the specifics of the works [Wieczorek 2009]. Therefore, special attention should be paid to dangerous zones. According to [*Wypadki przy pracy*… 2011; *Wypadki przy pracy*… n.d.] the most frequent accidents at the building site include:

– objects falling from a height,
– employees falling into an unprotected excavation or falling from a height,
– employees being run over by a means of transportation or hit by mechanical equipment or a handled element,
– employees being crushed because of incorrectly stored construction materials.

To minimise the above threats the dangerous zones should be marked by means of warning boards, railings and protective canopies. It is of particular importance to raise awareness among all employees staying at the building site and to provide them with continuous training. It is absolutely necessary to verify all licences, the validity of medical certificates, and qualification certificates, and to place emphasis on the use of working clothes and footwear, and personal protection equipment.

A temporary power supply line is another element of the building site potentially posing a threat. It is important to have it made on the basis of the conditions set by the operator of the local grid or to provide mobile transformer substations. Distribution boxes should be located in the way ensuring that the distance to the farthest supplied equipment does not exceed 50 m [Wieczorek 2009]. Materials, machinery or work stations must not be situated directly under overhead lines, at a distance shorter than that specified in the regulation [Dz. U. z 2003 r. Nr 47, poz. 401]. The location of temporary buildings, welfare facilities and offices, storage facilities and yards for construction materials is another vital issue. It is necessary to keep the right distances and observe the rules concerning location, storage dimensions and stacking heights, which quite often is not of much interest (see Fig. 1).

Fig. 1. Examples of elements of the building site and site compound protected in a reckless and inappropriate manner
Source: [Own photos].

It is equally important to plan properly temporary access roads designed for equipment and cargo vehicles. Minimum distances have to be kept, road pavement or roadway width have to meet the requirements, and at the unloading points the roads have to be widened.

Recapitulating, at the stage of executing the project, to avoid accidents or at least minimise their consequences it is necessary to prepare PBiOZ carefully, provide training to employees, display the notice concerning PBiOZ and mark dangerous zones.

1.3. Phase of operational use

The operational use of a building, which lasts many years, is the most difficult phase in the construction process safety management. Factors that influence the operational use of buildings and their condition include mainly:

- conditions resulting from the impact of operational use,
- conditions resulting from the climate and environmental pollution (changeable weather conditions, use of chemical agents in winter),
- conditions resulting from the natural wear and tear of the structure, adopted design solutions and quality of materials used.

During the operational use of a building numerous problems have to be solved on a continuous basis. On the one hand they are related to the fulfilment of required functions, whereas on the other hand they concern efficiency or possibilities of satisfying external requirements. Therefore, it is necessary to consider three basic groups of issues that relate to solving operational problems listed in Table 1.

Table 1. Groups of issues concerning the operational use of buildings

Group no.	Problem type	Important issues
I	operational use	– taking user satisfaction into account – improvement in the level of safety – environmental protection
II	maintaining the building in good condition	– damage prevention based on diagnostics – technical readiness of the building
III	management and planning of the operational use process	– operational use is planned, justified and controlled – decisions are economically and rationally justified – dissemination of operational use experience

Source: [Own work].

Taking decisions related to the operational use is a complex process, as in Poland there are no unambiguous regulations governing this area. Special attention should be paid to the "Polish Construction Law" [Dz. U. z 1994 Nr 89, poz. 414 z pozn. zm.], which covers the issues of operational use of buildings and their maintenance to a limited extent. Chapter 6 of this Act obliges building owners and managers to keep them in good technical and aesthetic condition.

An important role in providing the information about the operational use of a building is performed by the "Building Log Book", in which the owner or manager is obliged to implement consistent archiving and to update documentation and data from regular inspections, measurements and tests.

Expert assessments, contained in the log book, confirming that periodical inspections, annual inspections and inspections conducted every five years have been performed, are the documents of major importance from the point of view of operational use.

Mainly as a result of the well prepared and conducted inspection of the building condition a reliable picture of such condition can be obtained, together with recommendations for maintenance, renovations and modernisations. It is very important that they are sufficiently detailed and, particularly in the case of a larger number of facilities, that they form a set of comparable information, which can be helpful in analysing problems of operational use of different buildings and in creating databases that are later used to develop advisory systems. However, as evidenced by many cases, it is not enough to make an expert assessment, because it also has to be known what to do with the information thus obtained.

2. Use of expert systems to manage the construction process safety

2.1. Taking project-related decisions

The decision-making process has somewhat of a discovery in it, or risk taking, and it has economic, social, political or organisational consequences. The decision-making practice focuses on verifying alternatives which fulfil a set of desirable objectives. The decision consists in selecting one of them. In each decision-making problem there is at least one optimum decision with regard to which it can be objectively stated that no other better decision exists, while maintaining neutrality in relation to the decision-making process. The problem consists in selecting the alternative which fulfils a complete set of objectives to the fullest extent.

The use of expert systems should help in making the right choice. The presentation of possible decisions and factors affecting them in the form of a network, diagram or tree as well as assigning numerical values to them and creating a structure of interdependencies between relevant factors help in analysing profits and losses resulting from making a given choice. However, the correct construction of such system is very difficult and entails considerable experience, knowledge, analytical skills and cooperation with experts. The description of links between issues (factors) affecting the investigated problem and the analysis of information (observations) that can be used to diagnose this problem in detail are particularly important. However, if an appropriate set of the above-mentioned factors is available, such system can be helpful in taking decisions that reduce the uncertainty of data and create a valid risk scenario, thus making it possible to make decisions justified to a greater extent.

The use of expert systems in making choices related to construction issues can bring numerous benefits to both the investor and the contractor of a given construction project, as it involves the analysis of: financial efficiency, time and quality of execution, and related risks. The main objective of developing an expert system is to integrate the knowledge gained from experts – including in this case a group of construction engineers, building site inspectors and construction practitioners – and the data and information obtained from documentation, and also the history of operational use of buildings supplemented with the general knowledge of construction, indispensable to draw correct and complete deductions.

The objective of developing a system for diagnostic and decision-making support is to demonstrate the possibilities of using expert systems to improve the construction process safety by combining three key elements:

1. Decision theory – owing to which it is possible to maximise gains and minimise losses when taking a given decision;
2. Diagnostics – based on assessing, forecasting and planning activities related to the operational use of buildings and monitoring information;
3. Learning Bayesian Networks or Artificial Neural Networks or Support Vector Machine – a tool owing to which it is possible to link the expert knowledge of relations between the elements of the model with available data.

The subsequent subsections present expert methodologies used for building an advisory system model helpful in taking rational decisions at the respective stages of the construction process.

2.2. Learning Bayesian Networks

Bayesian Networks (also Belief Networks, Bayesian Belief Networks) are used for presenting dependencies between events on the basis of the decision theory and the fundamentals of the theory of probability. Formally such network is modelled by means of a directed acyclic graph in which nodes represent events and arcs stand for a cause and effect relationships between these events. Learning Bayesian Networks form a very good tool for solving problems in construction [Neapolitan 2004].

Bayesian networks can be provided by an expert and/or learnt from data. Data are treated as a set of m vectors ($x1(i)$, …, $xn(i)$), I = 1, …, m) generated independently of each other from the probability distribution represented by a certain "true" Bayesian network (X, S, P), where S – structure, P – parameters. On the basis of the data a Bayesian network (X, S', P') is created to reflect "as faithfully as possible" the network (X, S, P) [Vapnik 2000].

Building a Bayesian network (learning automatically) consists in structure learning (directed graph) and parameter learning (conditional probabilities) from a data set. Mainly two algorithms, K2 and PC, are used for this purpose. K2 is a heuristic algorithm searching through the space of possible solutions and building the result relying on the assessment of an instantaneous situation. In each step K2 extends the solution by one directed edge which improves the fitting of the result to the sample distribution. The activity is discontinued when no further improvement can be achieved. The algorithm makes use of its own assessment function. The other algorithm, PC, consists in minimising the number of indispensable *d*-separation tests, i.e. it performs lower-order tests quickly and efficiently. During the first phase of operation of the algorithm the network structure is established and afterwards some edges are oriented as far as possible. Thus, a partly oriented structure is generated, representing the whole class of potential Bayesian networks.

In algorithms it is assumed that the *D* sample (a set of data) is discrete and events in the sample occur independently and that when the data were gathered the dependencies between the attributes were constant. The information about events (cases) in the sample is complete, i.e. there are no missing values (empty cells) in the table. It is assumed that all legal structures of the network are equally probable and with the established network structure all possible correct sets of conditional probability tables are equally probable [Vapnik 2000].

To sum up, the interactive learning network is the solution giving the best results. In this solution the algorithm proposes certain modifications of the network, called changes (addition or deletion of a link) which can be accepted or rejected by a user on the basis of common sense, expert knowledge or only preferences. In addition, the user can modify the network any time, by means of a graphical user interface, and then the user can resume the learning process in the edition proposed by the learning algorithm.

2.3. Artificial Neural Networks

Artificial Neural Networks are probabilistic computational systems which determine the possibility of occurrence of an event, classification of phenomena or unknown value regression with a defined probability of an error. The operating principle is based on the way of functioning of the network of human nervous cells, the so-called neurons [Morajda 2007; Ossowski 1996]. On the basis of the results a network is created which “learns” during the learning, verification, validation and testing stages. When the network learns, data are processed by means of internal processing and activation functions [Ossowski 1996; StatSoft 2014]. On the basis of the investigation results and data collected in connection with disturbances it is possible to create a system forecasting the risk of occurrence of respective events, both random and planned.

2.4. Support Vector Machine

The support vector method is an algorithm giving satisfactory results in two types of problems: classification and regression [Asefa et al. 2005; Cristianini and Shawe-Taylor 2000]. The main operating principle of this tool is the determination of a hyperplane which is a value separator, i.e. it divides results into subgroups, classifies them. In regression problems the principle is similar: for the data that have not been classified their allocation to respective classes is established. The idea of this method is to create a classifier that will sort factors into acceptable and inacceptable, that is potentially safe or dangerous.

Conclusions

There are many techniques that support decision-making with regard to safety assurance. Many factors affecting safety occur as a result of disturbances taking place at the stage of both construction and operation of buildings.

To put the results of the conducted research into practice it is planned to develop a computer system designed to investigate, analyse and forecast safety during the construction process for the selected types of buildings. It has been assumed that the program based on Bayesian networks, neural networks and support vector machine method will represent the exact implementation of the conducted research and will provide a tool used in construction practice.

It can be presumed that the issues presented in the article, concerning the identification and forecasting of the construction process safety, will become a widely considered research problem in the future. The development of the described system will provide a convenient and transparent element of control during all stages of the process concerned.

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Conflict of interests

The author declared no conflict of interests.

Author contributions

All authors contributed to the interpretation of results and writing of the paper. All authors read and approved the final manuscript.

Ethical statement

The research complies with all national and international ethical requirements.

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