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Article

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SSD SmartRisk, a decision support system to help non-expert decision makers in case of chemical accidents

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Abstract
Chemicals may generate accidents that can affect workers as well the general population and the environment. Decision making in such circumstances might be very difficult, especially for small and medium (SME) enterprises that do not have their own experts. A decision support system – SSD SmartRisk- was developed by the authors, to help in such situations. SSD SmartRisk may be used as a roadmap with links to reliable and relevant sources of information and tools or by employing commercially available decision support software. The exemplification presented here refers to chemical hazards, but the system may be adapted for other types of risks. The system combines hazards and quantity of chemicals to make a preliminary ranking of the overall facility risk. It then recommends risk related measures and provides indications and links to existing tools that help put the measures into practice. The SME for which SmartRisk was made appreciated its support in making decision of its own or when collaborating with external experts or suppliers.

Keywords: *chemical accidents, risk management, decision support, SMEs*

INTRODUCTION

Chemical risks management may be difficult because of the high amount and variety of specific information that it involves and the complex judgment often needed for making decisions. This is even more difficult for small enterprises that cannot afford to hire or contract experts in this field. There are a number of instruments that could help in managing chemicals, some having open access offers. However, navigating through the offers and choosing the suited one might still be difficult for non-specialists. In addition, generally, more than one tool is needed to go through the process of decision making in order to manage chemicals and prevent chemical accidents.

There are various tools and methods to support exposure estimation, chemical risk evaluation, and assessment of vulnerability or impact characterisation. Some of them are for occupational risks, like SEIRICH [1]. Even more of them are for the environmental risks. There are several such tools at national level, some of them (H&V - the Czech Hazard and Vulnerability index, EAI- the Environment Accident Index, form Sweden or CDOIF form UK) being assessed in a project commissioned by DG Employment on behalf of the European Commission [2]. However, even accessing these tools is difficult for the general user. Some of the tools already mentioned or others, like Chemical Process Quantitative Risk Analysis - CPQRA [3] or the Accidental Risk Assessment Methodology for Industries ARAMIS [4] might be too complex for the medium user. Others are quite specific, like the model for risks related to hazardous chemicals transportation [5]. ECTOC HEATDG [6] has a very broad area, being a data base that helps user to identify human exposure tools that are available in the public domain. There are also tools developed or run by commercial companies, available on charge, like Effects [7]. Instruments that are both free and easy to use are also available, like those developed by the US EPA to help estimating and mapping impacts of chemical accidents and manage emergency operations, such as CAMEO [8], ALOHA [9] and MARPLOT [10].

Expert, tailored consultancy for decision-making is compulsory for complex cases or for situations where the risks are estimated to be significant. Complex applications, however, are adopted slower and need cooperative effort within the company and with its collaborators [11]. Simpler tools may be useful in dealing with less complex, less stringent situations. Small and medium enterprises (SMEs) are known for preferring less sophisticated approaches [12] as well as solutions that are easy to apply and transfer [13]. It takes visionary leadership, collaboration with innovative partners and well-educated workers to increase the likelihood of SMEs to adopt new technologies and methods [14]. In 2021 almost half (46%) of the EU population aged 16-74, did not have at least basic overall digital skills, with Romania having the worst situation of all Member States, in this respect [15]. Romania has also the highest proportion of enterprises with very low digital intensity [16] and less involvement in general and job-related adult training [17]. Under these circumstances some enterprises might be reluctant to use IT in production and probably even less likely to use it to improve chemical risk management. For such users it would be beneficial an easy to operate decision system that will structure clearly the main elements and will allow making better planning of preventive measures. Making such a system work using a software for decision support but also as a flow-chart version, made interactive by links to further instruments, could be a preferable approach.

MATERIALS AND METHODS

The SmartRisk decision support system has been developed in order to fit the requirements of a Romanian SME that makes small-scale utility projects for local communities or private residences. Discussions with the SME user addressed the functions, results and the operations the system should have. Exemplifications with existing tools as those presented above were used for practical clarifications and to baseline the architecture of the system.

In order to suite, the SME needs and capabilities, an analysis was performed that included the presentation of alternative approaches like specific software development, the use of licensed decision support software or an interactive roadmap. It was decided to focus on the last two alternatives. The support system began as an interactive roadmap and was then adapted to be used with a commercially available software, in this case XpertRule. The roadmap was meant to select relevant existing tools and organize them in a structure that will support the decision process in a way that will fit the SME's needs and expertise. Links to the tools would provide free access, while the flowchart would lead the user from one step to another. Various tools, such as those mentioned above, were reviewed with the user to select those considered most suited.

The SSD SmartRisk methodology for chemical risks has been established so as to be compatible with the usual theories of risk that define it as a combination of the severity of the consequences of an event and the probability of such an event to occur. It was also meant to relate clearly with the legislation applicable at various stages of the decision-making process. The SSD SmartRisk methodology for chemical risks was developed to have a decision-making scheme with a clear logic, based on objective criteria that are legally relevant and well-defined, whether qualitative or quantitative, while being easy for the beneficiary to use and not duplicating already existing resources (tools, databases etc.).

The system could be used mainly for prevention of accidents but it also contains basic measures (organizational) in case a chemical accident does occur. The contribution of SmartRisk to avoid major accidents or disasters was considered, using the definition for disasters given by the Center for Epidemiology and Disaster Research-CRED, a World Health Organization collaborator. According to the methodology applied by CRED for its database EM-DAT [18], a disaster is considered to meet at least one of the following criteria: ten or more people reported killed, one

hundred or more people reported affected, declaration of a state of emergency or call for international assistance.
The SSD SmartRisk methodology for chemicals goes through the following steps: hazard identification, risk level evaluation and indication of the types of prevention and protection measures matching the risk level, as presented in figure 1.

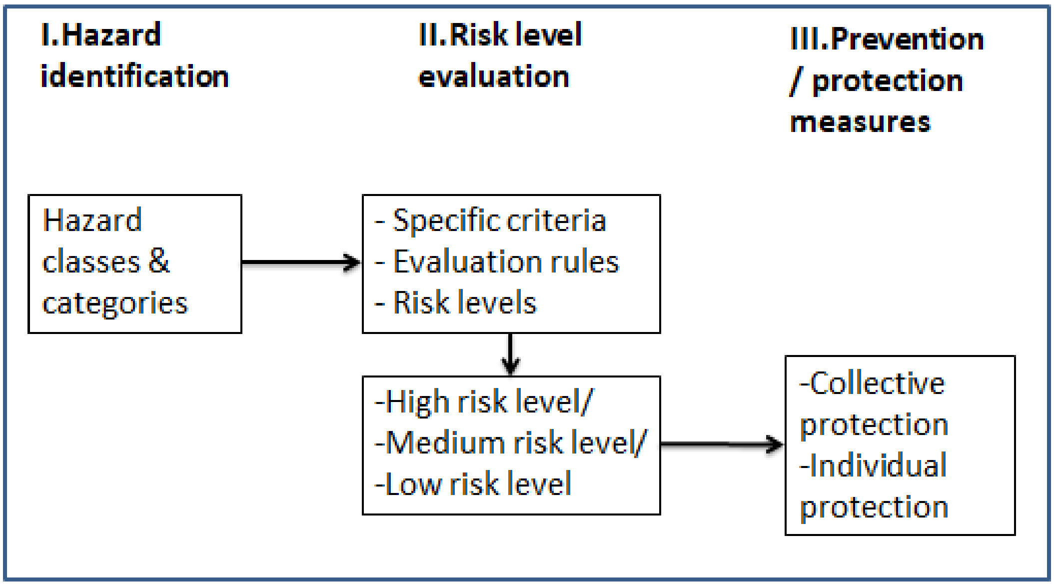

Fig. 1. Main stages of the SSD SmartRisk

Hazard identification is made for each substance that may be present on site. The user must have a detailed inventory of all chemicals that may be present on site, right from the design phase of the facility/process. The types of substances vary by field of activity but there can be large differences even within the same type of process, depending on the technologies and equipment employed.
Information on chemical hazard classification can be obtained directly from the documents that come with the substances when purchased by the enterprise or by accessing reliable sources, such as those recommended by SmartRisk. C&L Inventory database of the European Chemicals Agency – ECHA [19], was the first recommendation, where one can find both the harmonized classifications (agreed and mandatory in all Member States) and the so-called self-classifications of the different notifiers of the substance.
If the substance is not yet classified in any of the recommended sources (or in others) the user will have to make its own provisional classification regarding the effects, based on data from specialized literature. The initial classification can be changed as new information comes to light, preferably from authoritative sources. Recommendations on keeping chemicals inventory were presented with links to tools such as SEIRICH [1].
The risk level evaluation is done by using two criteria: the classification of the substance in terms of hazard and the quantitative threshold from which the presence of the substance on site can lead to major accidents, respectively. The provisions of the Seveso Directive [20] were used to define these criteria. The advantage is that the criteria can be clearly formulated, whether they are qualitative (hazard, indicated by standardized classes and categories) or quantitative (maximum estimated amount of the substance, expressed in tones). At the same time, this approach ensures legal relevance and coherence with the legal provisions. Three levels of risks (high, medium, low) were defined concerning the likeliness that the accident would generate consequences as those considered by CRED [18].
The decision rules regarding the classification on a certain level of risk are confirmation of the classification of the substance in classes and categories whose severity may lead to major accidents; exceeding the quantitative threshold from which the quantity of the substance present on the site has a significant probability of causing major accidents.

A list of hazard classes and categories was established, starting with those classes used by the Seveso Directive, like substances classified as toxic acute category 1, or oxidizing gas category 1 etc. The Directive focuses on hazards that have acute effects and the so called physical hazards (e.g. flammability or explosion), since many of the effects of the accidents are of this kind. SmartRisk also added hazards that have chronic effects: carcinogenicity, mutagenicity, toxicity for reproduction, endocrine disruptors, sensitizers and neuro-toxicants. Adding chronic toxicity classes was done because some of the chemical accidents have such long-lasting effects, like the accident in Seveso that inspired the Directive name. To give the tool a broader use, a last group of substances was added to the list, those with less severe hazards (e.g. irritant, non-respiratory toxicity, etc.) as presented in Table 1. The final SmartRisk list of hazards has a total of 25 entries for hazards (classes and categories).
The user will check class by class if its substances are on the SmartRisk list. If the answer is yes, it will pass to checking the next criterion, the quantitative threshold, like in figure 2. The threshold limits provided by the Seveso Directive were used for the hazard classes considered in the Directive. For the hazard classes added by SmartRisk, thresholds were proposed between 5 and 10 tones. In case a substance/mixture is classified with more than one of the hazards included in the list, the lowest threshold should be used to rank the overall risk.

Table 1. SmartRisk list of chemical hazard classes (additional to the Seveso ones) and their corresponding threshold for risk ranking

No.	Hazard criteria: class and category	Quantitative criteria (threshold)	Possible risk ranking
1.	Carcinogenicity, or mutagenicity or toxic for reproduction category 1A or 1B	5t	High/medium
2.	Endocrine disruptors	5t	High/medium
3.	Respiratory/skin sensitization Category 1 or 2	10t	High/medium
4.	Specific targeted organ, repeated exposure (STOT - SE) category 1 or 2, e.g. neurotoxicity	5t	High/medium
5.	Eye damage, corrosive category 1 or 2	10t	High/medium
6.	Other hazard classes (e.g. toxicity categories 3 or 4, irritant, non-respiratory toxicity etc).	-	Low

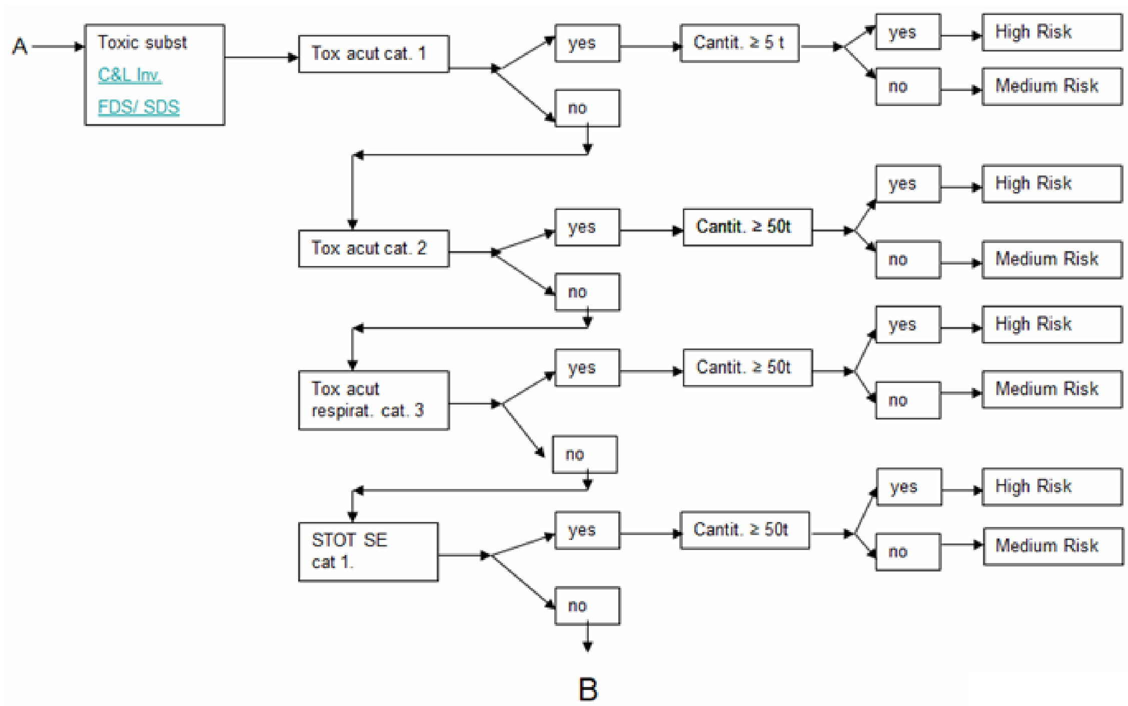

Fig. 2. Extract from SmartRisk flowchart containing links to the further sources

Measures to prevent accidents were presented, with links to further sources of information. All sources of information or tools provided had to pass quality criteria and to be free of charge. The measures were correlated with the evaluated risk level. Priority was given to collective protection but measures regarding personal protection equipment were also included.
The measures were established starting with the low risk level, more measures adding up progressively when passing to medium and high risk level, respectively.
By modeling the estimated impact zones the user can choose between various possible locations in order to minimize the impact on receptors. The isoconcentration lines within the impacted area can anticipate exposure levels for various accident scenarios.
Tools and guidelines were also recommended (with links) to help the user substitute hazardous chemicals, set alarms for toxic gases, plan the maintenance, evaluate the risks etc. Multiple criteria analysis and free applications to support it were recommended when decision involved comparing multiple aspects of various alternatives.
A general measure to align to technical progress was also included as a reminder of the need for updates. A manual for the use of SmartRisk was handled to the SME.
SSD SmartRisk was tested in a pilot for one of the projects of the SME, a chlorination station for a water supply station.

RESULTS AND DISCUSSION

According to the agreement with the SME user, the support system was provided both as a roadmap and to be used with XpertRule software.
The roadmap being a flowchart with further links to free instruments, does not require a license and is easier to use by the SME employees. The roadmap can also be used in order to train employees, helping them to understand the logic of the approach. The SME felt more confident to have the roadmap too, as a way to start or as an alternative to resort to, in case they had problems in using the software. Running SmartRisk on commercially available software also implies licensing, which is an extra cost for the SME.

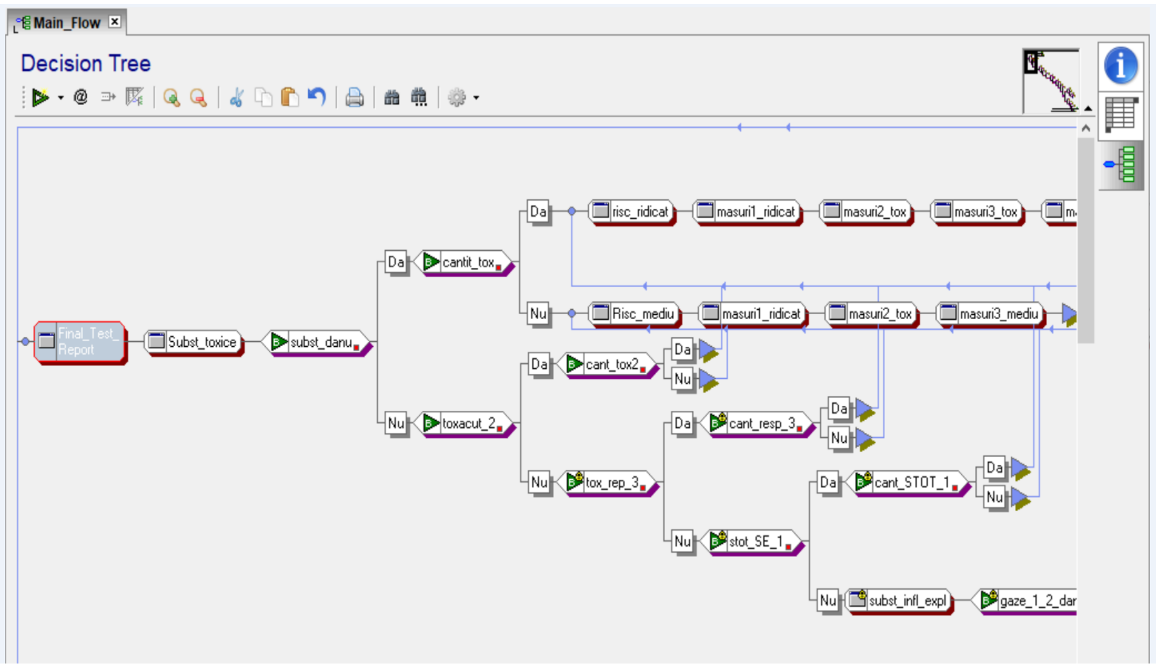

Fig. 3. Extract of SSD SmartRisk implementation using XpertRule software

A pilot testing of SmartRisk was performed. It simulated a chemical (chlorine gas) release in the atmosphere from a water treatment plant. Chlorine has a harmonized classification as oxidizing gas category 1 and Aquatic acute category 1. The quantity present on the site was less than the quantitative threshold of 50t. Combining hazard and quantity criteria the resulting ranking of the

overall risk for disasters was medium and a list of measures was recommended. For example, relevant tools for which links were provided were used, to estimate the impact area of chemical accidental release (fig. 4) or to make multi-criteria analysis for choosing the neutralizing reagent for chlorine (fig. 5).
The conditions for the impact area simulation were mild (21^0C, 3.5 km/h), with open country roughness, corresponding to the (potential) location of the treatment station.

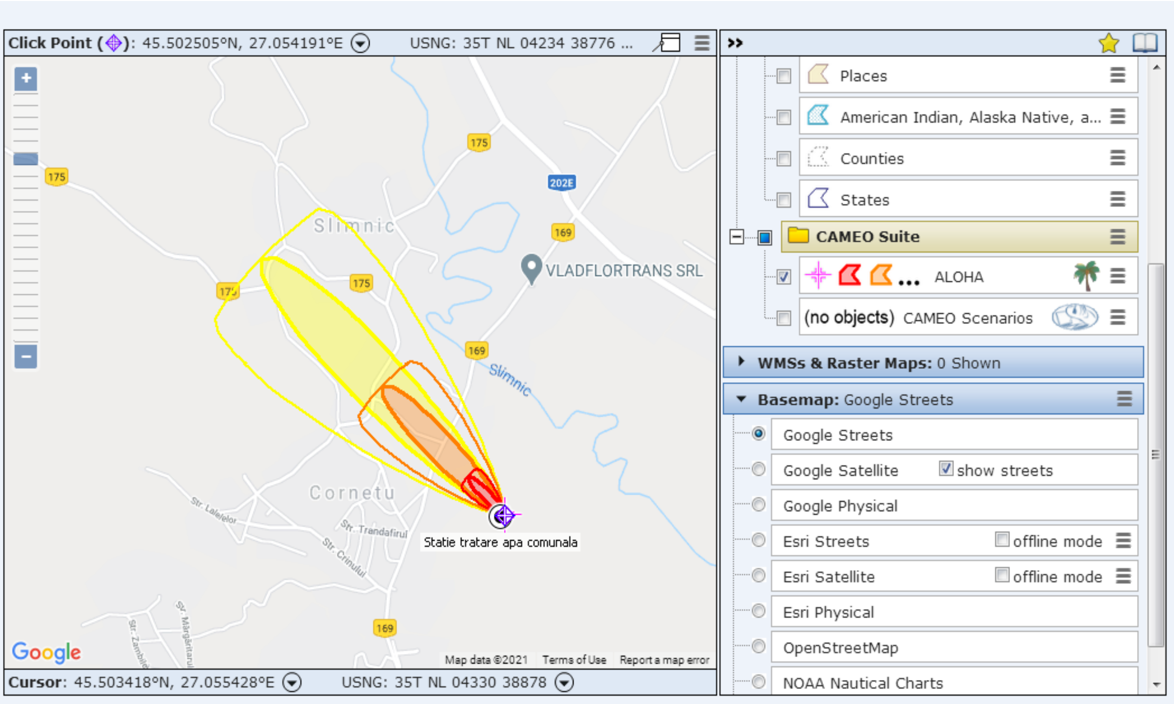

Fig. 4. The use of ALOHA-MARPLOT software to estimate impact area in SmartRisk pilot study for chlorine accidental release from a water treatment plant

The estimation of the impacted area showed that, in the wind direction, the concentration was 0.5 ppm at 1 km distance from the source of accident, and 2 ppm at 0.5 km. However, in the area closer to the simulated accident (approximately 0.1 km) the estimated concentration was 20 ppm. For comparison, the occupational exposure limit according to Romanian legislation [22] is 0.5 ppm as time weighted average for 15 minutes, while the lethal concentration is several orders of magnitude higher.
A multicriteria analysis was performed to select a neutralizing reagent for chlorine using publicly available data. For this exercise seven criteria were used to compare five reagents. The criteria considered aspects regarding effectiveness (specific consumption), risks (during use and post treatment), availability (price, suppliers), type of use (automated/manual). The reagents compared were sodium hydroxide, sodium metabisulfite, sodium thiosulfate, sodium sulfite, sodium ascorbate. The first two obtained considerable better scores than the rest of the reagents.
Based on the results of the initial risk evaluation other measures were also foreseen, like using an automated neutralization system with a corresponding alarm system and drawing accidents scenarios and interventions for the impacted zones, starting with the station working place. An overall score of 4.7 points out of maximum 5 was awarded by the beneficiary SME after testing SmartRisk.The user was satisfied with the way SmartRisk structured data, making it easier to navigate through the multi-faceted decision process. The time savings were also appreciated although the whole process remains time consuming. The results obtained during pilot testing were considered pertinent and intelligible by the users. The possibility to use SmartRisk both as a roadmap (interactive flowchart) and with a decision support software was reassuring for the user, helping its employees to make the step towards digitalization.

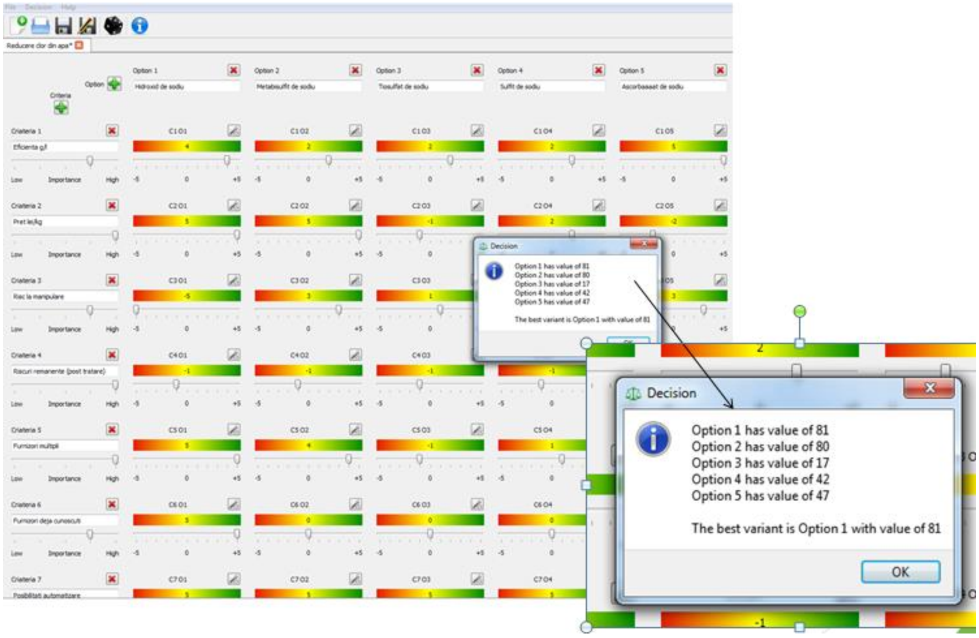

Fig. 5. Free decision maker [23] used in multi-criteria analysis for chlorine neutralizing reagent

CONCLUSIONS

The SME for which SmartRisk was developed appreciated its contribution in helping it taking decisions on its own or in facilitating a better informed communication and cooperation with service and product providers.

The SSD SmartRisk system is best suited for small installations with a low or medium degree of complexity. For more complex cases, the use of more advanced systems and specialized technical assistance is recommended.

SmartRisk does not perform a combined risk assessment for different types of risks, nor does it assess their mutual influence. It is obvious that the overall risk level can be influenced by the presence of several types of risks on site. It is recommended that the user take into account the need for additional measures, as the case may be.

SSD SmartRisk system has the following advantages: it can be used for decision making to prepare for major accidents but can also be used for lower risk situations; it is consistent with applicable legislation which supports legal compliance; it is easy to understand and the number of data/information and stages that the system involves has been reduced to what is strictly necessary; it is easy to use: the flow-chart of the roadmap is interactive, while developing an application with dedicated software does not require too much effort; it opens possibilities for refining decisions, providing direct links to other tools, selected based on quality and actuality criteria.

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