Integration of OTSM-TRIZ and Analytic Hierarchy Process for choosing the right solution

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Abstract

A relevant part of TRIZ literature concerns the steps of the problem solving process, hence the analysis of the troublesome situation, the identification of the core problem and its resolution. Conversely, few efforts have been dedicated to support the last phase of the conceptual design process, which regards the selection of the most promising solutions to be further developed. The lack within TRIZ of an instrument capable to fulfill the abovementioned task led the authors to investigate the classical decision making methods and their applicability in the context of selecting the most valuable concepts downstream of problem solving phases characterized by divergent thinking. Several potential approaches have been surveyed and, among the others, the Weighted Sum Method and the Analytic Hierarchy Process seem to hold some of the characteristics requested by an ideal method to facilitate the decision making. In this paper, both of them have been tested through a real case study in order to verify their actual applicability and to reveal strengths and weaknesses with a particular focus on their capability to guide the decision process when a plurality of parties (e.g. policy makers, domain experts) are involved. The testing activity revealed that the Analytic Hierarchy Process resulted overall more appreciated by the experimenters, thanks to the systematic approach employed to select the best solution among a sample of alternatives developed through the Network of Problems.

Keywords: Network of Problems; best solution selection; Analytic Hierarchy Process; hand steamer

1. Introduction

A general model of the classical TRIZ-based problem solving process can be summarized in a sequence of steps. The first one brings to the definition of the problem to deal with. This phase is well acknowledged as the most crucial task, since the identification of the right problem to be solved strongly impacts the success of the whole problem-solving activity. Once the problem has been defined, it needs to be expressed in a generalized form, usually easier to solve. At last, when suitable directions for the problem solving have been identified, the most promising solution has to be selected.

Among the tools belonging to the TRIZ body of knowledge, the Network of Problems (NoP) from OTSM-TRIZ [1] is one of the most powerful instruments to support the recalled tasks. Through the NoP the designer decomposes the initial problem into a set of sub-problems to be further analyzed. Such an approach allows the exploration of the solution domain through a divergent process which brings to a set populated by numerous, partially complementary, solutions. Afterwards, the solver has to assess each identified solution according to evaluation criteria and to select the most promising one. This step is insufficiently supported, since a specific tool lacks to direct the user towards the most valuable choice. Furthermore, a problematic issue concerns the high level of subjectivity commonly encountered when facing the task of ranking solutions. Indeed, severe difficulties are experienced when the personal perception of the decision makers affects at a great extent the assessment of solutions and the resulting disagreement gives rise to meaningful uncertainties. Several general-purpose Multi Criteria Decision Making (MCDM) tools are employed in the industry, as documented by technical and scientific literature. Nevertheless, each of them is influenced, although at varying degrees, by the decision maker's intuition and experience.

On the basis of the experiment presented in the remainder of the paper, it is hereby proposed to integrate, within the problem solving process suggested by OTSM-TRIZ, an already known decision making tool, i.e. the Analytic Hierarchy Process (AHP) [2]. Such a tool allows the solver to use a validated mathematical method to select the best solution with respect to the set of evaluation criteria defined at the beginning of the problem-solving process. Moreover, as demonstrated in [3], AHP helps to overcome the difficulties arising from decision makers' subjectivity, as well as to face disagreement emerging from a lack of group consensus during the evaluation task.

The paper is organized as follows. Section 2 presents a critical analysis of the state of the art concerning the decision making methods, paying particular attention to the task of choosing alternative solutions developed with TRIZ. The recalled case study is shown in Section 3, which compares two selection making methods. The subsequent chapter reports a broad discussion of the results and the planned future activities, mainly aimed at facing situations characterized by remarkable disagreements among the parties involved in the undertaking of the decision. Eventually, Section 5 is dedicated to pinpoint the main findings of the present paper.

2. State of the Art and Drivers for the Creation of a Meta-model to Rank TRIZ Solutions

This section is subdivided in three paragraphs. The first one presents an overall literature review regarding methods related to TRIZ for solutions classification. The second paragraph is devoted to outline the most diffused systems for decision making used for general assessment tasks. The surveyed methods have been evaluated with respect to the goal of the paper, i.e. finding a method which should be easy to learn, easy to use, little time consuming and maximally objective. In the third subsection the Analytic Hierarchy Process (AHP) has been described highlighting its main strengths claimed by literature.

2.1. Criteria to select the most favorable solutions designed with TRIZ

In solving real industrial problems by means of TRIZ, it may happen that the designer has to carry out the identification of the most promising solution direction, by choosing it among a large set of good hypotheses on the basis of already defined evaluation criteria. Usually, these parameters have to be defined before knowing the solutions in order to make the assessment procedure objective at the greatest extent. Indeed, it is widely recognized in literature that the knowledge of solutions strongly affects the definition of evaluation criteria as the personal preferences dictated by the skill of the designer could lead to selection rules tailored on a solution rather than another. If the problem to be solved is complex and it is faced by following the steps suggested by the NoP, it is not unusual to obtain a very large set of partial solutions which have to be selected and combined together in order to formalize one or more overall solutions for the main problem. In the TRIZ literature, a marginal amount of contributions concerns the selection or assessment of solutions [4]. In the few cases where such a problem has been tackled, the authors have tried to use one or more already existing TRIZ tools for assessment purposes. Iyer [5], besides mentioning AHP as a valid aid for the evaluation process (e.g. from the perspective of multiple stakeholders), proposes to evaluate the ideas generated with TRIZ by taking into account their Degree of Ideality. He suggests to combine the Laws of Engineering System Evolution (LESE) and the consequent Trends of Evolution with the Altshuller's System Evolution Curves, with the aim of evaluating solutions on the basis of their positioning on the S-curve related to the technology area under investigation, hence considering the closeness of the ideas to the Ideal Final Result. The suggested approach can be very helpful for solution assessment, but according to authors' experience, it requires the support of a TRIZ expert and it cannot be used by design teams with basic TRIZ training and education. Furthermore, a mismatch often takes place between customers and/or stakeholders preferences and the outcomes resulting from an evaluation process based on the LESE, since ideality criteria do not always meet the industrial exigencies in terms of commercial exploitability of the technical solutions.

In [6], Orloff declares that verification is a crucial and complex stage, because of the difficulty in managing different domains of technology and business in order to predict and assess the quality of a solution and the consequences of its application. However, he proposes a set of rules for the verification of ideas that could help to prevent serious mistakes when evaluating the quality of a solution. These rules are based on multiple attributes that a solution has to satisfy: e.g. the resolution of a contradiction, the occurrence of a super-effect or the controllability of the usage and so on. Despite such a method is a suitable technique to assess solutions, it seems to be too time consuming; moreover it does not take into account the evaluation criteria on the basis of which the solutions should be assessed.

Savransky[7] briefly discusses two methods for evaluating solutions or ideas: T-chart and the simple decision matrix. The T-chart is a two-column table focusing on solutions potential outcomes, classified in good/beneficial and bad/negative results. The decision matrix consists in a set of criteria upon which the potential alternatives can be decomposed, scored and summed to obtain a total score that is subsequently used to rank the solutions. This tool can be considered as a foundation for other methods belonging to the group of Multiple Criteria Decision Making (MCDM) techniques. More in detail, a decision matrix is typically built in MCDM with the aim of summarizing the selection criteria and the related level of fulfillment pertaining to each alternative solution. Table 1 depicts a decision matrix describing an exemplary situation which involves three alternatives and five different evaluation criteria.

Table 1. An example of decision matrix

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Alternative 1	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}
Alternative 2	a_{21}	a_{22}	a_{23}	a_{24}	a_{25}
Alternative 3	a_{31}	a_{32}	a_{33}	a_{34}	a_{35}

2.2. Overview of general techniques for supporting decision making

Outside of TRIZ domain, the literature reports plenty of methods developed for decision making viable to be employed for the selection of the most promising solution at the end of a Problem Solving process. A MCDM method, as the name suggests, can be appropriately employed in those circumstances when more than one criterion has to be considered (ex.: cost, quality, servicing, etc.).

One of the most common approaches based on the decision matrix, is the Weighted Sum Method (WSM) [8], especially used in mono-dimensional problems, i.e. when a plurality of influent factors can be assessed in terms of a common unit of measurement. According to WSM, if M solutions and N criteria exist, then the best alternative is the one that satisfies the following condition:

$$A^*_{WSM} = Max\left(\sum_j^N a_{ij}\, w_j\right) \quad , i = 1, \ldots, M (1)$$

where:

- A_{WSM} is the WSM score of the best alternative;
- N is the number of decision criteria;
- M is the number of alternatives;
- $a^{ij}$is the actual value of the i^{th} alternative in terms of the j^{th} criterion;
- w_j is the weight of importance of the j^{th} criterion.

The total score of each alternative is equal to the sum of products $a^{ij} \cdot w_j$. Such a method results very simple to understand and to apply, but, on the other hand, it cannot be considered as a very objective approach. Indeed, both the weight of each criterion and the values of each alternative are assigned by the decision maker (DM) basing the judgment on his own experience. The lack of objectivity makes the WSM poorly reliable as a valid tool in a problem solving process. However, since it is widely used, it has been taken as a benchmark for the scopes of the present work.

ELECTRE (Élimination Et Choix Traduisant la Réalité) [9] is a method for solutions selection that establishes a binary relationship between alternatives by considering a set of evaluation criteria. It claims that solution a outranks solution b if a greater number of positive criteria supports a and if there is no strong opposition towards a. The comparison among paired alternatives is performed through the usage of a “concordance matrix” where the outranking is recorded of one alternative over the others, while a “discordance matrix” takes into account the opposition of the other alternatives to the supremacy of the assessed alternative. Such a method has the advantage of its multidimensional nature but it is difficult to understand and to apply, because of the principles used in determining the concordance and discordance matrices. In addition, some thresholds (to claim the effective difference between two options) are often established according to DM’s opinion, thus affecting the objectivity of the decision process [10].

TOPSIS (Technique for Order Preference by Similarity to Ideal Situation) is a method developed by Huang and Yoon [11] as an alternative to ELECTRE. The basic concept of this method is that the best solution should have the shortest distance from the ideal solution in a “geometrical” meaning. A decision matrix of M alternatives and N criteria is firstly built; subsequently, the computation of the normalized decision matrix and the construction of the weighted decision matrix are carried out. This is followed by the definition of the ideal and negative-ideal solutions. According to them, the best alternative is the one which has the shortest distance from the ideal solution and longest distance from the negative-ideal one. Unlike ELECTRE, this approach is very easy to understand thanks to its simplicity and rationality but it results subjective because of the dependence on the DM’s judgment during the decision matrix building.

2.3. Insight of the Analytic Hierarchy Process

The last method taken into account is the already mentioned Analytic Hierarchy Process developed by Saaty starting from 1980 [2], which enjoys a widespread appreciation in the literature. Such an approach differs from the above mentioned ones, because it does not depend on the decision matrix. The authors report hereinafter a brief description of the method and explain why the AHP has been employed in the subsequent experiment.

The essence of AHP is the decomposition of a complex decision task into a hierarchy with a posed goal (ultimate objective) at the top of the scale, criteria and sub-criteria at intermediate levels and sub-levels of the hierarchy, decision alternatives at the bottom of the ladder (see Fig 1). This scheme closely resembles the decomposition logic of a big problem into sub-problems, as in the NoP approach. Elements, which may be criteria or alternative solutions, at a given hierarchical level are compared in pairs to assess their relative importance with respect to each superior level element they depend on, thus creating a comparison matrix at each step [8].

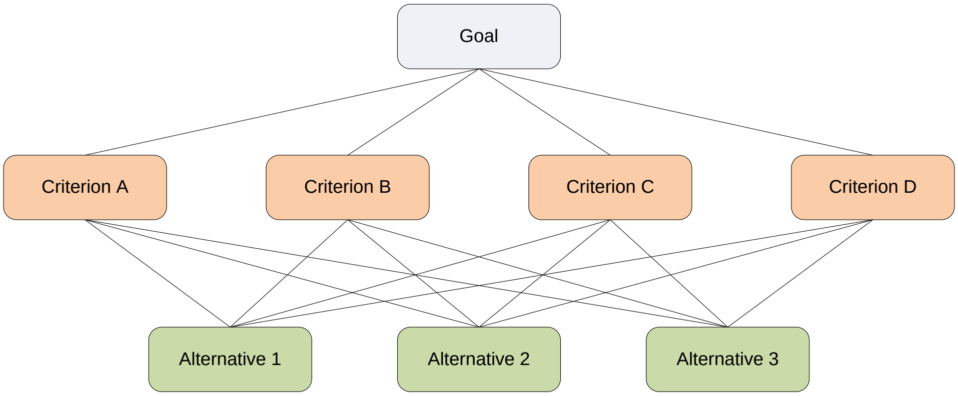

Figure 1: Hierarchy representation of the AHP approach

The input data for the performance of the AHP are obtained by pairwise comparisons between each couple of elements of the same rank that have to be assessed. The comparisons are carried out to determine the weights of importance of each decision criterion, or the relative score of the alternatives according to each decision criterion. At the end, AHP provides a scheme to check the consistency of comparisons. One of the most crucial aspects in many decision-making methods is the accurate estimation of the input data, which often refer to not measurable parameters, or at least to features that cannot be easily revealed. This problem does not impact just AHP, but represents a severe limitation also for many other methods, which require the DM to elicit qualitative information into quantitative values. Therefore, many decision-making methods attempt to determine the relative importance or weight of the alternatives with respect to each criterion involved in a given decision-making problem. With AHP, the DM has to express his/her opinion about the value of a single pairwise comparison at a time, typically by selecting his/her answer among 10-17 discrete choices, formulated according to the linguistic phrases shown in Table 2.

Table 2: Scale of Relative Importance

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocal of above non zero	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.	

The results of these comparisons are recorded in the judgment matrix (2), which should be both transitive (3) and reciprocal (4). Within the matrix A, the elements a_{ij} compare alternatives *i* and *j* of a decision problem [12].

$$A = \begin{pmatrix} 1 & \cdots & a_{ij} & \cdots & a_{1n} \\ \cdots & 1 & \cdots & \cdots & \cdots \\ 1/a_{ij} & \cdots & 1 & \cdots & \cdots \\ \cdots & \cdots & \cdots & 1 & \cdots \\ 1/a_{1n} & \cdots & \cdots & \cdots & 1 \end{pmatrix} \tag{2}$$

$a_{ij} = a_{ik} \cdot a_{kj}$ where *i*,*j* and *k* are alternatives in the matrix; for $j > k > i$ *(3)*

$a_{ij} = 1/a_{ji}$ *(4)*

The ranking of the alternatives is estimated by finding the principal eigenvector *w* of the matrix.

AHP provides a measure of the incongruence of each set of judgments, by calculating the so called consistency ratio (CR). This value expresses how much the matrix diverges from a completely random one. It is expressed by dividing the Consistency Index (CI), derived from the built matrix and calculated as reported in (5), and the Random Consistency Index (RI), which is related to completely random matrices of the same order (see Table 3). According to Saaty [2] the matrix is considered unacceptable if the CR is greater or equal to 0.10.

$CI = (\lambda_{max} - n)/(n - 1)$ *(5)*,

whereas λ_{max} is the maximal eigenvalue of the matrix *A*.

Table 3: Random Consistency Index. The first row expresses the order of the matrix.

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

For the purpose of the paper, AHP presents a lot of advantages, starting from its ease of use. Indeed, even if it involves the calculation of the matrix eigenvectors, several stratagems are available in literature to calculate them in approximate manners [13], which make the task approachable also to people not particularly skilled with algebraic calculations.

Another benefit of the AHP arises from the employment of pairwise comparison. As previously recalled, when a set of conceptual solutions should be assessed, it is easier to express the relative importance between two concepts rather than expressing an absolute judgment about the whole set. The possibility of performing a final check of the stated assessments is an important peculiarity of the AHP which decreases the uncertainty degree on the choice of the DM. Despite some disagreement [14], it is well-acknowledged that AHP allows a more objective assessment of the alternatives [15], although it is based on personal opinions which imply a not completely objective solution ranking as the totality of the MCDM systems. On the other hand, AHP is quite time consuming, especially if not supported by software applications. In [16] a study is reported aimed at comparing AHP, ELECTRE and TOPSIS through their employment for a shared case study, coming to the conclusions that Saaty's approach results the most reliable method since it allows the analysis of consistency of judgments, while TOPSIS can be considered the simplest stratagem.

3. Case study

In this chapter a case study will be presented to compare WSM and AHP, allowing to point out their differences and their pros and cons. These two methods have been preliminary chosen since, according to literature claims, they fulfilled some of the prerequisites of an ideal decision making system for individuating the most valuable solution among a given sample. WSM outperforms all the presented approaches thanks to its ease of use and intuitiveness, while AHP emerges as the least subjective method.
The work regards a hand steamer (similar to that depicted in Fig. 2) and it is a real case study conducted by the authors, aimed at innovating a product of a local company, whose name will not be revealed for the sake of confidentiality. Among a certain extent of problems regarding the artifact, one of the biggest concerns of hand steamer users regards the wire connection, which interferes with the movement of the people during the usage of the product. The company asks for a solution capable to continuously feed the steamer for all the working time without the hindrance of the wire, which sometimes could be even dangerous.

Fig. 2. Exemplary hand steamer

The task has been tackled following the approach suggested by the Network of Problems, which has been built in order to systematically map all the partial solutions and the sub-problems. The work started with the definition of the criteria to select the best solution, to be then used at the end of the process, by formalizing four main targets of the design process: the solution has to be effective, i.e. the power feeding has to be secured, cheap, light and little bulky. By properly translating these characteristics the selection criteria become:

- effectiveness;
- cost;
- mass;
- size.

Due to confidentiality agreement, just an excerpt is reported in Fig. 3 of the whole NoP, constituted by 62 problems and 130 partial solutions. The thorough development of the NoP has been carried out together with domain experts and at the end of the process four solutions have been identified:

1. providing the steamer with disposable batteries;
2. making the wire detachable when necessary and feeding the steamer for a short time with an internal battery;
3. using rechargeable batteries with a fast recharging system;
4. using a battery with the addition of a zeolite heater to guarantee a longer working time.

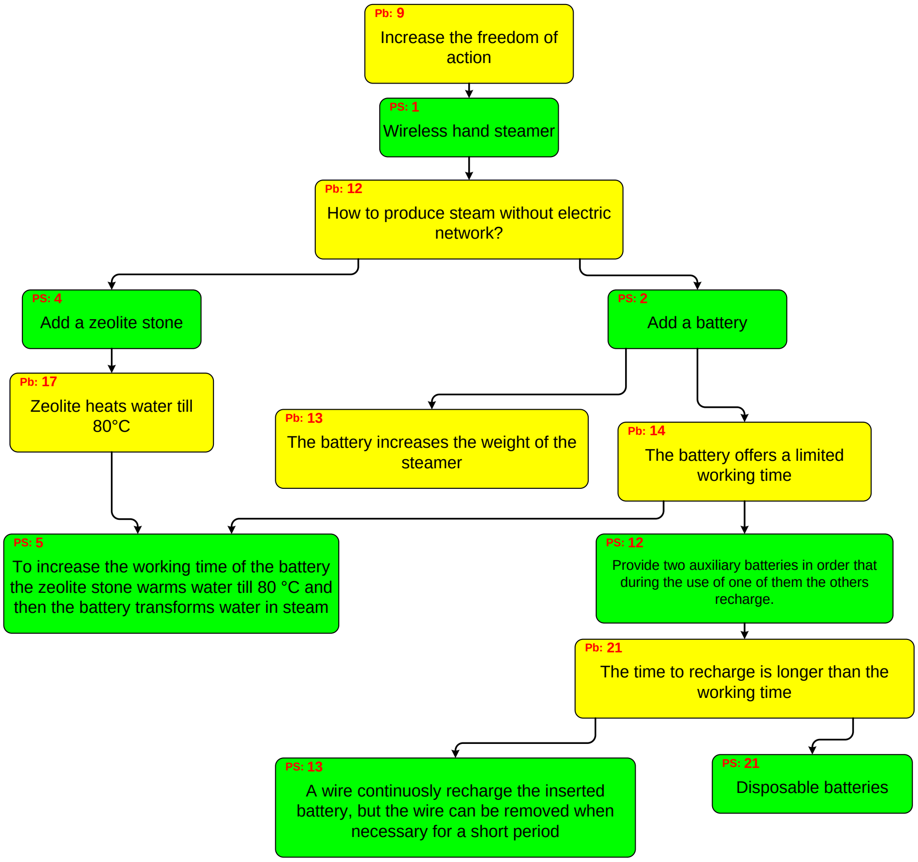

Fig. 3. An excerpt of the Network of Problems

The first attempt of ranking the alternatives has been performed by building a Decision Matrix (see Table 4) in order to apply the Weighted Sum Method. A range of values between 1 and 10 has been chosen to assign both the weight of criteria and to evaluate the performance of each solution with respect to the above metrics. The presented outcomes emerged from a final convergence of opinions among the authors and the involved experts, which resulted in a quite time-consuming task. More specifically, the time elapsed to apply the AHP consisted in about one hour and a half, approximately the double than for the experiment conducted through WSM (roughly 40 minutes).

Table 4: Decision Matrix. The first row lists the selection criteria, the column recalls the proposed solutions. The numbers under each criterion represent their assigned weight.

	Effectiveness of the solution	Cost	Weight	Size
	9	5	8	7
Disposable batteries	6	2	6	6
Removable wire and battery	3	6	7	5
3 fast rechargeable batteries	5	4	6	6
Zeolite and batteries	7	7	7	5

The first trouble encountered in building the matrix concerned the assignment of the weight to the criteria. Despite the range is considerably wide, the assigned weights belong to a narrow interval, since they vary from 5 to 9; besides three of them are consecutive. This phenomenon can be originated by two different aspects:

- the system through which the values are assigned, that is based on an absolute scale rather than forcing to perform mutual comparisons between the elements to be assessed;
- the disregard of evaluation parameters playing a minor, but not completely negligible, role in the decision making process.

Discussions emerged within the group of experts when the solutions have been assessed according to the criteria. In the decision matrix each alternative solution has been compared in terms of each decision criterion, but, because of the absolute scale, the judgment resulted very laborious and controversial. When the decision making example has been completed, the final score for each solution has been calculated according to (1). As reported in Table 5, the final ranking shows that the most promising solution (although with marginal differences with respect to the other options) is that which merge the feeding of a battery with the heating effect of the zeolite.

Table 5: the final score obtained with the WSM

Solution	Total score
Disposable batteries	154
Removable wire and battery	148
3 fast rechargeable batteries	155
Zeolite and batteries	189

The AHP approach has been subsequently tested (the overall needed time has been already reported above). First of all, the ranking of the selection criteria has been performed, and, to this aim, a first matrix has been built (see Table 6).The authors used a free Microsoft Excel template downloadable from the

Internet at the page *http://bpmsg.com/new-ahp-excel-template-with-multiple-inputs/* to perform the algebraic calculation required by the AHP method. The completion of the matrix allowed the calculation of the Consistency Ratio, so to evaluate the reliability of the judgments. At the first attempt, by roughly introducing the means of the values indicated by each decision maker, CR resulted in 19.7%, indicating a not negligible random component of the matrix. Hence, all the sentences have been rechecked during a collective discussion in order to correct inaccurate inputs. At the end, CR reached the value of 5.8%. With the same procedure, all the comparison matrices have been completed (see Tables 7a, 7b, 7c and 7d), performing the pairwise comparison of the solutions according to each single criterion. The principal eigenvector of each matrix has been calculated in order to rank the set of alternatives according to the specific parameter. All the computed eigenvectors have been collected in a final matrix, which has been multiplied by the eigenvector relating to the criteria classification, so obtaining the vector containing the final scores(6).

Table 6: the decision matrix concerning the assessment of the selection criteria. The capital letters mean: E = effectiveness, C = cost, W = weight, S = size. Consistency Ratio = 5.8%.

	E	C	W	S	Normalized Eigenvector
E	1	9	3	3	0.56
C	1/9	1	1/7	1/7	0.05
W	1/3	7	1	1	0.20
S	1/3	7	1	1	0.20

Table 7a: the decision matrix made to assess the solution in terms of the criterion of effectiveness. The acronyms stand for: DB = disposable batteries, RW = removable wire, RB = rechargeable batteries, ZB = zeolite stone plus battery. CR = 9%.

	DB	RW	RB	ZB	Normalized Eigenvector
DB	1	5	1	1/3	0.19
RW	1/5	1	1/5	1/7	0.07
RB	1	5	1	1/5	0.15
ZB	3	7	5	1	0.59

Table 7b: the decision matrix made to assess the solution in terms of the criterion of cost. For the meaning of acronyms see the heading of Table 7a.

	DB	RW	RB	ZB	Normalized Eigenvector
DB	1	1/5	3	1/3	0.11
RW	5	1	7	3	0.59
RB	1/3	1/7	1	1/5	0.07
ZB	3	1/3	5	1	0.22

Table 7c: the decision matrix made to assess the solution in terms of the criterion of weight. For the meaning of acronyms see the heading of Table 7a.

	DB	RW	RB	ZB	Normalized Eigenvector
DB	1	1/5	1	1/3	0.10
RW	5	1	5	3	0.58
RB	1	1/5	1	1/3	0.10
ZB	3	1/3	3	1	0.22

Table 7d:the decision matrix made to assess the solution in terms of the criterion of size. For the meaning of acronyms see the heading of Table 7a.

	DB	RW	RB	ZB	Normalized Eigenvector
DB	1	1/9	1	1/5	0.06
RW	9	1	9	3	0.64
RB	1	1/9	1	1/3	0.07
ZB	5	1/3	3	1	0.22

$$\begin{pmatrix} 0.19 & 0.11 & 0.10 & 0.06 \\ 0.07 & 0.59 & 0.58 & 0.64 \\ 0.15 & 0.07 & 0.10 & 0.07 \\ 0.59 & 0.23 & 0.22 & 0.22 \end{pmatrix} \cdot \begin{pmatrix} 0.56 \\ 0.05 \\ 0.20 \\ 0.20 \end{pmatrix} = \begin{pmatrix} 0.15 \\ 0.30 \\ 0.12 \\ 0.43 \end{pmatrix} \qquad (6)$$

Unlike what happened during the accomplishment of the test using WSM, the experts came to an agreement in a shorter time during the collective discussions. The opportunity to compare two criteria at a time proved its effectiveness in facilitating the assessment process.

The comparison between the results reached with WSM and AHP approaches (Table 8) shows that the most promising solution is the same for both the methods, while the assessment for the other three alternatives is completely different. For instance, solution number 2 judged as the second best by the WSM, has been assessed as the worst by means of AHP. Nevertheless, the most remarkable outcome is the considerable similitude among the final scores concerning the four options when adopting WSM, which does not allow to discern substantial differences among the alternatives. In other words, according to the results reported in Table 8, this specific application of WSM does not help the decision making, since it comes out to be very hazardous assessing the superiority of a certain solution with respect to a competing one. Conversely, the task performed by means of AHP clearly individuates the most promising solution and the second most beneficial alternative. In this sense, the methodology employing paired comparisons has effectively supported the choice of the solution.

Along with these considerations, it is worth to notice that the overall outcome of AHP has been considered more realistic by the domain experts, according to their intuition.

Table 8: comparison between the results obtained by WSM and AHP approaches.

Solution	Normalized WSM score	AHP score
Disposable batteries	0.24	0.15
Removable wire and battery	0.23	0.30
3 fast rechargeable batteries	0.24	0.12
Zeolite and batteries	0.29	0.43

4. Discussion

In the paper the authors tested two different methods for solutions assessment: the Weighted Sum Method and the Analytic Hierarchy Process. The application of the former has been unquestionably faster, even if this time saving brought a set of inconveniences in performing the task, as, for instance, the trouble in assessing the solution according to an absolute scale employed for evaluation purposes. The same problem has not arisen when the assessment has been carried out using the AHP approach. The possibility of judging according to a relative scale allowed to speed up the converging process among not fully congruent individual evaluations. The experiment involving the use of two methods and working with the same case study and the identical group of decision experts has resulted in different outputs. The most promising solution is the same for both the approaches, while the remaining alternatives have been ranked contrariwise. Major concerns regard the poor capability of WSM to rank the solutions in terms of their expected benefits.

Actually, it is very hard to define which are the causes of disagreement and, especially, if the differences are intrinsic to the methods or depend on different factors.

Beyond the specific achieved results and the time spent in performing the activity, AHP proved to be more suitable in the solution assessment because of the shorter time needed to find a trade-off between the different opinions of the participants to the decision process. Furthermore, AHP seemed appropriate for a conjoint use with the NoP, since such a process very often brings to the formulation of a considerable set of solutions.

On the other hand, AHP is not completely satisfying because of some peculiarities. First of all, AHP is more complex than other MCDM. Indeed, it requires carrying out several, although simple, operations which need some knowledge of algebraic calculations, especially if they are made by pen and paper. To this aim several software applications have been developed to aid the decision maker, so to facilitate the assessment process. Within the development of suitable tools for decision making, the authors will take into account the available resources in light of quickly implementing in computer applications the specific improvements oriented to solutions selection.

Overall, it is possible to assert that the experiment carried out with solutions originated through an OTSM-TRIZ approach has reflected strengths and weaknesses of decision making methods as claimed in the literature. The capability of pairwise comparisons to outperform absolute scales evaluations seems to result a distinguishing feature in engineering applications, as witnessed e.g. by [17] and [18]. Such characteristic becomes even more relevant in the initial phases of design tasks, thus including inventive problem solving, whereas more qualitative and hardly measurable parameters are involved [19].

If the outcomes of the present study mirror the evidences emerged in different contexts, it is reasonable to expect that the variability of the evaluations with respect to different decision makers can represent a remarked phenomenon. Hence, it represents a severe challenge for the fine-tuning of an original tool aimed at supporting the selection of partial solutions developed through the NoP.

4.1. Directions for managing uncertainties in the decision-making process

Especially with respect to AHP, the common strategy to take into account the variability of the results is resorting to the Fuzzy Set Theory, as witnessed by even recent applications, e.g. Durán and Aguilo[20]. Nevertheless, such approach is relentlessly affected by the argued efficacy of fuzzy sets within the management of uncertainties for decisions undertaking [21]. In each case, the major limitation for the purpose of the present research stands in the difficulty of employing such complex mathematical models within a large amount of industrial contexts.

On the other hand, a considerable number of opinions should be compared in order to manage conflicting judgements and extract rigorous evaluations through classical statistical methods: a sample of 28 expert subjects should be constituted for providing results characterized by a 95% confidence, as commonly in the practice [22]. Therefore, it would result advantageous, given the diffusedly limited teams in charge of technical decisions within industrial environments, to introduce pragmatic methods to consider the uncertainty, rather than computing poorly reliable statistical estimates.

On these premises, the authors judge Monte Carlo simulation method as an opportunity for dealing with the uncertainty associated with the variables that are introduced in the performances of both WSM and AHP. Monte Carlo method is a widespread technique tailored to support decisions, due to its capability to generate scenarios according to many varying and uncertain inputs. With a particular focus on engineering applications, the method is tailored, as assessed in [23], to deal with both epistemic (i.e. related to the lack of knowledge or caused by measurement errors) and aleatoric uncertainty (i.e. provoked by the variability of the involved parameters, surely predominant in the treated case). Moreover Monte Carlo simulation can be easily performed through extensively diffused and easy-to-use software applications [24], more specifically spreadsheets, as that employed for accomplishing the AHP procedure.

A future testing activity will be carried out with the methodological objective of replicating a large series of inputs concerning the items to be introduced within WSM and/or AHP. The simulation has to be performed on the basis of the data that have been introduced by a limited number of industrial experts applying the discussed decision making methods to support the task of selecting a preferred solution concept.

5. Conclusions

The present paper shows that classical methods of Multi Criteria Decision Making analysis can be used, at the end of a divergent Problem Solving process, to asses several solutions according to a set of evaluation criteria. In particular, two approaches have been tested: the Weight Sum Method and the Analytic Hierarchy Process. The methods have been experimented to assess a set of solutions resulting from a problem tackled with a NoP approach. The AHP method has proved to ease the convergence of different judgments within the decision group. Trade-offs are favored by pairwise comparisons that allow to focus on two elements at a time, instead of assessing through absolute scales the whole set of issues relevant for the decision undertaking. Moreover, AHP offers a check tool to verify if the assigned values are consistent or similar to a random set of evaluations. On the other hand, AHP is more time consuming with respect to WSM and it needs a computer aided tool in order to speed up the required algebraic calculations.

Future developments will concern the application of the methods to more complex problems in terms of both the number of decision criteria and the quantity of potential solutions. The planned experiment is needed to verify if the degree of convergence between the two considered approaches will significantly increase or decrease. Additionally, an integrated employment of AHP and the NoP has been planned, whereas the MCDM method has to be used all along the development of the network constituted by partial problems and solutions. Indeed, because of the intrinsic nature of the NoP, a single problem could be solved by several alternative solutions, each of them generating other sub problems, and so on, giving rise to an excessive expansion of the network. Instead of using the AHP just at the end of the problem solving process, when a plethora of alternatives should be assessed and compared, it may result more practical to integrate decision making supports at intermediate steps and choose the more suitable branches of the NoP to be further developed.

As reported in the discussions, another aspect that will be treated concerns the development of simple tools, hopefully integrated in a software application, able to aid the decision making process in case of severely divergent opinions among the people in charge. Although such endeavor cannot result in an enhanced objectivity of the selection task, the consciousness about the risks of the decision making can be boosted, by accounting the extent of the uncertainty intrinsic to MCDM methods, owning a not negligible stochastic dimension.

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