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Measuring operational performance of OSH management system – A demonstration of AHP-based selection of leading key performance indicators

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ABSTRACT

Occupational safety and health management systems (OSH MSs) have been implemented in numerous enterprises worldwide since the mid-1980s. While stakeholders still have expectations on better prevention of occupational injuries and diseases, and on improving the working conditions, it suggest that new approaches are now needed to ensure OSH MS effectiveness, including development of new methods that would facilitate measurement of OHS MS operational status aimed at the genuine improvement of OSH management practices. A review of literature on leading pro-active safety performance indicators (PPIs) provided a rationale for a concept to elaborate a relatively small number of key performance indicators (KPIs) for measuring OSH MS operational performance. As a basis for this process an initial set of 109 PPIs was developed, composed of 20 sub-sets assigned respectively to individual OSH MS components. Next, for the selection of KPIs the method of the Analytic Hierarchy Process (AHP) was employed. The ranking and prioritization of leading performance indicators was made in relation to a set of SMART (Specific, Measurable, Achievable, Relevant and Time-bound) criteria.

The objective of this paper is to demonstrate the application of the AHP method for the selection of leading KPIs for measuring OSH MS operational performance. The proposed set of KPIs should be tailored to specific conditions of an enterprise, such as the size, industry sector, types of occurring hazards, or the maturity of OSH management processes.

1. Introduction

1.1. Some remarks on the effectiveness of OSH management systems

Since the mid-1980s, an intensive development of concepts and models of OSH management systems (OSH MSs) has been observed, which is reflected *inter alia* by the adoption and dissemination, at an international level, of normative documents such as the International Labour Organization guidelines ILO-OSH 2001 (ILO, 2001) or the OHSAS 18001 specifications (BSI, 1999, 2007), which provide detailed, but non-mandatory, requirements for designing, implementation and conformity assessment of OSH MSs. The concept of these approaches were developed in response to the needs of enterprises and other stakeholders seeking to manage the OSH area in a more consistent and effective manner. They were ultimately aimed at the reduction of a number of accidents at work, near misses and occupational diseases, and consequently, the reduction of associated economic losses.

However, after over 20 years of the world-wide proliferation of OSH MSs no conclusive and sound evidence has been obtained that such systems are effective in terms of preventing and reducing the number of occupational accidents and diseases. What should be particularly referred to here are the results of a systematic analysis of scientific literature on the OSH MS performance as carried out by the team of the Canadian Institute for Work and Health (Robson et al., 2007), which showed that there was no sufficient evidence confirming the performance of OSH MSs, and that therefore OSH MSs were to be neither recommended nor objected to. A review of literature as conducted for OSH MS performance (e.g. publications by Nielsen, 2000; Zwetsloot, 2000; Drais, 2005; Drais et al., 2008; Calvert, 2009; Rocha, 2010; Granerud and Rocha, 2011; Hohnen and Hasle, 2011; IOSH, 2011; Borys et al., 2012; Gallagher and Underhill, 2012; Zwetsloot, 2013a) indicates that the main reason for such a state of affairs is neither the very concept of systematic OSH management nor the structure of system models, but too formal, and frequently bureaucratic and paperwork-intensive

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approach of numerous enterprises, certification bodies and auditor teams to ensure compliance of such systems with relevant criteria, without taking adequate consideration of the safety and health performance aspect of those systems. Furthermore, despite several attempts to develop and implement advanced tools to support OSH MS auditing (e.g. HSA, 2006; Mughal, 2007; Costella et al., 2009; BSC, 2013), there is still a need for further research regarding the measurement properties of OSH management audits (Robson and Bigelow, 2010; Robson et al., 2012).

According to some studies a low level OSH MS performance is related to auditors' insufficient knowledge and competence in the domain of OSH (Blewett and O'Keeffe, 2011), and to the absence of verification and validation of auditors' competencies (Dellacherie, 2010). It is also claimed that OSH MS auditors focus on checking on the formal compliance of system procedures with relevant criteria, rather than on getting to the core of technical issues, human factors, and the relationships between employees and employers, which actually provide a foundation of actions for the benefit of OSH (Fernández-Muñiz et al., 2012). In particular, with regard to the OSH MS audits, Blewett and O'Keeffe (2011) call straight out for the re-conceptualization of their role, since the main focus should be on the development of healthy and safe working conditions, and not on auditing the system.

Therefore, the above considerations lead to the conclusion that it is necessary to search for new solutions and arrangements that would improve the performance of OSH MS, which would consequently result in a positive contribution to greater acceptance of these systems among employers, employees and other stakeholders.

1.2. The concept of OSH management based on performance measurement

A recommended approach to the development of an instrument demonstrating the effectiveness of OSH MS is the use of measurable or qualitative performance indicators, which should allow for an on-going comparison of the existing performance level with the previously determined target level. This approach is already considered in current OSH MS models, as provided e.g. by ILO-OSH 2001 guidelines or OHSAS 18001 specifications. Although the mentioned documents include certain clauses on establishing and implementing procedures providing for proactive measures for monitoring OSH MS performance, it seems that those clauses are not sufficiently well interpreted or followed by managers, which can be related to a low level of OSH MS effectiveness, as it claimed in Section 1.1.

According to Cambon et al. (2005), three main approaches to the measurement of OSH MS performance may be basically distinguished: (1) result-based approach, (2) compliance-based approach, and (3) process-based approach. In the first, result-based approach, the so-called lagging indicators (also referred to as *outcome* or *negative* indicators) are applied for performance measurement. Whereas, for the two remaining approaches, leading indicators (also referred to as *pro-active*, *positive* or *predictive* indicators) are applied. Leading indicators (further referred to as PPIs[1]) being applied for the evaluation of system compliance with a given specification form a group of *structural performance indicators*, while those applied for the evaluation of effectiveness of internal system processes are referred to as *operational performance indicators*.

In the relevant literature, leading performance indicators are often confronted with lagging indicators, and numerous papers have been dedicated to the selection and functions of various types thereof (e.g. a special edition of Safety Science, issue 4 of 2009, which concerns the subject matter of process safety indicators). The lagging safety indicators usually are based on such data as the frequency of accidents at work and occupational diseases, accident- or sickness-related absence from work, the number of near misses, etc., but the usefulness of their application for the evaluation of OSH MS performance is challenged by numerous scholars (e.g. Mearns et al., 2003; Hollnagel, 2008; Herrera and Hovden, 2008; Juglaret et al., 2011; Pawłowska, 2013; Zwetsloot, 2013b). These indicators are based on data being both historical and delayed in time in relation to the occurrence of reasons affecting the values being measured, which, in practice, renders an appropriately rapid response and the introduction of corrective actions impossible. Moreover, in many enterprises, especially the small ones, accidents do not happen often, therefore no data are available for determining the indicators' values, even though employees may indeed be exposed to adverse working conditions. Whereas, changes in PPIs take place in advance of those in lagging indicators, and thus allow an earlier and efficient intervention in case of either possible non-compliances in the management system (structural performance) or weak points, disturbances or the absence of expected results in the sphere of operational performance, even before negative consequences of that situation, namely accidents at work or harmful exposures of employees, occur.

In the case of structural performance evaluation, the approach in question is not fundamentally different from the classic methods of auditing OSH MSs. This is due to the fact that structural performance indicators are of qualitative nature, and the application thereof comes down *de facto* to either checking as to whether individual components of the system are properly designed or evaluating the extent to which system procedures are implemented and being followed in the enterprise.

In turn, operational performance indicators provide information on the status of individual processes within the management system. As such, when tracked over time, such indicators provide information on progress of change within the management system and assist in forecasting future status and planning. Examples of such indicators include: the number of work stations at which risk assessment has been carried out or updated; percentage of employees trained in OSH in a given period; percentage of safety checks on machines and installations, as compared to the plan, etc.). Monitoring of such indicators' values allows getting a picture of how a given system operates at the shop-floor level, in contrast to the results of structural performance measurement, which actually tend to only indicate what the system consists of Cambon et al. (2006). Therefore, for the purpose of this study, it was assumed that in search of solutions allowing the evaluation of the operation of OSH MSs to be carried out better than before, one should mainly focus on making use of operational PPIs.

The mentioned assumption is fully in line with the recent concepts and methods of *resilience engineering*. According to its foundations, formulated *inter alia* by Hollnagel et al. (2006, 2012), organisational resilience is the "intrinsic ability of an organisation (or system) to adjust its functioning prior to or following changes and disturbances to continue working in the face of continuous stresses or major mishaps". Taking that concept into account the aim of operational PPIs would be to provide early warning signals on any irregularities or faults within OSH MS functioning. Instead of reacting to errors or non-conformities already detected one should in this respect strive to understand normal functioning of the system and to focus on monitoring its changes by means early warning indicators (Herrera and Hovden, 2008; Øien et al., 2011a,b).

The proposed approach does not exclude the need for the discussion and research on roles and potential applications of lagging performance indicators in the domain of OSH. But for the better clarity of concepts and methods presented in this paper a subject

[1] The article assumed that leading performance indicators would be referred to as PPIs (Pro-active Performance Indicators). Referring to them as LPIs (Leading Performance Indicators) would be confusing since the latter abbreviation might also relate to Lagging Performance Indicators.

matter of lagging performance indicators has been intentionally left outside the thematic scope of the study.

1.3. The need for key performance indicators (KPIs) for OSH management systems

The subject matter of systematized sets of performance indicators for measuring effectiveness of OSH management actions has been already addressed in several studies, for example by Redinger and Levine (1998), Redinger et al. (2002a,b), Cambon et al. (2005, 2006). The review of these studies shows that the measuring tools that they propose are characterized by a relatively large number of PPIs (up to several hundreds) as well as by several-level internal structures. Practical application of such complex measurement systems could be difficult since it involves large investment of time, the need for training and preparing personnel to perform measurements, and a large volume of information to be collected and processed. The other factor to be considered is the increasing information overload and large diversity of information processed by managers and decision-makers nowadays, which may negatively influence the quality of their decisions (Iselin, 1988; Hwang and Lin, 1999), thus impairing overall management performance. Therefore, one should strive to reduction of data and information, upon which important decisions are made, to the minimum necessary level.

Reports found in the literature (e.g. Perrin, 1998; Keeble et al., 2003; Chan and Chan, 2004; SCS, 2003; HSE, 2006; Shahin and Mahbod, 2007; Elzinga et al., 2009; Øien et al., 2011a,b) indicate the need for reducing the number of indicators down to several or a dozen or so major KPIs. Brown (1998) puts it bluntly that "... *it is worse to measure too many things than it is to not measure anything at all*". In the same context Mazri et al. (2012) underlined the need to ensure an adequate balance between representativeness and feasibility of applied KPIs. Representativeness implies the selection of such a number of indicators which is capable to reflect sufficiently real conditions of the system, while feasibility means the need to reduce this number to limit the potential burden for the organization. Furthermore, with regard to a large number of indicators, many of them may be interdependent (Rodriguez et al., 2009), since they may possibly be based on the same data, or be linked in cause and effect relationships. Thus, in terms of saving the efforts needed for the performance analysis, the interdependent indicators should be eliminated, to leave only those being best for the performance evaluation in a given area.

Therefore, it is highly justified to search for such systems of OSH MS performance measurement which comprise a minimum number of higher-level key performance indicators (KPIs); however, the number of those KPIs would need to be sufficient for proper evaluation of OSH MS status in a given enterprise or a part thereof.

1.4. Aggregation versus selection of KPIs

In order to create a relatively small set of KPIs on the basis of a larger initial set of candidate indicators (PPIs) two basic approaches are possible: *aggregation* and *selection*. Below both those approaches are characterized briefly with the aim to provide a rationale for choosing the better one.

1.4.1. Aggregation of the indicators

Aggregation consists in determining the value of a higher-level performance indicator, with the aim to reflect values of all underlying indicators (sub-indicators) in a collective and synthetic manner. Such collective indicators are usually referred to as *integrated*, *aggregate* or *composite* indicators. In general the aggregation of the indicators can be performed by calculating one of the following means: *arithmetic*, *geometric* or *harmonic*, while the arithmetic mean, often also referred to as *linear*, is the most simple, and relatively the most widely applied method in the domain of management. However, a necessary condition for applying linear aggregation is that all sub-indicators should have the same measurement unit. On the other hand, the geometric aggregation can be applied disregarding measurement units, but the values of all sub-indicators should not be negative (Nardo et al., 2005). In the course of linear aggregation the value of composite indicator is often calculated as a weighted mean of constituent indicators, but the ordinary mean can also be applied, as well as standardized scales, which can be used to receive the aggregate value within a certain range, e.g. <0, 1>.

The KPIs received in the course of aggregation of sub-indicators are being applied in many business and public sectors, in order to measure and compare the performance between enterprises, countries, regions etc. The variety of such applications can be illustrated by just few examples, concerning evaluation of the eco-efficiency (Jollands et al., 2003), performance of public services (Jacobs and Goddard, 2007), and safety performance of nuclear power plants (Saqib and Siddiqi, 2008).

There were also some attempts to develop and implement aggregate performance indicators in the area of OSH, but measurement systems referred to in the literature are based either on lagging indicators, such as injury frequency rates and severity rates (Venkataraman, 2008), or on the mix of lagging and leading indicators, as reported e.g. by Marsden et al. (2004) and Walker and Cheyne (2005).

Despite the fact that the idea of measuring performance by means of aggregate indicators is promising and simple, many scholars indicate its significant shortcomings. For example the weights are usually assigned to individual sub-indicators in a subjective manner, as very often there are no sufficient data to calculate the weights objectively. Assigning the weights can also be the subject of certain pressures of individuals, groups or units, whose actions may have an impact on or depend on the value of a given indicator (Jollands et al., 2003; Nardo et al., 2005). Moreover, the necessary condition for application of aggregate indicator is the mutual independence of all underlying sub-indicators, which is not the case in the area of OSH management, where many processes are inter-related.

Furthermore, the application of aggregate indicators in the OSH management domain require collecting data on large number of sub-indicators, as values of all sub-indicators are needed to calculate the value of higher-level indicators. Therefore this method may not be considered as leading to the simplification of the system, saving the time and money for running the system, and reducing the burden associated with carrying out the measurement process.

1.4.2. Selection of the indicators

Taking into account the aforementioned shortcomings of the aggregation method the other approach should be considered and deliberated on, namely the selection of the most significant and representative indicators out of the relatively large number of initially defined PPIs. But, where such large number of PPIs is available, a decision-making problem appears, in which questions arise: which KPIs should be selected from a given set of PPIs, or how to prioritize these indicators. The problem in question implies the need for defining the criteria for evaluation and selection of KPIs, and employing a relevant method in the domain of multi-criteria decision making (MCDM) analysis. For the criteria for evaluation and selection of KPIs, a set being frequently recommended in the literature, e.g. in the publications by HSE (2001), McNeeney (2005), Shahin and Mahbod (2007) and Zwetsloot (2013b), is the set of criteria denoted by the acronym of SMART, which stands for: Specific, Measurable, Achievable, Relevant, and Time-bound. Other scholars recommend the application of differently formulated criteria for selection of performance indicators, yet the substantive sense of the majority of them coincides, to a large extent, with the SMART criteria. For example, Kjellen (2009), by referring to Rockwell's paper (1959), considers good indicators to be as follows: quantifiable, valid and representative, ensuring minimum variability of results for the measurement performed under the same conditions, sensitive to change, cost-effective, and comprehended by most users. On the other hand, Carlucci (2010), based on a review of various sets of criteria as provided in the literature, proposes the selection of indicators being characterized by the following features: relevance, reliability, comparability and consistency, understandability and representational quality.

With regard to the criteria for the selection of KPIs, one should also consider a need to apply the principle of balance among performance indicators, which is the basis for the successful implementation of the Balanced Scorecard – a world-wide known strategic management system developed by Kaplan and Norton (1996). First, the principle requires avoiding any dominant indicators in a given set, and second, there should be an appropriate balance between leading and lagging indicators, financial and non-financial ones, as well as between indicators reflecting performance of activities carried out in favour of external and internal stakeholders.

The proposed approach to develop a set of KPIs by their selection from a large number of PPIs is also encumbered by certain disadvantages. In particular, it is possible that monitoring performance of certain areas of OSH MS by means of one or few KPIs may provide the managers with not sufficiently clear or precise image of this area, which, in consequence, may lead to the reduction of a range of possible protective and preventive measures, which could have been implemented to remedy potential OSH problems. But this potential drawback should be taken into account and minimized in the course of selecting KPIs, particularly by addressing this issue when applying respective criteria.

Nevertheless, the selection-based approach to KPIs has a one unquestionable advantage over the aggregation, namely the potential for significant simplification of the measurement system, and thus reducing an administrative burden and the costs of running the OSH MS. By applying this approach one can focus firmly on a smaller number of KPIs without the necessity to carry out measurement of all possible indicators. Additionally, the selection-based approach does not require mutual independence of indicators subject to the selection process.

1.5. Prioritizing PPIs with the Analytic Hierarchy Process

The criteria for selection of KPIs, which are mentioned in Section 1.4., depend on the purpose for which they are used, thus have different weights depending on the type of activity which is to be measured, and also on the subjective users' opinions. For example, for measuring the performance of processes oriented towards achieving specific results expressed in figures, the measurability criterion may be of most significance. On the other hand, for the selection of KPIs which indirectly indicate the advancement of actions towards an objective being difficult to measure (e.g. the level of risk awareness acquired be employees in the course of OSH training), ensuring the relevance thereof to the objective in question may be more important.

There are numerous MCDM methods, which may be applied for the selection of KPIs from a given set of PPIs. Those most frequently applied and described in the literature include *inter alia*: AHP (Analytic Hierarchy Process), ANP (Analytic Network Process), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), ELECTRE (Elimination Et Choix Tradusant La Réalite), or SMART[2] (Simple Multi-Attribute Rating Technique). An analysis of the characteristics and applications of those methods is not, however, the subject of this paper. In this regard, the reader may refer to a wide range of literature describing the methods, e.g. to the publications by: Saaty (1977, 1980), concerning the AHP; Saaty (1996, 2005), concerning the ANP; Hwang and Yoon (1981), concerning the TOPSIS; Roy (1968, 1990), concerning the ELECTRE, and Edwards (1977) and Edwards and Barron (1994), concerning the SMART technique. Furthermore, numerous publications have come out which include a comparative analysis of many of those methods, e.g. by Belton (1986), Zanakis et al. (1998), Ishizaka and Nemery (2013), as well as an analysis of practical applications of those methods, e.g. by Mardle and Pascoe (1999), Pohekar and Ramachandran (2004), Kiker et al. (2005), and Ananda and Herath (2009).

An analysis of the literature on applications of MCDM methods indicates that one of the most popular and most widely applied in practice is the AHP (Analytic Hierarchy Process) method, as developed by the American mathematician Saaty (1977, 1980). The method in question involves the determination of various levels of importance for defined criteria, and subsequently an expert comparison and ranking of decision variants in relation to those criteria. Given the relatively low level of complexity, the availability of relevant supporting software, and the possibility for applying it for solving decision problems in numerous economy sectors and areas of science and technology, the AHP method has been widely employed in hundreds of documented cases, which is confirmed by literature reviews of applications thereof, as published by Vaidya and Kumar (2006), and Subramanian and Ramanathan (2012). A review of selected applications of that method in the domain of OSH is presented in Section 2.4., and a short description of its steps is provided in Section 2.2.

1.6. Goals of the study

The main goal of the study is to demonstrate the application of an AHP-based method for prioritization and selection of leading indicators measuring OSH MS operational performance. A point of departure for this experiment is an initial list of PPIs, i.e. the group of indicators, which provide information on the stage of advancement of individual processes within the system, drawn up on the basis of a literature review and author's experience. Next, on the basis of obtained ranks of individual PPIs, relevant KPIs will be assigned to individual components of the system, in order to ultimately obtain a relatively small set of KPIs allowing for a better and easier method to measure OSH MS operational performance with a focus on early detection of any irregularities and faults in the system.

2. Literature review

2.1. Measuring performance of OSH management systems

2.1.1. Main types and features of positive performance indicators

As mentioned above in Section 1.2, when searching for solutions allowing a better evaluation of the performance of OSH MSs' operation, one should focus on making use of pro-active performance indicators, and in particular indicators of operational performance (within the meaning as introduced e.g. by Cambon et al., 2005). This is because the monitoring of such indicators' values will allow getting a picture of how processes operate at the

[2] As regards the Simple Multi-Attribute Rating Technique method, its acronym (SMART) is not to be confused with an identical acronym referring to the set of SMART criteria as mentioned above and described further on in this paper.

shop-floor level within a given system, in contrast to measurements performed using structural performance indicators, which provide information only on the degree of design and formal implementation of individual components of the system.

A slightly different presentation of PPIs was provided by Reiman and Pietikäinen (2010) and Reiman and Pietikäinen (2012), who introduced the division thereof into drive indicators and monitor indicators. Drive indicators allow the measurement of the degree of execution of selected actions in priority areas of the management system, such as leadership, competence management, hazard control, change management, etc. On the other hand, monitor indicators reflect the potential and ability of a given organization to operate safely. The indicators in question refer to such areas as: work and safety motivation, understanding of hazards, understanding of safety, technological aspects of safety, or environmental variability.

2.1.2. A review of selected methods for measuring performance of safety management systems

In the literature on the performance of safety management, there are many reports on both the implementation of framework methods of performance measurement, comprehensively covering various areas of safety management, and on the application of selected or single leading indicators, as well as their impact on the frequency of accidents or other safety outcomes. A large proportion of those reports concerns research and guidelines on application of methods of performance measurements in process safety management systems (i.e. in systems for the prevention of major industrial accidents in process industries), or in systems of safety management in road and air transport, etc. Although some of the conclusions on process safety indicators referred to in this literature may include certain contributions to discussions in the domain of OSH management, due to the particular specificity thereof they do not allow to draw adequate and useful conclusions to be directly included in the domain of OSH. Therefore, in the further section, only the methods of performance measurement being typical and directly useful in the area of OSH MS are focused on.

In this section, 5 selected methods of OSH MS performance measurement are briefly described: (1) Safety Element Method (SEM), (2) Universal Assessment Instrument (UAI), (3) Self-Diagnostic OHS Tool, (4) Tripod Delta, and (5) Safety Climate Assessment Questionnaires. First 3 of those methods are included in the analysis conducted by Sgouru et al. (2010), which adopted the following evaluation criteria: (1) theoretical framework, (2) holistic features, (3) validation of the method, (4) required expertise, (5) flexibility, and (6) motivation for improvement. The results of this analysis show that none of the analysed methods sufficiently fulfils all the mentioned criteria; however, those criteria may provide a good basis for the selection of existing methods for specific applications, as well as for the development of new measurement methods. The descriptions of OSH MS performance measurement methods as provided below are directed neither at carrying out such an evaluation nor at the selection of the best method. The aim of the review is only to outline the general picture of the selection process and the general characteristics of PPIs being applied in various methods and frameworks for the measurement of OSH MS performance.

2.1.3. Safety Element Method (SEM)

The SEM method was designed for the evaluation and improvement of OSH management performance in the Norwegian mining sector within the context of supporting mining enterprises in their efforts to ensure compliance with the requirements of OSH legislation (Alteren and Hovden, 1998). SEM is a relatively simple method since it assumes carrying out the evaluation within 6 main elements and 12 sub-elements of OSH MS, and the values of assessments for individual elements are determined on a 5-level scale. The main 6 elements subject to the evaluation are as follows: goals and ambitions, management, feedback systems and learning, safety culture, documentation, and results indicators. The SEM method was practically verified as part of the pilot implementation in four Norwegian mines (Alteren, 1999), where it received positive users' feedback. Furthermore, following the verification, it was concluded that the ratings of OSH MS performance as obtained using the method in question were, in those enterprises, well correlated with OSH outcome indicators such as the lost time injuries frequency, and a severity rate of injuries.

2.1.4. Universal Assessment Instrument (UAI)

Universal Assessment Instrument (UAI) was conceptually developed at the University of Michigan (Redinger and Levine, 1998) in order to evaluate the performance of OSH MSs which, in that period, began to be widely disseminated in the USA and other countries. The initial version of the instrument consisted of 27 sections, 118 OSH MS principles, and 486 measurement criteria belonging to 5 categories: initiation – OSH inputs; formulation – OSH process; implementation/operation – OSH process; evaluation – feedback; and improvement/integration – Open System Elements). For the forming thereof, elements of four management system models were analysed and used: (1) a model used in the Voluntary Protection Programme (VPPPA, 1996); (2) British standard BS 8800:1996 (BSI, 1996); (3) an OSH MS model developed by the American Industrial Hygiene Association (AIHA, 1996); and (4) a model of environmental management system in accordance with the ISO 14001:1996 standard (ISO, 1996). UAI was subsequently implemented on a pilot basis, and tested in 3 enterprises (Redinger et al., 2002a,b). The tests showed that the UAI was able to evaluate various levels of performance of OSH management systems being measured, yet, being a rather complex instrument, it required certain competence from its users in order to be successfully applied.

2.1.5. Self-Diagnostic OHS Tool

The measurement tool developed by Roy et al. (2004, 2005) at the Canadian University of Sherbrooke (Quebec) was intended for subjective self-evaluation of OSH MS performance using the questionnaire method, and consisted of 67 statements-indicators divided into 9 subject areas: organizational systems, management commitment, employee responsibility, norms and behaviours, continuous improvement, prevention-oriented activities, organizational structures, communication, and workplace compliance. Respondents participating in the measurement were provided with a 10-point scale for expressing their opinions on proposed statements concerning activities within the framework of OSH MS. The tool was partially tested in three Canadian enterprises (Cadieux et al., 2006; Roy et al., 2008), yet the test results indicated the need for modification thereof in order to achieve a satisfactory validation level.

2.1.6. Tripod Delta

Tripod Delta is a comprehensive questionnaire-based tool as proposed for the measurement of OSH MS performance by a team of French and Dutch experts (Cambon et al., 2005, 2006). Theoretical foundations for the development of this tool were provided by a Tripod method developed at the University of Leiden and the University of Manchester for the needs of oil and gas industry. The Tripod method assumes that the most efficient manner of accident prevention is to control the working environment and identify its weak areas which may lead to human errors or system disturbances, and consequently to accidents. When developing this tool, the base of questions of the Tripod Delta Survey was used, which includes approx. 1500 validated questions aimed at identification of the above-mentioned weak areas. According to the authors of the tool, approx. 900 questions included in the base could have been used as indicators for the measurement of OSH MS performance. In the test version of the tool, 230 structural performance indicators and 90 operational performance indicators were applied. The indicators were assigned to appropriately specified 14 components of OSH MS, the model of which was proposed on the basis of an analysis of the requirements of both the OHSAS 18001 document and the ILO-OSH-2001 Guidelines.

The Tripod Delta tool was implemented on a pilot basis in one enterprise in the automotive sector in France (Cambon and Guarnieri, 2008). The testing results were positively received by the company management, and helped to demonstrate that safety of work is largely dependent on such factors as management concept, maintaining order and cleanliness, and efficient communication. In addition, the results of the implementation of the Tripod Delta questionnaire allowed the development of a more comprehensive plan of corrective actions, the improvement of communication between the management staff and employees, and the creation of conditions under which the employees could express their opinions and be involved in actions being directly related to them (Guarnieri, 2006).

2.1.7. Safety culture/climate assessment Questionnaires

Exploration of the level of safety culture using questionnaires for the measurement of safety climate is considered to be one of alternative methods of the evaluation of management performance in the area of OSH. Methodological foundations for evaluating the safety culture using the measurement of safety climate were proposed by Zohar (1980), and subsequently numerous researchers have employed the method to explore the employees' perception of and attitudes towards OSH-related problems, and to explore the correlation between the safety culture and the outcomes in terms of reduction accident rates, or the propagation of safety behaviours. Out of numerous papers concerning the subject matter of safety culture evaluation, publications by the following authors may be provided as an example: Flin et al. (2000), Mearns et al. (2003), Itoh et al. (2004), Gyekye (2005), Smith and Wadsworth (2009), Clark (2010), Biggs and Banks (2012), Frazier et al. (2013). In addition, the dissemination of methods of safety climate measurement was contributed to by *inter alia* providing access to on-line versions of questionnaires for measuring the safety climate, e.g. Safety Climate Tool (HSE, 2013), as well as the publication of tutorials supporting users in the selection and application of such tools, e.g. EU-OSHA (2011).

The relevant literature presents various approaches to the perception of the safety culture level as either a leading (positive) indicator or a lagging indicator of OSH management performance. A review of the literature as conducted by Payne et al. (2009) leads to the conclusion that the indicator in question exhibits both "leading" and "lagging" features at the same time, yet the application thereof as a leading indicator seems to be more advantageous. Zohar (2010) reports that after more than 30 years of research and experiments on the measurement of safety climate, it can be concluded that it is a robust leading indicator or predictor of an enterprise's performance, useful for obtaining favourable results in terms of safety management.

However, some researchers indicate some drawbacks of this method, especially pointing out the uncertainty of social research being conducted with the use of questionnaires. For example, it is not possible to accurately determine the extent to which employees are really convinced of the need for safe behaviour, and whether they provide true answers while being aware of the social expectations about their behaviour (Biggs and Banks, 2012). Moreover, a fairly significant limitation of the safety climate surveys rests in the need to involve all the workers of the enterprise, or at least their carefully selected sample, to fill in the questionnaires. Such undertakings are not easy to carry out and it usually implies certain costs. In order to make use of this method for measuring OSH performance level on an ongoing basis, the safety climate surveys should be repeated at least once or twice per year.

2.1.8. Correlation of positive indicators and occupational accident rates

In addition to the results of above-mentioned studies on the implementation of framework systems for the measurement of OSH MS performance, the literature provides examples of the applications of selected PPIs, which indicate the positive relationship between those indicators and the specific results of actions in the area of OSH, particularly in terms of the impact on the reduction in the rates of accidents at work. For example, Iyer et al. (2004) adopted the so-called Intervention Application Rate (IAR), being calculated on the basis of man-hours involved in work for the benefit of OSH. Actions covered by this PPI were carried out in a Canadian enterprise in the energy sector in the following four categories: raising OSH awareness and motivation, skill development and training, new tools and equipment design methods and activities, and equipment related activities. The study showed that the rate of accidents at work decreases exponentially while the value of adopted IAR grows.

In turn, Aksorn and Hadikusumo (2008), when exploring the performance of 17 programmes for the improvement of OSH in the construction sector in Thailand, noted that the greatest impact on the reduction in accident rate is exerted by actions in the following areas: accident investigations, safety inspections, control of subcontractors, and incentives for employees to work safely. Furthermore, Hinze et al. (2013), when discussing the concept of PPIs application in the construction sector, focused on two indicators: (1) percent of worker observations that were safe, and (2) number of positive reinforcements provided per 200,000 h). Based on the research conducted in a major American construction company, it was demonstrated that the indicators in question are very well correlated with the rate of accidents at work, i.e. with the basic outcome indicator measuring OSH performance.

2.1.9. Criteria for the selection of KPIs for OSH management

As mentioned in Section 1.3, the introduction of an effective method of OSH MS performance measurement requires the reduction in the number of applied PPIs down to several or a dozen or so most important KPIs. This implies the need for the selection, out of the set of available indicators, of only those best and most significant ones, while being guided by a set of relevant selection criteria. In the literature one may find various requirements, which are expected to be fulfilled by good indicators (e.g. Hale, 2009), but one of the most popular sets of criteria, used in management when setting goals and selecting performance indicators, is the set denoted by the acronym SMART (which stands for Specific, Measurable, Achievable, Relevant and Time-bound). Table 1 presents the meaning thereof, and provides their substantive equivalents as proposed in the literature. In particular, those are references to the criteria cited by Kjellen (2009) on the basis of the publication by Rockwell (1959), which concern the area of safety management, and to the KPI selection criteria as proposed by Carlucci (2010) for business management.

An analysis of the SMART criteria as provided in Table 1, and the comparison thereof with other criteria as proposed in the literature, show that the SMART criteria sufficiently cover the set of features which should be exhibited by good KPIs. The SMART criteria are recommended by many professionals in the domain of performance management systems. Therefore, those criteria, within the

Table 1
The meaning of SMART criteria and their references to other sets of criteria.

Criterion	Meaning of the criterion	Respective criteria by Kjellen (2009)	Respective criteria by Carlucci (2010)
Specific	The name of the indicator should precisely define the phenomenon under research, and should be comprehensive to all users The indicator should be appropriate for the measurement of effectiveness of the implementation of specific goals for a given action	Indicators should be comprehended by those in charge with the responsibility of using them	Understandability and representational quality: concise and unsophisticated
Measurable	It should be possible to technically measure the indicator's value based on a properly selected unit	Quantifiable and permitting statistical analyses	Comparability and consistency: the possibility for comparison of the indicator's value between enterprises, and of the values measured at different times
	Data for the measurement should be identifiable, and relatively readily available	Sensitive to change in environmental or behavioural conditions	
	The indicator should provide appropriate accuracy and repeatability of the measurement	Provide minimum variability when measuring the same conditions	Reliability: the indicator is fault-tolerant, and reliably measures what is to be measured; data for the measurement are available without high costs
	The indicator's values may be used for comparisons between enterprises or organizational units		
Achievable	The indicator's values should be achievable under given conditions and in the foreseeable period of time The resources (human, technical, information, etc.) necessary for the collection of data for the measurement should be sufficient	Cost of obtaining and using measures is consistent with the benefits	Not addressed
Relevant[a]	Measurement using the indicator should contribute to accomplishing the general objectives of a given system, process or action The indicator should be relevant to the operation of an enterprise or organizational unit, as well as for its users The results of the measurement using the indicator should be appropriate for fulfilling relevant requirements concerning documentation of the actions	Valid and representative of what is to be measured	Relevance: the indicator provides information which allows a proper adjustment of actions being carried out, or a proper forecast of the results of those actions in the future
Time-bound	It should be possible to determine the period in which a given value of the indicator may be achieved The time for achieving a given value of the indicator may be divided into successive stages	Not addressed	Not addressed

[a] Occasionally, in the literature the letter R represents the criterion of Realistic or Rational, by which it is understood that the indicator should represent the goal which the user is going to pursue, and that the goal is going to be achievable. According to the author, such a meaning of this criterion is included in the criteria of "Achievable" and "Relevant".

meaning provided in Table 1, were applied in the study described in subsequent sections of this paper.

2.2. Introduction to the Analytic Hierarchy Process (AHP)

The AHP method was developed by Saaty in order to solve complex decision-making problems in a relatively simple manner. The method is one of the multi-criteria decision analyses, and is applicable to solving problems containing more than one decision criterion. In this section, only a general outline of the AHP method is presented to the extent necessary to understand the process of selection of KPIs for the measurement of OSH MS performance. Readers interested in a more detailed description of the mathematical foundations and techniques of computer calculations used in the method in question may refer to the work of Saaty (1977, 1980) or Saaty and Vargas (2012), or other numerous publications and web-based tutorials which present, in an user-friendly manner, the method in question and the numerous practical applications thereof (e.g. papers by Forman and Gass, 2001; Haas and Meixner, 2005).

The AHP method is generally implemented in four following stages:

(1) decomposition of a decision problem and a construction of a hierarchical model of criteria and decision variants affecting the solution of the problem,
(2) pairwise comparison of the criteria, and generating the vector of weights for individual criteria,
(3) pairwise comparison of decision variants in relation to individual criteria, and generating the local weight vectors for those variants in relation to those criteria,
(4) determination of the vector of global preferences of decision variants, arranged in relation to the contribution of variants in achieving the objective of the ultimate decision problem.

In this case, we are dealing with a multiple decision problem, the aim of which is to select a certain number of KPIs for individual components of OSH MS through structuring, by the degree of significance, of the subsets of PPIs assigned to those components. The hierarchical model of this problem for the i-th component of OSH MS is presented in Fig. 1. The highest level of the hierarchy is the goal of the problem, the second level is the SMART criteria as applied for the ranking of PPIs (within the meaning specified in Table 1), while the third one is the decision variants i.e. the set of PPIs defined for the i-th component.

In stages 2 and 3, when comparing the individual objects in pairs, square comparisons matrices A are created in the following form (1):

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ 1/a_{12} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ 1/a_{1n} & 1/a_{2n} & \dots & 1 \end{bmatrix} \quad (1)$$

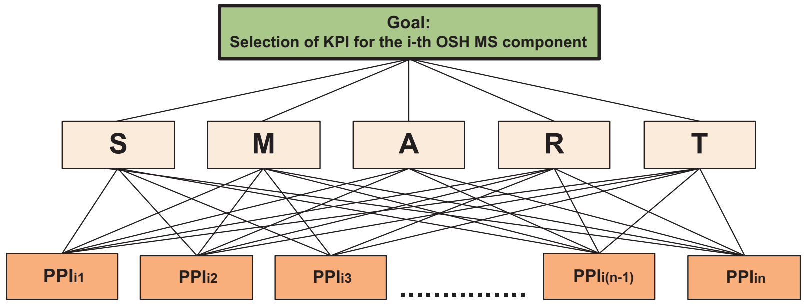

Fig. 1. A hierarchical model of i-th decision-making problem concerning prioritisation of the PPIs for the i-th component of OSH MS.

where values of elements a_{ij} indicate to what extent object X_i being compared is preferred to object X_j.

For the elements located on the diagonal of matrix A, i.e. for $i = j$, numerical values $a_{ij} = 1$. In the next steps, the square of the comparison matrix is calculated, and the values obtained are summed in each row. The result of the summation is an eigenvector of the matrix, which is then normalized so that the sum of its elements is 1. The process of squaring the matrix is repeated until the eigenvector of the matrix stops changing. Numerical values of the elements of that vector represent the resulting weights (ranks, preferences, the level of significance, priorities) of individual objects.

In stage 2, the objects being compared are criteria, and performing of the above operations leads to obtaining a vector of weights of individual criteria (V_k). In stage 3, the objects being compared are decision variants, and they are compared in pairs in relation to each individual criteria. Therefore, in stage 3, matrix A_n is constructed as many times as there are various criteria, and for each of them the above calculations are made. Thus, eigenvectors V_n of a given matrix A_n represent the weights of individual decision variants in relation to criterion n.

Both prioritisation of the criteria in stage 2 and prioritisation of decision variants in stage 3 are performed through the pairwise comparison of individual objects, using the basic predominance rating scale of 1–9, as proposed by Saaty (Table 2). In principle, the evaluators are expected to express their ratings in odd numbers (1, 3, 5, 7 and 9), while even numbers (2, 4, 6 and 8) are used where there is no consensus in the group of evaluators as to the predominance ratings being expressed in odd numbers. In certain applications, the use of a limited scale of 1–7 is permitted where difficulties may occur among the evaluators with distinguishing the verbal ratings: very strong predominance (rating 7), and extreme predominance (rating 9) of one object over another.

In the final stage 4, the vector of global preferences of decision variants is determined by calculating the sum of products of the weights of individual variants as specified in vectors V_n, and the weights for a given criterion resulting from vector V_k. Arranging the objects being compared by their corresponding numerical values from the highest to the lowest reflects the ranking of objects obtained as a result of the AHP analysis.

Table 2
Basic rating scale for pairwise comparison of objects in the AHP method.

1	Equal
2	Between equal and moderate
3	Moderate
4	Between moderate and strong
5	Strong
6	Between strong and very strong
7	Very strong
8	Between very strong and extreme
9	Extreme

A significant element of the AHP analysis is the calculation of consistency index CI (2) and consistency ratio CR (3) for each comparison matrix, which indicate the extent to which ratings provided by a given expert are mutually consistent:

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

where λ_{max} is the highest matrix eigenvalue, n is the number of objects being compared, and RI is the random index, the value of which is determined depending on the matrix dimension n on the basis of a table as proposed by Saaty (1998). The comparisons are assumed to be internally coherent when $CR \leqslant 0.1$. Otherwise, it must be considered that inconsistencies have occurred in the comparison process, and therefore the comparisons must be repeated while verifying the awarded ratings.

2.3. Software tools applied for the AHP analyses

The analyses using the AHP method can be performed easily and quickly with the support of numerous available IT tools. Those to be mentioned here include *inter alia* the Expert Choice software as developed by Saaty, and in particular its web-based version Comparion Suite (http://expertchoice.com), as well as many other software tools available either free of charge or for a fee in an on-line version or as stand-alone packages, e.g. Hipre 3+ (Mustajoki and Hämäläinen, 2000), ABC AHP (Oregon State University, 2012), Decision Lens (http://www.decisionlens.com), and MakeIt-Rational (http://makeitrational.com).

In this study, all AHP analyses were performed using the MakeItRational tool, which had been selected due to the simplicity of constructing hierarchical models and making comparisons, as well as a comprehensible user's manual in the form of several video tutorials available on the website. Favourable opinions on the tool in question are also expressed by other researchers, *inter alia* Sabharwall et al. (2011) and Ishizaka and Nemery (2013).

2.4. Examples of AHP method applications in occupational safety and health domain

In order to verify the possibility of using AHP for the selection of KPIs that would be assigned to individual OSH MS components, a literature-based review of OSH-related AHP applications has been conducted. The review revealed that this method had been successfully applied in various studies in the OSH domain. Below, several selected examples are provided, which illustrate the diversity of possible AHP applications in this domain.

2.4.1. Prioritization of OSH issues and elements in OSH management systems

One of the first applications of the AHP in OSH management domain was a study conducted by Jervis and Collins (2001), which concerned the ranking of main areas of OSH MS in the order of the corresponding cost-benefit ratio for actions for the benefit of OSH. The aim of the research was to indicate to the managers the areas worth investing in due to their potentially highest return on investment ratio. Similar AHP-based research was conducted by Chan et al. (2004), who focused on the implementation of OSH MSs in construction companies in Hong Kong in accordance with the model as specified in standard BS 8800 (BSI, 1996). Analogous research on the prioritization of OSH management system components was repeated in Hong Kong several years later, at that time focusing on larger production enterprises (Law et al., 2006).

In the study focused on OSH in the construction sector, Teo and Ling (2006) employed the AHP for establishing the hierarchy of issues taken into account by contractors of construction projects when attempting to ensure a high level of work safety on building sites. Another study related to OSH in construction has been reported by Shapira and Simcha (2009), who employed the AHP for establishing the hierarchy of significance for the impact of 21 various organizational, technical, environmental and human factors on work safety on building sites, which were associated with the use of tower cranes.

2.4.2. Decision support in occupational risk assessment processes

Another field for AHP applications is supporting processes of occupational risk assessment and management. One of the examples is a study, which concerned the development of a new model of occupational risk assessment being adapted to the needs of SMEs (Fera and Machiaroli, 2010). Application of the AHP allowed the authors to propose a new approach to establishing priorities of risk factors in SMEs, the main concept of which is to depart from the fixed list of main types of hazards towards the flexible development of a list of risk factors.

Other research on the AHP-based risk assessment involved comparing the weight of risk factors, such as mechanical, electrical, human and other ambient physical factors and nuisances, in relation to the potential ability to trigger the so-called undesirable events, which included work-related illnesses, drop in productivity, drop in quality, inadequate design, pollution, and explosion and fire (Badri et al., 2012). A similar approach was reported by Aminbakhsh et al. (2013), who compared the impact of various factors of occupational risk within the context of taking into account the relevant protective and preventive actions at the time of planning and budgeting of construction designs.

2.4.3. Decision support when selecting production equipment and protective equipment

The AHP method may also be successfully employed for supporting decisions concerning the selection and use of technical means of production and protective equipment. For example, Maldonado-Macias et al. (2010) employed the AHP for the evaluation of the extent to which the criteria of ergonomics and safety of operation are taken into account when selecting equipment to be purchased and installed in advanced manufacturing technology enterprises. In the next example study, Caputo et al. (2013) applied this method for setting priorities for the use of various equipment ensuring safety when operating machines, such as a fixed enclosing guard, mobile enclosing guard, safety light curtain and two hands control system.

2.4.4. Application of fuzzy versions of AHP method in OSH domain

The afore-mentioned AHP applications in the domain of OSH related to the original version of the method, as proposed by Saaty (1977, 1980), in which the participants' verbal opinions referring to both the criteria being compared and variants of decision correspond to precisely defined numerical values (usually natural numbers within the range of 1–9). Some scholars, however, challenge the appropriateness of such scale, since in real-life situations it does not reflect the inherent imprecision and vagueness which are naturally associated with the presentation of human preferences and decisions in the form of specific numbers. Therefore, fuzzy versions of the AHP method were developed, in which either study participants express their preferences in the form of intervals or where one verbal variable corresponds to several approximate numerical values (Laarhoven and Pedrycz, 1983). That version of the method has found wide application in solving decision problems in numerous sectors of business and social activities, although Wang et al. (2008) indicated some of its drawbacks, mainly due to the fact that results fail to reflect the relative significance of the criteria and decision alternatives being compared.

Despite those objections, just two examples of studies applying the method may be noteworthy, in order to present a broader spectrum of possible research concepts in the domain of OSH. In the first one Dağdeviren and Yüksel (2008) determined the impact of various factors occurring in work systems on faulty behaviour risk. The authors made an expert comparison of the relative impact of 14 various factors divided into 4 categories: organizational, personal, job related and environmental. In the second study Zheng et al. (2012) applied the fuzzy AHP for the evaluation of safety and health conditions in hot and humid environments of underground mines. The research compared the impact on working conditions of 10 factors grouped in 3 categories: work, environment, and worker-related.

3. Methodology

3.1. General overview of the methodology

The study aimed at the selection of a limited number of KPIs for individual components of OSH MS was conducted in 3 main stages, as presented in Table 3.

In the 2nd stage of the study for the expression of opinions in the processes of AHP pairwise comparison, a team of 5 experts, namely researchers of the Department of Occupational Safety and Health Management of CIOP-PIB, was employed. The R&D activity of this Department is focused on the development of innovative methods and tools supporting managers in improving OSH management performance, also including such issues as criteria for the evaluation of OSH MS, occupational risk assessment methods, analysis of accidents and incidents at work as well as cost-benefit analyses of OSH-related interventions. All members of the team, including the author, have carried numerous projects on OSH management in close collaboration with enterprises, namely with senior managers, safety managers and employees' representatives. Team members are also experienced consultants and trainers on OSH management systems; two of them participate actively in the works of national and international technical committees and expert groups, which elaborate standards and guidelines on OSH management.

The 3rd stage of the study was carried out by the author on the basis of analysis of the literature and his expertise in the field of OSH MS standardization, implementation, and conformity assessment.

3.2. Developing a list of PPIs for individual components of OSH management system

A starting point for the development of the initial set of PPIs for the measurement of effectiveness of actions in various areas of

Table 3
Main stages of methodology applied for the selection of KPIs for OSH MS components.

No	Name of the stage	Actions performed
1.	Development of the initial set of PPIs for the measurement of OSH MS performance	• Analysis of normative documents on OSH MS (ILO-OSH 2001, OHSAS 18001, etc.) with regard to • Analysis of the scientific literature, guidelines, tutorials and other materials • Determination of an OSH MS model (broken down into main components) as a basis for defining the PPI subsets • Development of PPI subsets for individual components of OSH MS
2.	Determination of ranks for individual SMART criteria for the selection of indicators	• Analysis of the scientific literature on applications of the AHP method • Analysis of guidelines, tutorials and other informative materials • Construction of a hierarchy model for the decision process within the framework of the AHP method • Entry of data on SMART criteria into the AHP software tool[a] • Pairwise comparison of SMART criteria (in a session with experts), and generating a SMART weight vector
3.	Prioritization and selection of KPIs for individual components of OSH MS	• Entry of data on PPI sets into the AHP software tool • Pairwise comparison of PPIs in subsets assigned to individual components of OSH MS • Generating the PPI weight vectors, and the selection of KPIs with highest priorities

[a] In this study, all AHP analyses were performed using the MakeItRational tool (see Section 2.3).

OSH MS was the adoption of a relevant model of the system, which allows developing the list in a structured manner. Currently there are many models of formal OSH MSs in use worldwide, most of which are based on the continual improvement cycle frequently referred to as the PDCA (Plan-Do-Check-Act) cycle. Due to the fact that at the time of conducting the study there was only one generally accepted international standard concerning OSH MS, namely ILO-OSH 2001 guidelines (ILO, 2001), a model as specified in this document was adopted as a general framework for describing and structuring the components of OSH MS. In addition, in terms of the overall concept and structure, that model is equivalent to many other models of OSH MS as proposed in numerous other normative documents and guidelines, or as discussed in the literature (e.g. Redinger and Levine, 1998; Chan et al., 2004; Law et al., 2006).

The original ILO model consists of 5 main areas (Policy, Organizing, Planning and Implementation, Evaluation, Action for Improvement) which are further divided into a total of 16 components, of which one (namely Hazard Prevention) consists of 5 significant subcomponents (Prevention and control measures; Management of change; Emergency preparedness and response; Procurement, and Contracting). In order to facilitate both the drawing up of a list of performance indicators and further analysis, the model in question was modified after having adopted a single-level structure consisting of 20 main components; however, the substantive contents thereof were defined in such a manner so as to fulfil all ILO guidelines criteria for OSH MS. The list of components of the thus modified OSH MS model, designated by the letters from A to T, is provided in Table 4.

Initial subsets of candidate PPIs for measuring performance within the framework of individual components of OSH MS have been obtained as results of a review of PPIs as proposed in the selected literature, as well as result of analysis of lists of PPIs recommended in various sectoral guidelines on effectiveness of OSH management. The literature sources have been considered for the review if their essential subject matter corresponded with the applications of leading performance indicators in the field of OSH, and if the indicators referred to in these sources were relatively numerous and constituted a coherent performance measurement system covering at least several OSH MS components or processes. In particular the publications by the following authors have been considered: Shaw, 1994; Toellner, 2001; Basso et al., 2004; Iyer et al., 2004; Grabowski et al., 2007; Dingsdag et al., 2008; Carson and Snowden, 2010; Bellamy & Sol, 2012; Hinze et al., 2013. As regards guidelines for the improvement of OSH management performance, lists of indicators provided in documents published by the following organisations have been

Table 4
List of main OSH MS components which form the basis for defining the initial sets of PPIs.

Symbol	OSH MS main component
(1) Policy	
A.	OSH policy
B.	Workers' participation
(2) Organizing	
C.	Responsibilities and accountability
D.	Delivering OSH training
E.	Evaluation and improvement of OSH programmes
F.	OSH MS documentation
G.	Communication
(3) Planning and implementation	
H.	OSH goals and improvement plans
I.	Risk assessment processes
J.	Implementation of risk control measures
K.	Management of change
L.	Emergency preparedness and response
M.	Procurement
N.	Contracting
(4) Evaluation	
O.	Performance monitoring and measurement
P.	Investigation of work-related accident, diseases and incidents and their impact on OSH
Q.	Management system audit
R.	Management review
(5) Action for improvement	
S.	Preventive and corrective action
T.	Continual improvement

investigated: Step Change in Safety (SCS, 2003); The Chamber of Minerals & Energy, Western Australia (CME, 2004), Victorian WorkCover Authority (VWCA, 2011), and International Council on Mining & Metals (ICMM, 2012).

The process of the compiling an initial set of PPIs was approached in 3 steps. Firstly, leading OSH performance indicators listed in the mentioned sources have been reviewed and extracted, with a particular aim to qualify only those that are able to measure operational status of management system processes; this implied in general, that simple quantitative indicators were left out of consideration, as they are only adequate to measure structural system performance.

Secondly, the lists of extracted PPIs were screened in order to eliminate indicators used in a narrow scope, and often to reflect specific technical problems related to OSH conditions characteristic for certain sectors or production technologies, or used in specific variants of OSH management systems. A few examples of such eliminated indicators include: frequency of technical inspections of specific installations or devices, percentage of given machines that have received planned maintenance or percentage of workers who have completed special courses or were permitted to carry out jobs requiring special skills or knowledge. The effectiveness and necessity for using these indicators for OSH MS performance measurement has not yet been disputed by their elimination to any extent, however, it was assumed that for the purpose of this study, one should focus on the selection of universal indicators, i.e. particularly ones that refer directly to the requirements for organizational arrangements characteristic for the components of the adopted OSH MS model, and may be generally and broadly applied in enterprises throughout various sectors, disregarding specific technologies and working conditions.

Finally, the remaining PPIs have been assigned to individual OSH MS components, according to the model presented in Table 4. The redundancy where various literature sources recommended similarly defined indicators, or indicators formulated differently but based on the same input data, has been eliminated by keeping only one of the redundant or similar indicators, thus resulting the remaining indicators being mutually exclusive.

As a result of the selection process described above, an initial list of PPIs has been compiled and is presented in Annex 1. The list includes 109 indicators in total grouped in 20 subsets corresponding to 20 main components A-T of the adopted model of OSH management system.

The PPI subsets derived in this process consist of indicators of diversified structures and quality, i.e. some constitute relatively simple counts of actions to be carried out within OSH MS, and the others are the fractions expressed in percentage. Such different forms of indicators are often proposed in the literature within the same measurement systems; for example SCS (2003) defines one indicator to be a *number of management safety visits completed* (i.e. a simple count of actions), but also defines another one as a *percentage of jobs for which risk assessments are carried out*. Therefore it was assumed that at this stage such a diversity of indicator forms is acceptable. As one may expect the indicators that do not reflect good practice of performance measurements are likely to be eliminated at a later stage when they are confronted with the SMART criteria.

4. Results

4.1. Weighting SMART criteria for the selection of OSH management performance indicators

An example of the application of SMART criteria for the selection of KPIs using the AHP method was described by Shahin and Mahbod (2007), but their study concerned the selection of KPIs for overall management systems, and the case study as presented in the publication concerned indicators for measuring business performance of a hotel. As regards our study, the meanings and weights of SMART criteria have been chosen specifically for the selection of KPIs for the measurement of OSH MS performance. Particularly the meanings of individual criteria as described in Table 1 were provided to and used by the experts involved in the analysis. At the same time, it was assumed that the target set of KPIs should be homogeneous in terms of the conditions applied for selection of KPIs from all the subsets of PPIs, and therefore in all analyses the same weights of SMART criteria were applied for pairwise comparisons of PPIs.

Taking account of the subsequent steps of the AHP method (as described in Section 2.2), the team of experts made a pairwise comparison of individual SMART criteria, thereby creating a matrix of comparisons. Next, as a result of appropriate calculations, a following vector of SMART weights was obtained: [$S = 0.0822$; $M = 0.2529$; $A = 0.1448$; $R = 0.4384$; $T = 0.0817$].

The highest significance (ca. 44%) has been attributed to the "Relevant" criterion i.e. the relevance of the indicator to the actions performed in a given area of OSH MS, and to the adequacy thereof within the context of the contribution to the achieving of overall objectives for a given area of activity as well as the entire system. The second highest significance (ca. 25%) was attributed to the "Measurable" criterion, thus emphasising that KPI should have such characteristics as to allow for technical measurement of the indicator's value, and that the data should be identifiable and relatively readily available to persons involved in the measurement. The measurable features of KPI should also include its validity (i.e. measuring parameters which actually reflect the activities subject to performance assessment) and its reliability (i.e. measuring with consistency).

For the remaining criteria, adequate attention should also be paid to the "Achievable" criterion with a weight of 14.5%. This is because the KPIs' features should be selected in such a manner so that its values being set to be achieved were ambitious, yet at the same time achievable under given conditions. The remaining two criteria, namely the "Specific" (S) and "Time-bound" (T), were evaluated as the least significant at an almost identical level of approx. 8%.

4.2. Selecting KPIs for OSH management system components

As previously mentioned, the basis for the selection of KPIs measuring OSH MS performance was a set of 109 PPIs divided into 20 sets respectively to individual components of OSH MS. The set of PPIs is provided in Annex 1 along with the indication of the corresponding provisions of guidelines ILO-OSH 2001. The number of PPIs in individual subsets is varied, and ranges from 4 to 9.

For each subset of PPIs, a hierarchical model of the decision-making process was constructed (according to the structure provided in Fig. 1), i.e. a total of 20 models were constructed, and within each of them pairwise comparisons of PPIs were made in relation to SMART criteria (taking account of their afore-mentioned weights), thus creating 20 comparison matrices. Verification of the internal consistency (CR) of these matrices was being performed by the software tool on an on-going basis when entering the subsequent ratings. In case of no consistency, a verification of the analysis and a respective correction of the previously entered ratings were performed.

Results of the calculations in the form of vectors of local (in relation to a given criterion) and global preferences of PPIs for individual areas of OSH MS are presented in Table A (see supplementary data). Designations of PPIs in that Table correspond to the designations of respective PPIs as provided in Annex 1.

4.3. Final list of KPIs for measuring OSH MS performance

A review of the values of global preferences for PPIs in individual areas of OSH MS showed that in many areas one might indicate not one but 2 or 3 PPIs with high preference values being very similar to each other (differences of the order of several per cent). It was therefore assumed that for each OSH MS component, one KPI of the highest rank would be proposed, and also that 1 or 2 "alternative" KPIs with slightly lower values of global preferences would be additionally assigned to selected components. Thus, the final set consists of 20 main KPIs and 14 alternative KPIs. The list of KPIs thus assigned to the components of OSH MS is provided in Table 5.

The notion of "alternative KPIs" means that such indicators may be considered by managers to be applied instead of the ones determined as "main KPIs". Therefore, assuming that the OSH MS model consists of 20 components, the maximum number of KPIs to be used for measuring its performance should still remain 20.

Table 5
The final set of KPIs assigned to individual OSH MS components.

OSH MS component	KPIs (main[a] and alternative)
Policy	
A. OSH policy	**A_1: Number of OSH policy reviews and updates carried out by top management**
	A_2: Percentage of workers declaring good knowledge of OSH policy
	A_3: Number of safety walkthroughs performed by top managers
B. Workers' participation	**B_1: Number of OSH improvements proposed by workers**
	B_2: Number of OSH Commission meetings on regular OSH issues
Organizing	
C. Responsibilities and accountability	**C_1: Percentage of work posts with defined OSH responsibilities and duties**
D. Delivering OSH training	**D_1: Percentage of workers participating in OSH refresher courses**
	D_2: Number of hours for OSH training per person
E. Evaluation and improvement of OSH training programmes	**E_1: Percentage of OSH training courses reviewed and improved for their quality and effectiveness**
F. OSH MS documentation	**F_1: Percentage of OSH MS procedures improved due to corrective actions**
	F_2: Percentage of workers participating in trainings on OSH MS structure, procedures, etc.
G. Communication	**G_1: Number of meetings conducted by managers to inform workers on OSH issues**
	G_2: Rating of the effectiveness of OSH communication via workforce survey
	G_3: Number of issues of company's OSH bulletin or other internal OSH publications
Planning and implementation	
H. OSH goals and improvement plans	**H_1: Number of measurable OSH improvement goals established in the enterprise**
	H_2: Percentage of tasks in OSH improvement plans verified and accepted with regard to the quality and effectiveness
I. Risk assessment processes	**I_1: Percentage of periodically verified risk assessment processes with regard to their validity and correctness of risk control measures applied**
J. Implementation of risk control measures	**J_1: Percentage of workers informed on risk levels and risk control measures applied**
	J_2: Number of risk control measure implementations with hierarchy of measures considered
K. Management of change	**K_1: Number of analyses of impact on OSH carried out with regard to changes in OSH regulations, technologies and knowledge**
	K_2: Percentage of workstation with risk assessment verified in course of introduction of new machinery, materials, changing work method etc.
L. Emergency prepared-ness and response	**L_1: Percentage of workers trained on emergency procedures, including rescue activities and first aid**
M. Procurement	**M_1: Percentage of periodically verified OSH requirements applied in purchase specifications**
	M_2: Percentage of purchased larger objects for which risk assessment has been carried out prior to bringing them into use
N. Contracting	**N_1: Number of contractors assessed for their compliance with OSH management requirements**
Evaluation	
O. Performance monitoring and measurement	**O_1: Percentage of definitions of leading and lagging performance indicators subject to periodical review and update**
P. Investigation of work-related accident, diseases and incidents and their impact on OSH	**P_1: Number of corrective and preventive actions carried out as a result of root cause analyzes of work-related accidents, diseases and incidents**
	P_2: Percentage of medical consultations carried out within the programme of workers' health surveillance
Q. Management system audit	**Q_1: Percentage of OSH MS components or processes subject to assessment during internal OSH MS audits**
R. Management review	**R_1: Percentage of recommendations formulated by top managers at OSH MS reviews considered in OSH improvement plans**
Action for improvement	
S. Preventive and corrective action	**S_1: Percentage of completed corrective and preventive actions in relation to all actions initiated by OSH MS audits and reviews, OSH performance monitoring, and root cause analyses of work-related accidents, incidents and diseases**
	S2: Percentage of completed corrective actions reviewed and evaluated for their effectiveness
T. Continual improvement	**T_1: Number of new OSH goals and objectives established in the framework of OSH MS continual improvement**
	T_2: Number of OSH management KPIs subject to benchmarking with other companies

[a] Main KPIs are indicated in bold.

One may argue that despite the significant reduction of the initial set of 109 PPIs down to 20 KPIs, the final number of KPIs is still too large to be easily managed in enterprises. However not all KPIs should be measured and reported at the same time and frequency. A practical arrangement, limiting the administrative burden related to OSH MS performance measurement, could be the determination of which KPIs should be measured more frequently, e.g. once a week or month, and which could be reported less frequently, e.g. every 6 months or annually.

5. Discussion

5.1. Perspectives for the exploitation of study results

The primary goal of the study, namely the demonstration of prioritization of leading indicators of OSH MS operational performance using the AHP method, was achieved. The composition of initial sets of PPIs subjected to prioritization was based on a review of selected literature on safety performance indicators, and thus it was *a priori* assumed that all 109 PPIs being analysed were relevant to the measurement of OSH MS operational performance.

Application of all those indicators within one system would undoubtedly ensure a large volume of data and high reliability of performance measurements being carried out, yet it would not be purposeful and possible in the industrial reality due to the large amount of costs incurred. This is because systems based on such a large number of indicators would be very complex, require maintaining extensive documentation and records associated with the measurement of so many indicators, and would also generate high labour intensity among managers and the personnel involved in OSH-related actions. Therefore, the goal of the performed prioritization of PPIs was not the selection of indicators being just **relevant** to the measurement of OSH MS performance, but the selection of indicators being **the most relevant**, and thus the reduction in measurement and monitoring actions down to a much lower number of KPIs, which involves much lower operational costs of maintaining such systems.

The list of KPIs as provided in Table 5 requires further studies and validation in various industry sectors, yet it is a starting point for the development of other sets of KPIs which would be tailored to specific determinants of an enterprise, such as the size, organizational structure, the industry sector or the type of activity, the type of occurring hazards and the level of associated risk, as well as the level of safety culture or the maturity of the OSH management system being in place in a given enterprise. In this regard, particularly the use of alternative KPIs as presented in Table 5 will need to be considered, since managers may, for the above-mentioned reasons, prefer and select for the application those indicators or other similar ones, and not the KPIs for which the highest values of global preferences were assigned.

The implementation of procedures for monitoring KPIs in enterprises as part of their OSH MS will allow managers to respond more effectively to the earlier indications of irregularities in the operation of OSH MS. The data from KPIs' monitoring may also be used by internal and external auditors of OSH MS for the evaluation of effectiveness of the implemented organizational solutions in terms of their potential for ensuring the continual improvement of all actions and processes within the OSH MS. In addition, the KPIs being measured at the level of company's individual divisions or departments may be applied for the inter-departmental benchmarking, which will provide the management with relevant information allowing them to take decisions and actions associated with e.g. the verification of the established goals and adopted action plans as regards OSH, or the reallocation of resources as allocated to such actions.

5.2. Limitations of the study and recommendations for further research

The study was targeted at demonstrating a concept of enhancing the measurement of OSH MS performance by using a minimum number of KPIs. Since the proposed set of selected KPIs is based on opinions of the author (supported by a group of experts in the 2nd stage, when ranking of SMART criteria has been performed), further research to validate that concept is necessary. First, the results of the KPIs selection process should be verified and endorsed by involving more OSH experts in this process. Then, the proposed KPI-based model of OSH MS should be tested by means of pilot interventions, which could be implemented in selected enterprises already maintaining OSH MS.[3] It can be assumed that further studies will ultimately lead to the development of various sets of KPIs to be recommended for application by enterprises operating in various sectors, or being different in terms of the size or the type and rank of hazards occurring therein.

Moreover, when making comparisons of PPIs using the AHP method, it was initially assumed that the target set of KPIs for the measurement of OSH MS performance should be homogeneous in terms of the criteria of selection of KPIs from the sets of PPIs, which means that for the selection of KPIs for all components of OSH MS, the same weights of SMART criteria will be applied. However, that assumption requires a thorough verification through analyses and consultations with experts and managers in the domain of OSH, since certain areas of OSH MS may require e.g. more *measurable* indicators, and others more *relevant* ones, while still others require ones e.g. more *achievable* or *specific* for a given area. This limitation, however, should be considered and explored with care, since the potential assignment of various weights of selection criteria to various OSH MS components may significantly complicate the analyses being performed using the AHP method, and thus reduce the transparency of that method in terms of it being accepted and applied in the future by OSH managers.

Another subject of future studies may be the validation of the selection of KPIs being obtained using the AHP method with the selection of KPIs as performed using either other MCDM methods or e.g. the Delphi method. Section 1.5 mentions methods being most frequently employed in this domain, and it would be appropriate to check on their suitability for the research problem in question, and in particular to compare the resulting sets of KPIs with those obtained using the AHP method.

6. Conclusions

Despite the fact that OSH MS have been implemented and maintained in numerous enterprises all over the world for more than 20 years, there has so far been no sufficient evidence that these systems are effective in terms of preventing and reducing the number of accidents at work and occupational diseases. Therefore the further development and dissemination of OSH management systems depends on the ability to demonstrate that such systems can be effective, which may be achieved by implementing suitable methods and tools, aimed at the stimulation of operational performance of those systems.

In line with the mentioned demands, the paper presents a concept of making use of operationally focused minimum set of key performance indicators assigned to individual OSH MS components. This approach will make it possible to measure, at a basic level, the performance of such a system, and provide reliable data for the genuine improvement of OSH management practices.

The study has demonstrated that the Analytic Hierarchy Process can be successfully applied in the process of selecting the KPIs out of a larger set of candidate PPIs, particularly when this process is based on the utilisation of SMART criteria (i.e. Specific, Measurable, Achievable, Relevant and Time-bound). Having had such KPIs implemented at the enterprise level, they could provide managers with a synthetic and concise picture of the system performance, and would allow them to respond more quickly and effectively to early warnings of irregularities in the operation of OSH MS detected across all system components.

The proposed approach may be especially adapted in enterprises for determination of their own individual sets of KPIs, which would be tailored to their specific conditions, type of economic activity, level of safety culture, or the stage of advancement of OSH MS being in place.

Acknowledgments

The concept and the AHP-based method of the selection of KPIs for measuring operational performance of OSH management system, which is proposed in the article, have been adopted for further elaboration and validation within a research project entitled *Development and validation of a KPI-based method and a user-friendly software tool for resilience-focused measurement of OSH management system performance (KPI-OSH Tool)*. The project was initiated in 2013 in response to the SAF€RA first joint call for trans-national research proposals. SAF€RA is an ERA-NET project entitled *Coordination of European Research on Industrial Safety towards Smart and Sustainable Growth*, funded by the European Commission in the 7th Framework Programme on Research, Technological Development and Demonstration (Grant Agreement No. 291812). The SAF€RA consortium aims at coordinating the research investment

[3] The activities aimed at further development and validation of the KPI-based concept of measuring performance of OSH management systems have already been undertaken within an international research project KPI-OSH Tool (see Acknowledgments).

among the EU Member States in the field of industrial safety (see: http://www.safera.industrialsafety-tp.org).

The KPI-OSH Tool project runs from May 2014 till June 2016. It is carried out by an international consortium composed of three partners: CIOP-PIB (Central Institute for Labour Protection – National Research Institute, Poland), FIOH (Finnish Institute of Occupational Health, Finland) and Tecnalia Research & Innovation, Spain (see: www.oshkpitool.eu). Within a framework of SAF€RA the contribution of the mentioned partners has been funded as follows: in Finland – by FIOH and the Ministry of Social and Health Affairs, in Poland – by CIOP-PIB, and in Spain, Basque Country – by Instituto Vasco de Seguridad y Salud Laborales (OSALAN).

Appendix A . Initial list of PPIs composed of 20 (A-T) subsets for measuring performance of individual OSH MS components

Summary of respective OSH MS provisions	PPIs for measuring operational performance of respective OSH MS components
Policy	
A. OSH policy	
• Establishment by the employer of the OSH policy in consultation and agreement with the workers. • Defining contents of OSH policy, including employer's commitment to the prevention of accidents and diseases, compliance with OSH regulations and standards. • Ensuring that workers and their representatives are consulted and involved in all activities of OSH MS.	B1. % of workers' representatives appointed for OSH issues (in relation to all workers) A1. Number of OSH policy reviews and updates carried out by top management in consultation with workers A2. Number of top management meetings with OSH issues in the agenda A3. Number of safety walkthroughs performed by top managers A4. Rating of top management commitment in OSH management via workforce survey A5. % of enterprise budget spent on OSH improvement activities A6. % of workers declaring good knowledge of OSH policy of the enterprise A7. % of OSH applicable regulations and standards observed in the enterprise
B. Workers participation	
• Underlines that workers participation is the main factor ensuring OSH MS effectiveness. • Requirement for consulting the workers regarding OSH activities and introduction of solutions which encourage participation of workers in OSH MS activities, including the OSH Commission.	B1. % of workers' representatives appointed for OSH issues (in relation to all workers) B2. Number of OSH-related consultations carried out by managers with workers B3. Number of OSH Commission meetings on regular OSH issues B4. Number of risk assessment activities conducted with workers' participation B5. Number of OSH improvements proposed by workers or their representatives B6. Rating of effectiveness of workers' participation in OSH management via workforce survey
Organizing	
C. Responsibilities and accountability	
• Requirements to define responsibilities, duties and empowerment of managers and workers related to OSH MS, including designation a top management member responsible for the whole OSH MS and promotion of workers' participation.	C1. % of work posts with defined scopes of OSH-related duties and responsibilities C2. % of workers instructed or trained on their OSH-related duties and responsibilities C3. % of workers and managers with reviewed OSH-related duties and responsibilities C4. % of workers declaring awareness of their duties and responsibilities with regard to OSH MS
D. Delivering OSH training	
• Requirements related to competence in the field of OSH and introduction of solutions assuring that all persons will have the competence meeting such requirements.	D1. % of workers who were the subject of initial OSH instructing or training D2. % of workers participating in OSH refresher courses (in relation to the established plan)

(continued on next page)

Appendix A (*continued*)

Summary of respective OSH MS provisions	PPIs for measuring operational performance of respective OSH MS components
	D3. % of managers participating in OSH refresher courses dedicated for managerial personnel D4. % of workers participating in additional courses on specific OSH issues D5. % of training hours performed on OSH courses (in relation to the established plan) D6. Number of hours for OSH training per person
E. Evaluation and improvement of OSH training programmes • Defining requirements regarding OSH training programs and methods of their implementation.	E1. % of right answers per persons from tests to evaluate the effectiveness of OSH training E2. % of workers assessed as competent in OSH following inductions and OSH training courses E3. Number of OSH training programmes reviews to identify gaps and needs for improvement E4. % of OSH training courses reviewed and improved for their quality and effectiveness
F. OSH management system documentation • Requirements regarding creation and maintenance of OSH MS documents and records, indicating their content form, as well as their identification, reviews, updating, publication, accessibility and storing.	F1. Number of new OSH instructions implemented on new workstations F2. % of OSH instructions periodically reviewed and updated F3. % of OSH MS operational procedures reviewed and improved in course of corrective actions F4. % of workers participating in trainings on OSH MS structure, procedures, documents, etc.
G. Communication • Introduction of organizational solutions and procedures assuring appropriate receiving and responding to internal and external OSH information, and their flow among all levels of the organization. • Requirement for reception and responding to concerns, ideas and other OSH-related information coming from workers.	G1. Number of meetings conducted by managers to inform workers on current OSH issues G2. Number of OSH-related messages distributed among workers by means of emails, bulletins etc. G3. Number of issues of company's bulletin or other internal publications concerning OSH problems G4. Number of external OSH informational materials (reports, articles, regulations, etc.) distributed internally G5. % of managers' responses to proposals of OSH improvement submitted by workers G6. Rating of the effectiveness of OSH communication via workforce survey
Planning and implementation H. OSH goals and improvement plans • Planning the activities related to implementation and maintenance of all OSH MS elements. • Establishing measurable OSH action targets and defining recommendations for their formulation and implementation. • Defining priorities for activities and quantifiable measures of OSH targets, and preparation of plans to achieve OSH targets, including criteria to verify task implementation and effectiveness.	H1. Number of measurable OSH improvement goals established in the enterprise H2. % of measurable OSH improvement goals subject to periodical verification and updating H3. % of OSH improvement plans with measurable targets and evaluation criteria H4. % of the enterprise or a department budged spent on the completion of OSH improvement plans H5. % of tasks in OSH improvement plans which were completed and evaluated on time H6. % of tasks in OSH improvement plans which were verified and accepted with regard to their quality and effectiveness
I. Risk assessment processes • Establishing procedures of ongoing identification of hazards and occupational risk assessment and introduction of adequate preventive and protective measures for risk reduction and control.	I1. % of workstations with risk assessment documented and risk control measures planned to be implemented I2. % of risk assessment processes completed and documented (in relation to established plans)

Appendix A (*continued*)

Summary of respective OSH MS provisions	PPIs for measuring operational performance of respective OSH MS components
	I3. % of verified risk assessments with regard to their validity and correctness of control measures applied I4. % of workstations with risk levels assessed as medium to high (requiring planning of risk control measures)
J. Implementation of risk control measures • Defining hierarchy of preventive and protective measures, which should be compliant with national laws and good practice, and taking into consideration current state of knowledge on OSH.	J1. % of workers informed on risk levels and respective risk control measures to be applied on their workstations J2. Number of risk control measure implementations, in which hierarchy of measures has been fully considered J3. % of risk control and preventive actions completed as results of risk assessment (in relation to all assessments) J4. Number of workers with risk level reduced by means of application of collective protective equipment J5. Number of workers with risk level reduced by means of application of personal protective equipment J6. % of reduction of PPE applications in relation to application of other types of risk control/preventive measures J7. Mean time from hazard identification/risk assessment to introduction of respective risk control measures J8. Number of PPE items inspected for their appropriate selection for identified risks and appropriate use by workers
K. Management of change • Assessment of impact of all internal and external changes on OSH, undertaking adequate preventive measures before introduction of such changes, information and training for workers subject to such changes. • Carrying out identification of hazards and risk assessment before each modification of work places, introduction of new work methods, materials, processes and machines.	K1. Number of analyses of impact on OSH carried out prior to internal changes, introduction of new technologies, work processes, etc. K2. Number of analyses of impact on OSH carried out with regard to changes in OSH regulations, technologies and knowledge K3. % of workstation with risk assessment verified in course of introduction of new machinery and materials, changing work method etc. K4. Number of workers informed on results of risk assessments carried out in course of changes introduced on their workstations K5. Number of workers additionally trained or instructed on OSH in course of changes introduced on their workstations K6. Number of OSH MS procedures and instructions verified/ modified in course of introduction of organizational changes, new manufacturing technologies, machinery and equipment, modification of work processes, etc.
L. Emergency prevention, preparedness and response • Establishing organizational arrangements for emergency prevention, preparedness and response including: internal communication and co-ordination, providing first aid, firefighting actions, evacuation, training and exercises. • Co-ordination of such arrangements with external emergency services and communication with such services, authorities and neighbor organizations.	L1. % of reviewed and updated OSH MS procedures and work instructions concerning planning and performing dangerous jobs L2. Number of emergency procedures consulted with external emergency services, local authorities and society L3. Number of emergency plans and procedures periodically verified and updated L4. Number of emergency plans and procedures verified and updated as result of rescue action experiences L5. % of workers trained on emergency procedures, including rescue activities and first aid L6. % of hours of OSH training courses dedicated to emergency prevention, preparedness and response L7. % of workers participating in trial emergency evacuations L8. % of emergency equipment periodically inspected and maintained with regard to their technical efficiency

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Appendix A (*continued*)

Summary of respective OSH MS provisions	PPIs for measuring operational performance of respective OSH MS components
	L9. Number of inspections and tests of major hazard installations and safety critical equipment
M. Procurement • Establishing the procedures to ensure conformity of goods and services purchased by the organization with respective OSH requirements.	M1. % of periodically verified OSH requirements applied in purchase specifications of machinery, equipment, etc. M2. % of purchase agreements with specified OSH requirements for machinery, equipment, materials, etc. M3. % of purchased products verified for their compliance with OSH requirements specified prior to purchasing M4. % of purchased larger objects (machinery, installations, etc.) for which risk assessment has been carried out prior to bringing them into use
N. Contracting • Organizational arrangements assuring contractors' compliance with the same OSH requirements and management rules as those applied by the organization. • Arrangements include selection of contractors, co-operation methods, registration of accidents and diseases, OSH training and monitoring contractors for OSH performance.	N1. Number of contractors assessed by the enterprise for their compliance with established OSH management requirements N2. % of periodically verified and updated OSH management requirements established for contractors N3. % of contractors who have submitted reports on risk assessment and other OSH aspects related to their workers N4. Number of OSH inspections carried out periodically by the enterprise on workstations of the contractors N5. % of contractors' workers trained on OSH in relation to their work performed for the enterprise
Evaluation O. Performance monitoring and measurement • Establishing monitoring methods for selected OSH aspects including quantitative and qualitative indicators. • Defining the role of proactive and reactive monitoring in OSH MS improvement, in particular in the area of solutions for hazard identification and risk assessment.	O1. Number of leading vs. lagging performance indicators monitored to measure OSH management performance O2. % of definitions of leading and lagging performance indicators subject to periodical review and update O3. Number of leading and lagging performance indicators subject to analysis by top management during OSH management reviews O4. Number of leading and lagging indicators established for monitoring effectiveness of OSH improvement plans
P. Investigation of work-related accidents, diseases and incidents and their impact on OSH	
• Requirements regarding analyzing of the reasons of work-related accidents, diseases and incidents to identify inconsistencies in OSH management system. • Analyses should be carried out by competent persons, with co-operation of workers, documenting their outcome and presenting the results to OSH Commission, as well as undertaking adequate corrective and preventive activities.	P1. % of completed investigations of work-related accidents, diseases and incidents in relation to all respective events registered P2. Proportion of work-related injuries registered and investigated in relation to all accidents and incidents registered P3. % of medical consultations carried out within the programme of workers' health surveillance P4. Number of corrective and preventive actions carried out as a result of root cause analyzes of work-related accidents, diseases and incidents P5. Number of workers trained to conduct root cause analysis and investigation of accidents, diseases and incidents P6. Number of reports on root cause analysis and investigation of work-related accidents, diseases and incidents subject to discussion and responding to at the meetings of top management (including the OSH Commission)
Q. Management system audit • Requirements to carry out periodic internal audits of OSH MS according to established policy and program.	Q1. Number of person-days of internal OSH management system audits carried out periodically Q2. % of OSH MS components or processes subject to assessment during internal OSH MS audits

Appendix A (*continued*)

Summary of respective OSH MS provisions	PPIs for measuring operational performance of respective OSH MS components
• All system elements should be subject to audits and requires implementation of audits by competent persons and consulting the auditing process and results with workers.	Q3. Number of non-compliances and observations identified and registered during OSH MS internal audits Q4. Number of corrective and preventive actions initiated and carried out as a result of internal OSH MS audits Q5. Number of workers trained in auditing with approved competencies as internal OSH MS auditors
R. Management review	
• Requirements for the top management to carry out periodic OSH management reviews. Defines objectives for reviews and range of reviewed factors. • Requirements concerning documenting reviews and submission of their outcomes to the OSH Commission, workers and their representatives, and to persons responsible for specific OSH MS elements.	R1. Number of OSH MS components or processes subject to analysis at OSH MS reviews R2. Number of OSH policy items and strategic OSH goals reviewed by top management during OSH MS reviews R3. Number of recommendations for improvements formulated by top management at OSH MS reviews R4. % of recommendations formulated by top managers at OSH MS reviews considered in OSH improvement plans
Action for improvement	
S. Preventive and corrective action	
• Requirements to introduce organizational solutions regarding preventive and corrective actions, which should include identification and analysis of the source reasons for inconsistencies and initiation, planning, implementation, effectiveness verification and documenting preventive and corrective actions.	S1. % of completed corrective and preventive actions in relation to actions initiated as result of monitoring OSH performance, OSH MS audits and reviews, and analyzes of accidents, incidents and diseases S2. % of corrective and preventive actions preceded by in-depth cause analysis of OSH MS non-conformities S3. Number of person-hours devoted to implementation of preventive and corrective actions within OSH MS S4. % of completed corrective actions subject to final review and evaluated for their effectiveness S5. Mean time from identification of non-conformity in OSH MS to termination of respective corrective actions S6. % of the company's OSH budget spent on implementation and assessment of corrective and preventive actions
T. Continual improvement	
• Requirement to introduce organizational solutions ensuring continual improvement of all OSH MS elements and definition of a range of factors which should be taken into account in such solutions. • Requirement to compare OSH activities and their effects with activities and effects of other organizations (benchmarking).	T1. Number of new OSH goals and objectives established in the framework of OSH MS continual improvement T2. % of completed tasks related to improvement of OSH MS components or processes (in relation to the plan) T3. Number of OSH MS components or processes evaluated as being significantly improved within a given period T4. Number of OSH management KPIs subject to benchmarking with adequate KPIs reported by other companies T5. Number of OSH policy changes or OSH MS improvements recommended as result of KPIs' benchmarking

Appendix B. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.ssci.2014.11.018.

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