Selection of occupational health and safety management software using Analytic Hierarchy Process

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Abstract: The complexity of health and safety management issues is increasing, as well as the related information flows. This motivates the current interest in occupational health and safety management software packages and the forecast of strong growth for their market. However, to the best of our knowledge, reliable and validated methods and tools to support the selection of the most suitable occupational health and safety management software are not available in the literature. For this reason, we propose a multicriteria method in order to help decision-makers select the best health and safety software package among a set of available alternatives, considering multiple potentially conflicting factors. The method is based on Analytic Hierarchy Process (AHP), which is widely used to support information systems selection. The elements, i.e. factors important for the selection, were identified and arranged into a hierarchical structure. The hierarchy consists of a Goal and three levels of elements (4 Strategic Criteria, 11 Criteria, and 12 Sub-criteria) related to health and safety aspects, costs, complexity and technical features, and others. This paper describes the proposed method and the results of an implementation case study in an Italian manufacturing firm. The case study proved the applicability of the method; furthermore, it tested its effectiveness in supporting CEOs and safety managers during the software selection process. Further implementation case studies are required in order to validate the effectiveness of the method in other contexts.

Keywords: Occupational health and safety; OHS; AHP; Multiple-criteria decision making; Software selection.

1. Introduction

Over the last decades, a wide range of occupational Health and Safety (H&S) regulations have been implemented in the world's largest economies. As a consequence, firms have to comply with several legal requirements. In addition, they can also comply with voluntary national and international technical standards and guidelines published to aid organisations in assessing and managing certain H&S risks or in implementing management systems (e.g. OHSAS 18001). On the other hand, also the level of flexibility required in manufacturing has increased. Organisations are thus forced to: be very reactive; optimise and computerise production and auxiliary processes; adopt an integrated management of all the processes; efficiently manage internal and external information flows. As a consequence, H&S management must be agile and proactive in ensuring the lowest level of risk for workers. ERP (Enterprise Resource Planning) systems and/or other business software packages can help organisations to meet these needs, especially those related to the management of the flow of information and documents (Skove, 2001).

A recent survey by Verdantix (2016) of EH&S (Environment, Health and Safety) senior managers shows that their priority is the improvement of EH&S information management; this explains their motivation for investing in H&S software. Companies are very interested in investing in third-party software to reduce operational risk, mitigate regulatory risk, and save time on H&S data collection and aggregation (Gilbert, 2005; Verdantix, 2016). The attention to H&S software is also confirmed by forecast of strong growth for their market (Verdantix, 2014). To conduct an effective software selection, the adoption of a systematic process by companies is essential, owing to the number and complexity of requirements (and thus criteria) and the profusion of alternatives. A non-systematic or not well structured process, in fact, can prove ineffective and expensive. An effective process requires a multicriteria method that helps decision-makers make preference selection in a set of available alternatives characterised by multiple potentially conflicting attribute (Yazgan et al., 2009). However, to the best of our knowledge, reliable and validated methods and tools to support the selection of the most suitable occupational H&S management software are not available in the literature. For this reason, we propose a multicriteria method based on Analytic Hierarchy Process (AHP) as a valuable tool for the H&S software selection. Indeed, AHP has been widely used to support the selection of information systems such as ERP (e.g. Wei et al., 2005), or the decision-making in the field of H&S (e.g. Rossi et al., 2013a, 2013b).

2 Analytic Hierarchy Process

The basic problem of decision-making (and so of a software selection) is to choose the best option from a set of competing alternatives that are evaluated under conflicting criteria. AHP is a multicriteria decision-making tool developed in the 1970s by Saaty (1980) to solve problems that involve prioritisation of potential alternative solutions considering both qualitative and
quantitative criteria. Briefly, and according to Saaty (1980, 1987, 2008), the AHP procedure is in the following.

1. Structuring the decision problem into a hierarchy

The decision problem is decomposed into factors that are important for the decision, arranging them in a hierarchical structure with various levels: from the top (i.e. the Goal) through intermediate levels (i.e. elements or criteria) to the lowest level (i.e. the decision alternatives).

2. Making pairwise comparisons and obtaining the matrices of element evaluation

The elements of each level are compared pairwise, weighting their importance compared to the corresponding element of the higher level.

3. Determining local and global priorities of elements

The vectors of local priorities or weights of elements in each matrix are calculated. When a vector is normalised, it becomes the vector of local priorities of the elements with respect to the element of the higher level. The global priorities of elements at the level immediately under the Goal are equal to the local priorities. The global priorities of elements at the next level are obtained by weighting the local priorities of this level by the global priority at the level immediately above and so on.

4. Verifying the consistency of comparisons

Once each local priority vector has been determined, the consistency of the pairwise comparison matrices has to be evaluated by means of Consistency Ratio (CR) (Saaty, 1980). In general, a CR of 0.10 or less is considered acceptable. If it is higher, the comparisons may not be reliable and have to be made again.

5. Making pairwise comparisons, obtaining the matrices of alternative evaluation, determining local priorities of alternatives and verifying the consistency of comparisons

Using a very similar procedure (steps 2, 3 and 4), the local priorities, or scores, of alternatives with respect to each element of the lowest level can be estimated. Alternatives are compared pairwise, expressing their relative preference with respect to each element of the lowest level.

6. Determining global priorities of alternatives

The local priorities (scores) of an alternative with respect to each of the elements of the lowest level are multiplied by the global priorities (weights) of those elements. The global priority or final score of the alternative is the sum of these products. Finally, the rating of the alternatives is determined by their global priorities.

3 Elements and hierarchy

The identification and definition of the elements (i.e. factors important for the selection), and the construction of their hierarchy were the first steps of our research. We defined a Goal and three levels of elements (4 Strategic Criteria, 11 Criteria, and 12 Sub-criteria). Our Goal is to satisfy the company’s objectives, and to manage H&S at work with the support of the best software. The hierarchy of elements and the alternatives are shown in Figure 1. Note that the number of alternatives to compare can be chosen by the decision-maker.

The elements have been identified after a detailed analysis of scientific and technical literature, discussion with experts, CEOs, safety, operation and IT managers, and software vendors. Each level of the hierarchy consists of one or several homogeneous groups of elements; elements of each level may be regarded as constrains, refinements, or decompositions of the element above. The elements reflect the need of managing the processes required to comply with rules, regulations, policies, and procedures. Gilbert (2009) underlines the importance of defining business needs and consequent software requirements because they establish the groundwork for software selection and provide the basis for measuring the success of a software effort. We have not included “software security” issues in the hierarchy because we consider security (i.e. the ability to continue to function correctly under malicious attack) as an essential prerequisite for commercial software. We define the elements as follows, based on the references in Table 1.

<table>
<thead>
<tr>
<th>Strategic criteria</th>
<th>Criteria</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>OHSAS (2007, 2008)</td>
</tr>
<tr>
<td>Customer service</td>
<td>Initial, annual, and learning cost</td>
<td>DiBenedetto (2004)</td>
</tr>
<tr>
<td>and update</td>
<td></td>
<td>Gilbert (2004)</td>
</tr>
<tr>
<td>Costs</td>
<td>Size and business</td>
<td>-</td>
</tr>
<tr>
<td>Firm characteristics</td>
<td>Interoperability, flexibility, and technical performance</td>
<td>ISO/IEC (2011)</td>
</tr>
<tr>
<td>Complexity and technical features</td>
<td></td>
<td>ISO (1998)</td>
</tr>
</tbody>
</table>

Functionalities (FU): includes the features relating to H&S processes managed by the software and the service offered by the software house.

Health and safety processes (HS): covers, in breadth and depth, the key aspects of a H&S management system, helping to comply with laws, procedures, and standards.

Risk assessment (RA): concerns the support to all phases of risk assessment (hazard identification; exposure assessment; risk evaluation), also considering the possibility to quantify the risk level.

Documentation (DO): regards the writing of relevant documents (e.g. procedures, safe work instructions, reports, records) and their management (e.g. distribution, revision, control, responsibility).

Monitoring and control (MC): includes the support to the implementation and management of maintenance and operational controls, internal audits, performance measurement and management (as defined by Bititci et al., 2016).
Corrective actions (CA): considers the procedure for dealing with nonconformities, taking corrective and preventive actions, identifying activities, responsibilities, resources.

Personal Protective Equipment (PP): concerns the management of personal protective equipment (requirement identification; equipment selection, distribution, replacement).

Health Surveillance (HS): regards the surveillance activities done by the occupational health practitioner, from scheduling medical exams to tracking results, collecting employee health data, and ensuring compliance.

Training (TR): concerns the planning and organisation of information and training activities for workers regarding their H&S risks, instructions specific to tasks, and the H&S management system (e.g., Cocca et al., 2016b).

Incident investigation (II): covers the procedure to record and analyse incidents (accidents and near misses) in a timely and methodical manner (e.g., Cocca et al., 2016a).

Safety Data Sheets (SD): considers the process of authoring and distribution of safety data sheets, in case of producers of substances and mixtures, and of management and updating of them, in case of users.

Customer service and update (CS): concerns the client technical support and product services provided by the vendor (e.g., helpdesk, on-site support, user manual), and its willingness to release periodic software updates.

Cost (CO): considers the overall cost of ownership including possible hardware expansion, as well as licence and customisation, support and maintenance fees.

Initial cost (IC): includes, for example, the purchase cost, the cost to install and deploy the system, costs of software upgrade, customisation, and possible additional hardware.

Annual cost (AC): includes all periodic costs, e.g., quoted licence and support fees, hardware and software maintenance, system audit to ensure the system continues to serve its purpose, internal help desk operations.

Learning cost (LC): includes the cost to train end-users and system administrators on how to adequately use the software, and the cost of any operational inefficiencies during learning period.

Firm characteristics (FC): considers some features of the firm (i.e., size and industry) important for H&S.

Size (SI): concerns facilitations and exemptions regarding H&S management based on the number of employees or balance sheet; e.g., small organisations can generally carry out a simplified risk assessment.

Business (BU): concerns needs to assess some risks and manage some processes that are typical of an industry; e.g., risk of oxygen deficiency (Stefana et al., 2015, 2016) or biomechanical risk (Cocca et al., 2008).

Complexity and technical features (CT): includes a set of technical aspects and software quality properties pertaining usability, interoperability and portability, flexibility and customisability, and technical performance.
Usability (US): regards how a software package can be used by specified users to achieve specified goals with effectiveness, efficiency, satisfaction in a specified context.

Interoperability and portability (IP): concerns the degree to which the software exchanges and uses information with other software, and can be transferred from one hardware or usage environment to another.

Flexibility and customisability (FL): concerns the degree to which a software can be used in contexts beyond the initial one, and can be configured as necessary, making it easy and satisfying to operate and control for the user.

Technical performance (TP): regards the main technical properties in terms of robustness and user error protection, reliability and availability, and utilisation of resources and acquisition of additional ones.

Robustness (RO): concerns the degree to which a software package protects users against making errors, copes with erroneous inputs and errors during execution.

Reliability (RL): concerns the degree to which a software package performs specified functions under specified conditions for a specified period of time, and is operational and accessible when required for use.

Resources (RS): considers the amount and types of resources required by a software package to perform its functions (e.g. other software or additional hardware).

4 Case study

To test the developed hierarchy, we conducted an implementation case study in an Italian firm, a world leader in the manufacture of valves. After a pre-selection, the CEO and the safety manager chose two possible alternatives: 1) an ERP module dedicated to H&S management; 2) a stand-alone program. We supported the decision-maker (the CEO, in collaboration with safety, IT and operation managers) in applying our method, in particular explaining them the AHP step-by-step procedure and elaborating data with Super Decisions software v.2.6.0-RC1, developed by Creative Decisions Foundation.

As an example, Table 2 shows the pairwise comparison matrix of the Strategic Criteria with respect to the Goal, their local priorities, and the CR value. Since CR is less than 0.1, the check of matrix consistency is positive. Table 3 shows the global priorities of the lowest level elements, shown in Table 3. The most important elements are “Initial cost” and “Risk assessment”.

Table 3: Global priorities of elements of the lowest level

<table>
<thead>
<tr>
<th>Strategic Criteria</th>
<th>Criteria</th>
<th>Sub-criteria</th>
<th>Global priorities</th>
</tr>
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<tbody>
<tr>
<td>FU</td>
<td>HS</td>
<td>RA</td>
<td>0.13952</td>
</tr>
<tr>
<td></td>
<td>DO</td>
<td></td>
<td>0.08169</td>
</tr>
<tr>
<td></td>
<td>MC</td>
<td></td>
<td>0.03384</td>
</tr>
<tr>
<td></td>
<td>CA</td>
<td></td>
<td>0.02973</td>
</tr>
<tr>
<td></td>
<td>PP</td>
<td></td>
<td>0.02547</td>
</tr>
<tr>
<td></td>
<td>HS</td>
<td></td>
<td>0.01716</td>
</tr>
<tr>
<td></td>
<td>TR</td>
<td></td>
<td>0.07308</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td></td>
<td>0.01995</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td></td>
<td>0.03609</td>
</tr>
<tr>
<td></td>
<td>CS</td>
<td></td>
<td>0.09131</td>
</tr>
<tr>
<td></td>
<td>CO</td>
<td>IC</td>
<td>0.17609</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td></td>
<td>0.07395</td>
</tr>
<tr>
<td></td>
<td>LC</td>
<td></td>
<td>0.02329</td>
</tr>
<tr>
<td></td>
<td>FC</td>
<td>SI</td>
<td>0.02339</td>
</tr>
<tr>
<td></td>
<td>BU</td>
<td></td>
<td>0.02339</td>
</tr>
<tr>
<td></td>
<td>CT</td>
<td>US</td>
<td>0.05691</td>
</tr>
<tr>
<td></td>
<td>IP</td>
<td></td>
<td>0.01861</td>
</tr>
<tr>
<td></td>
<td>FL</td>
<td></td>
<td>0.04545</td>
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<tr>
<td></td>
<td>TP</td>
<td>RO</td>
<td>0.00165</td>
</tr>
<tr>
<td></td>
<td>RL</td>
<td></td>
<td>0.00417</td>
</tr>
<tr>
<td></td>
<td>RS</td>
<td></td>
<td>0.00526</td>
</tr>
</tbody>
</table>

Table 4 shows an example of pairwise comparison matrix of alternatives; in particular, the two alternatives are here compared pairwise with respect to the element “Risk Assessment”. Local priorities show that decision-makers have judged “Alternative 2” as the preferable alternative from the risk assessment point of view. For lack of space, we omit all other pairwise comparison matrices.

Table 4: Example of comparison matrix of alternatives

R-A | Alternative 1 | Alternative 2 | Local Priorities |
<table>
<thead>
<tr>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>1/2</td>
<td>0.33333</td>
</tr>
<tr>
<td>Alternative 1</td>
<td>1</td>
<td>1/2</td>
<td>0.33333</td>
</tr>
<tr>
<td>Alternative 2</td>
<td>2</td>
<td>1</td>
<td>0.66667</td>
</tr>
</tbody>
</table>

At the end, the combination of global priorities of elements of the lowest level and local priorities of alternatives resulted in the following global priorities or final scores of alternatives: Alternative 1 (ERP module): 0.56784; Alternative 2 (stand-alone program): 0.43216. Since these scores represent the relative ability of each alternative to achieve the Goal, the firm opted for the extension of their ERP system, acquiring the module dedicated to H&S management. The case study showed that the use of the proposed hierarchy is efficient and easy, also thanks to the element definitions we provided. Furthermore, it is a first test of the effectiveness of our decision-making method.
method in supporting CEOs and safety managers during the software selection process.

5 Conclusions

An organisation looking for a H&S management software has to identify a solution able to satisfy its business needs among thousands of available alternatives. Therefore, it is important to follow a rational selection process that adopts a multicriteria approach. A new software selection method based on AHP is proposed in this paper. In order to test its applicability it has been used in an Italian firm. The method has successfully guided the comparison of alternative solutions and led to the final choice. To validate the effectiveness of the method in other contexts, further implementation case studies are required.

References


