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SUPPORTING PRODUCT INNOVATION IN UNCERTAINTY CONDITIONS: A U-sDSP BASED DECISION MAKING APPROACH

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ABSTRACT
International competition intensification and product development process shortening have heightened the pressure to innovate, representing this issue nowadays a hallmark of all mature companies. Product innovation process is not always successful, due to its high level of uncertainty which makes difficult the best technical solutions selection, notably during the early stages of the product development process. Even if the decision making phase appears to be critical, formal and effective methodologies and tools are not often systematically applied in industry, and furthermore they lack both of rigor and of the capacity to really support human decision-making phases. In this paper a design paradigm is discussed in order to support the early phases of the product innovation process. Once evaluated the high potentials of TRIZ theory in supporting the idea generation phase, this work is focused on testing and improving the u-sDSP decision making approach in order to enable an agile implementation of this formal technique in the industrial context. The authors' proposed methodology is then applied to an industrial case study from the domestic appliances industry.

Keywords: Decision-Based Engineering Design, Product Innovation, Project Screening

1 INTRODUCTION
Today industrial context is characterized by high competitive pressures, limited resources and low budget. For this reason firms decide to develop new product only once technical, marketing and production requirements have been deeply evaluated, in order to effectively lead to desired results and proactively guide research efforts in a direction consistent with enterprise mission and strategy. Especially during the product development process (PDP) conceptual design phase, rapid assessments are required, so that trade-offs can be performed with minimal time and costs efforts. Since it is difficult to obtain precise information upon which to base decisions, an high level of uncertainty characterizes this evaluating procedure: future benefits of new technologies and qualitative factors are both uncertain and difficult to measure since they require the coordination of a huge variety of enterprise departments. Newer advanced technologies may offer improved performances but they also make the PDP more risky and challenging. Even if it is not possible to reduce this high level of uncertainty strictly connected to innovation, useful methodologies can be applied in order to support early design decisions in a more formalized way. These ones can enable company to capture and represent the intentions and rationale behind a proposal, and also facilitate the communication among enterprise departments. The implementation of these decision making techniques can lead to positive implications also from the organizational point of view. Since R&D projects represent the means by which technology strategies are implemented, the long-term success of a company is often determined by the effectiveness of its project selection process. In order to weed out projects that have little chance of being approved these ones are usually compared only basing on costs, benefits, and risks, without take into account technical aspects such as design and production ones. To evaluate design concepts the majority of companies currently use informal methods which may not be really effective. Firstly they hinder information exchange and reuse and secondly, due to the absence of a rigorous validation methodology, it is not clear how to determine if the proposed design concept is consistent with the requirements.
This overview suggests how product innovation is as fundamental as difficult to perform in an industrial context. For this reason authors' aim is to define a formal methodology which acts in two directions: stimulate designers creativity, in order to identify several technical alternatives, and then

enable them to rapidly and effectively select the best one. The research activity discussed in this paper is the continuous of a previous one [1] focused on applying and testing the efficiency of idea generation methodologies into a specific industrial context: TRIZ theory has been selected. Starting from this analysis, the u-sDSP decision making approach is then discussed and tested in a real test case from the domestic appliances industry. The real usefulness of this methodology has been assessed while main implementing difficulties have been identified and then, solutions are proposed.
In the next section, previous works related to decision making methodologies are reviewed. Then an analysis of the problems connected to the difficulty of managing innovation in industry is performed and the fundamentals of authors' approach are presented. A real industrial case from domestic appliances industry is then detailed. Finally, closing remarks and outline aspects of further research conclude the paper.

2 BACKGROUND

In situations where large numbers of options, attributes, associated risk and uncertainty contribute to the complexity of decisions, it is very important to employ a design tool that supports decision-making by accurately capturing both the perspective of a designer and the uncertainty associated with system attributes [2]. Indeed, while the management of objectified requirement statements and detailed geometry models is well supported, different design alternatives creation, management and best choice identification is not properly fostered. Several steps forward are to be taken, being strongly present, in the engineering research community, a growing recognition that decisions represent the fundamental construct in engineering design [3]. Starting from more general evaluation methods as the one discussed by Pahl and Beitz [4], or more intuitive ones, such as Pugh controlled convergence method [5], the literature about decision-making theory is now becoming more and more interdisciplinary involving aspects ranging from mathematics until psychology and management. A remarkable literature review about decision making methodologies is discussed by Tang in [6]. Following the Keeney [7] approach Tang classifies and discusses three research streams: normative, descriptive and prescriptive. While the first group deals with the logical consistency of decision making, the second one concentrates on representations of how and why people make decisions and finally, the third one is about the practical application of normative and descriptive theories [8]. In the normative approach great effort has been putted upon the challenge of quantitatively measuring the merit of design alternatives: mathematical oriented approaches, based on expected utility theory [9], have been defined to model uncertainty in the design process. The utility theory models the decision situation by mapping the design option space to the performance attribute space, and then obtains the designer's preference information regarding the tradeoffs among these attributes. Indeed both rigorous mathematical approach [10,11] as well as more fuzzy one [12] have been proposed. Despite of its mathematical elegance, utility theory is not without crises or critics as well argued in [6]: indeed a sort of bias approach is followed by decision makers when selecting utility values and their probability since people have a preference for certainty to an ambiguous gamble with higher utility. Omitting the discussion about descriptive theories which, even if of great interest, they do not match with the paper intent, the literature review analysis has been then focused on prescriptive theories in which practical applications of both normative and descriptive theories are present. In particular, in such a context the Analytical Hierarchy Process, proposed by Saaty [13] has been applied in engineering design process in order to process the inevitably subjective and personal preferences of an individual or a group in making a decision. In this theory both mathematical approach and a list of judgment criteria are combined together in order to enable the designer to correctly interpret the results obtained from the analysis: in Saaty's approach the utility theory is absent since he uses "importance" as the criterion of decision. On the contrary both Howard's decision analysis method [14] and the Keeney's Value Focused Thinking (VFT) [15] are based on the Utility Theory. In accord with Fernández et al [16] although mathematical rigor is fundamentally important, utility for practical applications is crucial as well. For this reason in their research they have been combining the selection Decision Support Problem (sDSP) [17,18] with the utility theory, in order to create a qualitative and axiomatic method for supporting human decision-making throughout the design process; they called their approach as utility-based selection decision support problem (u-sDSP). While utility theory implementation enables the approach to be based on a more mathematical foundation, guiding the quantification of designer preferences and the evaluation of the different alternatives, the sDSP gives a more structured and information-based characterization which is necessary to translate the human element.

Going deeper into this research branch, Tang's work [6] presents a new prescriptive design method for corporate decision-analysis applying well known engineering methods, such as Design of Experiments and the Gage Theory, to the decision process. In addition, business area approaches such as the Balanced Scorecard [19], can also be mentioned, which is based on the analysis of tangible and intangible benefits in long and short term. Even if this approach does not consider only financial and organizational aspects, it is obviously more focused on the economic area.

Most of these methods try to deal with the problem of information lacking during early decision process phase and guarantee more formal and structured ways to deal with decisions. But also more effort have to be put on enabling decision makers, such as designers, on acquiring the knowledge necessary to address problems in order to manage the sources of uncertainty and reduce the risk of failure. This means enabling decision makers to learn as much as possible during the product development process, preserving the rationale behind decisions so that a good level of expertise could be reach in order to more easily come up and deal with new ideas and technical alternatives selection.

In this work the u-sDSP methodology has been chosen by authors as a reference method since the decision making process is analyzed in a well formalized and structured way, being able, in the mean time, to capture both the "voice of the consumer" and the "voice of the company". In particular, authors have identified a good balance between mathematical rigor and the ease of use and applicability especially in specific industrial context where nowadays no structured decision processes are present. Furthermore, one of the u-sDSP method main goals is to develop a decision making process among different technological solutions which will be leading to a final product in good compliance with both market requirement and industrial constraints so that, not only customer needs are considered as it happens in the QFD approach. Finally, an interesting analysis of stakeholders' likes and dislikes was quantitatively possible by u-sDSP implementation: utility functions definition can represent a good formalization method. In the next paragraph a deeper analysis of the u-sDSP method is performed and additional aspects are discussed.

3 MANAGING INNOVATION IN INDUSTRY

3.1 The selection of technological alternatives in consumer goods industries

Product competitiveness results, on one side, from product quality, industrial process optimization, industrial cost efficiency, top range products and low environmental impact; on the other side, it is now driven by new product concepts that can generate new needs and push new trends. This breakthrough approach is today more ascertained not only for high-tech product but also for other consumer goods, such as domestic appliances, whose complexity may seem lower in comparison with the previous ones.

Once an innovative or enhanced function is required, strong attention is firstly put on identifying suitable technologies in order to achieve project targets. It is also evident that the estimated new targets have to be compared with the current ones, which are well assessed by common practice in the industrial implementation. But comparing mature technological solutions with new concepts is often a critical operation to perform because a preliminary evaluation can significantly affect further project development. While an incorrect analysis can lead to exclude a promising technology, causing the company in being a follower in new technologies introduction, on the other side, too optimistic evaluations can trigger too high expectations into the market, and the brand image can be negatively affected in case of an incomplete target achievement. Accordingly to author's experience, especially companies involved in non-high tech goods production, they usually tend to operate this kind of technological evaluation by means of non structured methods, such as brainstorming activities and technical information research among potential suppliers, and generally referring to engineering judgments and senior specialists advisoring. This situation has then lead authors on trying to introduce in this industrial field more formal methodologies to face with the drawbacks of uncertainty in new product development. In particular, the case study hereby presented comes from the domestic appliances market since several efforts have been pushed over the last decade, by the most important domestic appliances companies, to put into market innovative products with significantly enhanced or completely new performances.

3.2 Steps to implement the u-sDSP method in product innovation processes

The u-sDSP method is based on eight main steps, as well described by its authors in [16]. The first step obviously requires the identification of the main objectives to be pursued by product innovation: in other words, the possible alternatives coming from the concept generation idea. Furthermore, as pointed out by Fernández et al, each alternative has to be considered at the same level of detail, in order to maintain all the design rationale related to the decision phase. In addition, to obtain a more valid and effective result in case of product innovation, it is important to apply this analysis also for already implemented technical solution, in order to consider their results as reference for future evaluations and comparisons.

Once the possible alternatives have been identified, the second step consists in choosing the independent attributes to be considered during selection: it is mandatory to detail them giving as much as possible a quantified description. In this phase, a full identification of all the potential attributes is also crucial, being this possible by a strong interaction of all the team members involved in the project, in order to completely characterize each technological alternative. Accordingly to the aforementioned issue, it is important that attributes identification is performed by professional and experienced team members belonging to different company departments since the integration of diverse perspective and ideas is at the core of the creative process and therefore is a central determinant of the innovativeness of the new product concept.

Each attribute is then defined as a numerical parameter, with a preferential target and unacceptable values. It is worth to point out that in an industrial context, the possible parameters variation range will often result in discrete sets of values instead of continuous ranges, as it will be clearly discussed later in the case study description. The next action consists in defining the probability distribution functions for each parameter and each technological alternative: designers, and, generally speaking, technicians, play the fundamental role of giving a brief explication of each new idea, accordingly to which marketing and industrial departments can perform their preliminary analysis. It is anyway clear that this one also represents an uneasy activity to carry out, mainly due to the lacking of detailed information: with specific regard to the technological performance, intensive communication between marketing and technical oriented people seems to be an important factor.

The next decision step is to assess the utility function for each attribute, its shape and how the function itself is fitted by the data, in order to represent decision maker's preferences. Especially for this step it could be useful storing all these information in a database for a faster retrieving in case of future decision making analysis, in order to preserve all the information related to the product innovation process. As recommended by the u-sDSP method authors, it is also a good practice to check the utility function for consistency through the identification of hypothetical situations in which the outcome of a decision is uncertain.

Since each attribute is defined by a specific utility function, it is then necessary to combine all these functions into a multi-attribute utility one in order to give the possibility to decision makers to perform a trade-off among multiple attributes. To operate this evolving step, a list of detailed assumptions and guidelines has been defined following a mathematical rigor.

Once carried on all these preparing steps, it is then possible to calculate the expected utility of each alternative as a function of multiple attributes and their associated probability distributions using the single-attribute utility functions and scaling constants. Finally the most promising alternatives are the ones with the highest overall expected utility; a critical analysis of the result is then mandatory. Applying this approach also to analyze already implemented solutions could represent a sort of reference point to critically discuss further data. In their work Fernández et al [16] clearly underline which could be the possible causes of error, mainly due to a wrong and non complete evaluation of all the parameters and to an incorrect utility function definition; accordingly to author's opinion and practical experience, potential solutions are represented by a detailed organization of decision making team and a continuous involvement and valorization of each single person, to be sure that everyone in the team will have enough information related to each alternative in order to enable them on performing an effective product modeling regarding his/her point of view.

3.3 Enhancing early stages of product innovation: the proposed approach

The early stages of the product development process are really critical since they strongly influence the effectiveness of all the next product development process phases. Furthermore they offer the largest potential for optimization in terms of cost savings, technical effectiveness and time reduction.

Evaluating all these aspects, the definition of a more successful design paradigm is required in order to better formalize, systemize and manage these early phases. In particular two are the main purposes: 1) stimulate designer creativity to enhance the idea generation phase and 2) support the choice of the best technical solutions (or concept). In figure 1 the early phases of the product development process are detailed in order to clearly formalize the main steps of authors approach. The idea generation activity is considered really critical to enhance the final product success rate: especially in radical innovation, engineers and technicians have to extend their creativity in order to find the best technical solutions and positively change product day-life image. In order to overcome "psychological inertia", which persuades engineers on reasoning only inside their own paradigm or "enterprise area", as demonstrated in authors previous work [1], TRIZ theory implementation allows the access to really effective problem solving methodologies and tools, to stimulate and discipline thinking activity leading to really effective problem solutions. Once ideas are generated a first critical and not really formal analysis can be performed by designers together with marketing experts, in order to carry on the first idea screening and select only the most promising alternatives. This explicit initial screening of generated ideas results in a positive effect since it reduces the range of the different alternatives that will be evaluated in the next phase, simplifying the work of decision makers. Once ideas are selected, engineers have to transform them into concepts represented by sketches, to describe a shape, or technical report to analyze in detail the involved technology. In this case patent analysis can represent a really valid aid in order to identify different applications of the same technology. All these information are required to better perform the decision making phase.

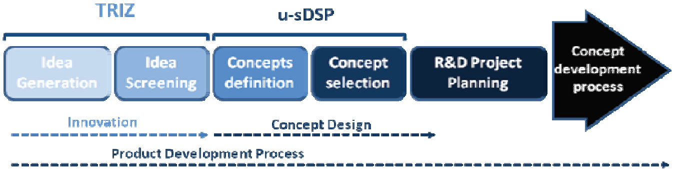

Fig 1. The product development process: improving the early phases.

Indeed it is necessary that all the decision makers have as much as possible a clear characterization of each alternatives. This is a mandatory aspect in order to identify all the necessary parameters to consider in the u-sDSP method, as underlined in the previous paragraph. It would be ideal that each company department would be represented by a decision maker in order to carry on the evaluation process from a concurrent point of view: customer need, target markets, business objectives and technical and production efforts are the principal parameters influencing the go/no-go decision. Accordingly to author's opinion, a "QFD-approach" can be chosen while considering the aforementioned parameters to determine the best attribute sets: as in traditional QFD analysis several different phases have to be progressively implemented (product planning, product design, process planning and process control), in a similar way the best attribute sets to be implemented in the u-sDSP method application shall be ideally subdivided in different subsets, having firstly in mind the final consumer point of view, secondarily the designer's one, and so on, progressively comprehending all the stakeholders. Such an approach will result in a global u-sDSP analysis in which specific views will highlight the contribution of any specific stakeholder to the final result.
Once chosen the best technical solution, a planning activity is performed in order to structure the R&D project that will embody the selected concept. Following this approach a product plan is correctly defined in which the new product development portfolio is determined. On one side, stimulating a more effective choice of the technical solution will enable the decrease of the likelihood to start unsuccessful projects. On the other side, such a method will lead to a product development process characterized by a strong interaction among different company departments: if fruitful collaboration among technical, industrial and marketing departments is likely to occur since the very beginning phases of the product development process, overall project management and project target achievement will be enhanced.

4 CASE STUDY

The core item of this chapter consists in analyzing a real industrial problem, proposing possible technical solutions, and then choosing the most promising one, in order to solve the specific issue of

improving product performance on a domestic appliance. The u-sDSP method has been applied, on one side, accordingly to the most updated theory, but, on the other side, also implementing specific solving approaches in order to best fit with the case study characteristics, requirements and targets; any implemented diversification will be highlighted and explained as the case study will be described step by step. Authors were strongly committed in developing a decision making tool to be applied in the real industrial production field, so that the aforementioned distinctive solutions have been mainly elaborated in order to enhance method pertinence and relevance. This case study grew up during a real innovation project, being, in the early phases of the project itself, a heavy requirement in enhancing current product performance; the project manager, by direct interaction with the main company departments involved in the new product development (technical areas, marketing, purchasing area, system engineering, industrial area..), acted as an "information catalyst". Performance evaluation parameters, industrial constraints, user-like recommendations and so on were developed in collaboration with the previously indicated departments, via brainstorming sessions, specific meetings, technical session with external consultants and also by means of a consumer test: this incremental approach gave to the project, even if in a early stage of the product development cycle, a strong and comprehensive view on final user requirements, together with a focus on project industrial feasibility.
The authors were aware of the risks connected to linking a technical quantitative prioritization, which is the final output of u-sDSP method, with the variability of inputs coming from a human panel. First of all, when asking people to express and formulate their own ideas, in order to collect all the necessary elements for u-sDSP method, "thinking traps" have to be avoided, as indicated in [20]. As evidenced by the authors, spontaneous ways of reasoning can occur, which heavily and incorrectly influence final decision: giving disproportionate weight to the first received information, favoring alternatives that perpetuate the existing situation, seeking information which support the own point of view are typical examples of potential mental distortions which can prevent anyone to take a reasonable decision. Specific cautions were taken by the authors when collecting information, in order to promote fruitful interaction among the involved stakeholders, and appropriately evidencing when judgments seemed to be affected by any form of psychological inertia. Special attention was given also to "homogenize" the human panel level, both in terms of panel statistical validity and panel technical preparation. First of all, three people for almost every company area (R&D, marketing, purchasing area, system engineering, industrial area..) were involved in the analysis, also verifying to have, for each category, a group formed by a junior profile, a middle experienced one and a senior one. Secondarily, each common session was anticipated by a preliminary phase in which the authors briefly explained the technological alternatives to non-technical profiles, in order to allow anyone to briefly understand new concepts features and characteristics, and then being able to participate to the common session.

4.1 Case study presentation

The case study deals with product performance improvement in domestic appliances market; more in details, the focus was put on enhancing drying cycle (DC) performance for clothes, basically by referring to cycle duration and cycle dewatering capability.

Table 1. Technical solution concepts to be investigated.

	TRIZ inventive principle	Technical solution concept	Concept implementation on current products
1	Go from linear to rotary motion, use centrifugal forces (14)	Mechanical spinning	Already present (standard washing machines)
2	Change an object's physical aggregate state (35)	Vaporization of clothes absorbed water by a hot air flow and subsequent vapor elimination	Already present ("exhaust" wash-and-dryers)
3	Use combined ultrasonic or electromagnetic field oscillations (18)	Vaporization of clothes absorbed water by a microwave field	To be investigated; several patents are present
4	Use combined ultrasonic or electromagnetic field oscillations (18)	Vaporization of clothes absorbed water by a ultrasonic field	To be investigated
5-6	Use waste resources, energy, or substances (25)	Vaporization of clothes absorbed water by a hot air flow and subsequent air preheating by exhaust vapor	Already present (standard wash-and-dryers)
		Dewatering by mechanical compression	To be investigated; several patents are present

Drying process today represents a typical phase of standard sequence of domestic appliances cycles, such as dishwashers, washing machines, wash-and-dryers and dryers; the aim is to reach targeted values of residual humidity of the items (clothes, crockery) which underwent previous washing phases, in order to restore beginning conditions. Potential improvements on drying phase could be very appealing for final consumers; the following list shows the most commonly assessed features, parameters and criticisms:

- Energy consumption, up to 30-40% of total cycle for wash-and-dryers
- Up to 40% of total cycle duration of dishwashers
- Handling operations of garments load to be repeated twice for a consumer that washes clothes in a washing machine and dries the same ones in a dryer.
- inhomogeneous distribution of dried load final humidity
- undesired effects for consumers, e.g. the "fog" coming out of the dishwasher tub when door is open at the end of the cycle.

The present case study, as already underlined in the previous section, represents the ideal continuation of a preliminary research work [1], whose aim was to develop possible technical solution concepts for enhancing drying performance of washing machines, wash-and-dryers and dryers, by means of TRIZ theory application. Table 1 resumes the main concepts emerging from the TRIZ analysis, by implementing a reduced Contradiction Matrix, together with further concepts, emerging from standard brainstorming activities.

In the present case study, the technical solutions emerging both from TRIZ methods and from more traditional approaches will be analyzed and evaluated accordingly to a specific set of parameters, also defining probability functions for each attribute and each technology. Due to the fact that both already implemented and non commonly used technologies emerged among TRIZ suggestions, the method will also pursue an overall technology comparison and ranking, being able to contemporarily compare deeply known traditional methods, such as mechanical spinning, together with emerging technological solutions, whose feasibility to the specific problem has not already been analyzed (such as ultrasonic dewatering). As will be more deeply described in the further conclusions, this last issue emerged as significantly interesting, being a very frequent and realistic case the one in which a comparison, and a subsequent decision making process, are required between an assessed industrial solution and an almost unknown technology alternative.

4.2 From continuous to discrete functions

As already discussed in the previous sections, u-sDSP classic method has been slightly adapted in order to better fit to the specific industrial case study. In particular, one implementing difference is based on considering discrete functions instead of continuous ones.

As it will become clearer in the following sections, strong attention has been invested in the definition of a correct and realistic utility function for the identified attributes. As already emerged in previous works, such as in [21], the smaller is the increment, the more difficult it is for people to express their preferences. Being the present study focused on qualitative or semi-quantitative attributes, many of whom taken by final users experience, it seemed even overblown and superfluous putting strong attention in defining a continuous function when it was not possible to perceive more than 4 or 5 different levels for the related utility function in standard conditions.

Accordingly to this discretization, the expected utility for a single attribute a_j of a technology alternative will be defined as:

$$E[u(a_j)] = \sum_{i=1}^{n} u(a_{ji}) f(a_i) \qquad (1)$$

being $\{a_{j1}, a_{j2}..a_{jn}\}$ the set formed by all the finite possible values for attribute a_j, $u(a_{ji})$ the correspondent value of the utility function and $f(a_{ji})$ the correspondent value of the probability function. The total expected utility function for a technology alternative will result by the weighted sum of the expected utility functions related to each single $-j$ attribute, by assuming utility independence and additive independence conditions, as it follows:

$$E[u(A)] = \sum_{j=1}^{m} k_j E[u(a_j)] \qquad (2)$$

being $j=1,2..m$ all the chosen attributes. The k_1, $k_2..k_m$ scaling constants will be calculated by hypothesizing lottery questions or certainty equivalents. Utility independence and additive independence conditions will be assessed by directly testing the appropriate lotteries.

4.3 Attribute choice and characteristics

As stated in section 3.3, the attributes listed in Table 2 have been identified for being the most important and representative, by hypothesizing two different points of view: the final user and the company one. For each attribute the unit of measurement is also indicated, together with the possible values and the specific reference, always by considering "best in class" products; for homogeneity, 6kg load appliances have been considered. The attributes related to the first category (final user point of view) derive from a requirements identification, analysis and choice, performed by a combined team of designers, project managers and marketing specialists, to keep in touch with the "voice of the consumer". They represent the most important parameters that can be classified in order to assess, from the final user point of view, that a satisfying drying process occurred (final humidity rate and DC duration), together with a strong focus on the environmental impact (DC energy consumption) and general quality characteristics (product placing easiness and product safety).

Table 2. Case study attributes definition and characteristics.

	Attribute	Stakeholder	Values	Reference
1	Clothes final humidity rate (Weight%)	Final user	45% (end of mech. Spinning cycle) 15% (before ironing) 5% (dried) 0% (totally dried)	
2	DC duration [min]	Final user	Standard + 40% Standard + 20% Standard(~120min) Standard - 20% Standard - 40%	DC duration of a wash-and-dryer, 6kg load
3	Product placing easiness	Final user	Easy Standard Difficult	Standard washing machine (mechanical spinning), 6kg load
4	DC total energy absorption [kWh]	Final user	0 1 3,6	Standard washing machine (mechanical spinning), 6kg load
5	Product safety (N° of components)	Final user	High safety Standard safety Low safety	Standard washing machine (mechanical spinning), 6kg load
6	Product complexity (N° of components)	Company	0 12 17 22	Standard washing machine (mechanical spinning), 6kg load
7	Mark-up (Total cost %)	Company	M1 M2 M3	M1 represents the mark-up for middle range products, M2 the mark-up for upper range products, M3 represents the highest possible value

As highlighted in the previous section, taking into account the final user "language", discrete variation ranges have been chosen for these attributes. As an example, clothes final humidity rate is a quantitative parameter, whose exact value can be precisely indicated by a weight measurement in a continuous range. Anyway, only four values have been considered, because they have found to represent possible real clothes final conditions, accordingly to user experience: final humidity rate is given by a tactile sensation rather than a weight measurement in everyday life. The attributes related to the second category (company point of view) rely on parameters that usually act as significant metrics to assess the product/project feasibility for the company. The most important factors are the "product complexity" ones, which supply an overall view about the product impact on the assessed production cycle, together with the "mark up", that gives a brief cost indication on the convenience of manufacturing a specific product. About product complexity, the number of components of the drying module has been identified as good metric: the more the component to be manufactured and/or purchased, the more complicated the product assembly, and the higher the risk of modifications to be implemented on the production line. Reference product is assumed to be a standard washing machine, whose drying module has no components, due to the fact that the drying operation is performed via mechanical spinning.

About mark-up, it is interesting to note that numerical values, even if available, were not allowed to be considered, because of company confidentiality so that only qualitative ones will be considered. Volumes have not taken into account due to the fact that such an innovation improvement would certainly lead to a "first to market" product in term of outstanding performance, so that a niche positioning would be the first market positioning to be pursued; volumes revision typically occurs once the new concept strongly shows a good market acceptance, being this last consideration usual in a traditionalist market such as the domestic appliances one.

4.4 Utility function definition

The next step is now to build up the utility functions related to each attribute, accordingly to the approach of utility theory. Each function will represent a relation between the possible attribute values and the quantitative preference level that can be assigned to each of them. Utility function are usually defined in the range 0..1, first of all by identifying the ideal attribute value, whose utility is assumed to be 1, and the unacceptable attribute value, whose utility is assumed to be 0. Intermediate levels have to be identified by asking the decision maker a series of question, formalized in the "lotteries" approach.

Table 3. Case study attributes utility functions.

	ATTRIBUTES	
		U
1	Final humidity rate	
	45%	0,150
	15%	0,500
	5%	1,000
	0%	0,100
2	Drying cycle duration	
	Standard+40%	0,000
	Standard+20%	0,000
	Standard (120 minutes)	0,500
	Standard-20%	0,750
	Standard-40%	1,000
3	Product placing	
	Easy	1,000
	Standard	0,900
	Difficult	0,050
4	Drying cycle energy cons.	
	0	1,000
	1	0,750
	3,6	0,150
5	Safety	
	High	1,000
	Standard	0,500
	Low	0,250
5	Product complexity	
	0	1,000
	12	0,750
	17	0,500
	22	0,250
6	Mark-up	
	M1	0,250
	M2	0,750
	M3	1,000

For the present case study, lotteries have been carried out among chosen set of consumers, to which hypothetical events choices were presented; subsequent answers analysis and elaboration led to the utility function determination. This step results are listed in Table 3. It is noteworthy to highlight that, accordingly to consumers indication, it has been possible to build up representative utility functions; preference levels, as spontaneous consequence, do not always exhibit constant increasing or decreasing tendency, such as in the case of the final humidity rate utility function. By considering this attribute, one can see that the preference levels gradually increase with final humidity lowering, down to 5% weight residual water content; in case a complete drying can be achieved, utility function suddenly drops to its lowest value (0,1), being this behaviour strictly in line with common sense: extremely dried clothes are always affected by wrinkles so that, even if water is completely extracted, they are definitely uncomfortable to wear and show.

4.5 Probability function definition

In order to compare technological alternatives, probability function for each attribute and each technological solution have been defined; such an approach made the authors able to compare, with the same quantitative metric, both well assessed technology alternatives and technological concepts whose feasibility and industrial application is still not present on the market.
In the first case, being the alternative a well known and assessed technology, already implemented on existing products, several information were available on the targeted performances, so that probability function was set always as "0" value, except for the targeted value, whose probability was set as "1". For example, the final humidity rate to be pursued by traditional mechanical spinning cannot be less than 45%: indeed, the probability value for this technology to obtain a 45% final humidity clothes was set as "1", whilst other final humidity values probability were set as "0".
In the second case, probability discrete distributions were chosen among already available data and engineering judgments; for some technology alternatives, such as microwave drying, preliminary bench test were executed, in order to more directly check technological feasibility. About ultrasonic drying, scientific literature has been explored in order to get hypothetical performance figures.

It is interesting to underline how u-sDSP method application can lead to a strongly efficient management of prototyping activities, by postponing the more detailed assessment of technical performance, to be done with appropriate prototypes, to a subsequent phase, when the selection and evaluation process has been performed. A traditional experimental approach would require specific tests on each technological alternative, with a consequent effort to be spent on the prototypes needed for testing. Such an approach can be difficult to implement, notably when companies suffer for the lacking of resources (time, people and money) to be allocated on projects, representing this fact a very frequent situation. Via the application of the u-sDSP method, it is possible to optimize the effort on preliminary prototypes, and the use of probability functions helps the researcher in hypothesizing non deterministic scenarios. The expected response of the potential technological alternative can be therefore characterized by means of a quantitative metric, even if there is a certain degree of uncertainty. It is anyway clear that an accurate definition of the probability function is fundamental, in order to get reliable results from calculation runs. Probability functions are reported as attachment in the last section together with the whole calculating process.

4.6 Method implementation and results

The u-sDSP method has finally been implemented accordingly to the expected utility function definition, as in paragraph 4.2, the formulas being easily calculated by a standard spreadsheet. The k_1, k_2..k_m scaling constants values were determined by hypothesizing *m-1* trade-off comparisons, and then setting the normalizing condition; a *m* variables linear system was obtained, and solved by the matrix inversion method. Final technology alternative results are summarized in Table 4. The graphical adopted format also implements coloured histograms, for a faster view: the longer the bar, the higher the value. Total expected utility values express their own importance mainly from a comparative point of view: not the bare absolute numbers, but the relative differences are important. The subsequent ranking gives the technological alternatives prioritization which will lead to a reasonable choice of the best concept, accordingly to u-sDSP model construction. It is clear that numerical results correctness strongly depends upon all the quantitative parameters which have been previously introduced, as utility function, probability function and scaling constants values.

Table 4. Technological alternatives prioritization results.

	Final User point of view - subtotal	Company point of view - subtotal	TOTAL
ENERGY BY MECHANICAL ACTION			
Mechanical spinning	0.407	0.360	0.767
Mechanical compression drying	0.324	0.325	0.649
ENERGY BY OTHER SOURCES			
WD drying cycle	0.261	0.387	0.648
WD exhaust drying cycle	0.132	0.439	0.570
Microwave drying	0.332	0.354	0.686
Ultrasonic drying	0.316	0.207	0.523

Technological solutions have been grouped into two subsets: the ones which implement the use of mechanical energy and the others which provide the required energy for water elimination via other means, such as by an hot air flow (the solution currently implemented on already existing wash-and-dryers) or by microwave and ultrasonic fields. About the first group, the already implemented mechanical spinning alternative evidently emerges as the best choice, accordingly to u-sDSP method: mechanical compression drying, to be performed by an auxiliary device, results in not being considered as an outstanding alternative. About the second group, microwave drying appears to be first in the prioritization; it is interesting noting that currently produced wash-and-dryers exhibit the highest final values only by considering the company point of view: it happens because they are well known and engineered products and, at the same time, their mark-up is relevant. Microwave drying technological concept is classified, together with the ultrasonic drying alternative, as one of the best choices accordingly to the final user point of view; this fact is mainly due to the supposed enhanced performance than can be achieved via the implementation of these technologies.

CONCLUDING REMARKS

Decision making procedures deeply influence the final success of the product innovation process; an increased understanding of the importance of decisions made in the conceptual design stage is markedly of interest. In this paper a formal methodology has been characterized in order to overcame these drawbacks and improve early stages of product innovation, being the research contribution twofold: 1) improve the idea generation phase stimulating designers creativity 2) formalize and systemize the decision making phase. An industrial case study has demonstrated the validity of the proposed approach. This work then shows how the implementation of the u-sDSP method during the early phases of the product innovation process can lead to several positive implications. First of all, it enables to trace the design rationale which has guided the choice; this information can then been stored in a data base or in a dedicated PLM module. Moreover, utility functions can also be updated during the product development, so that it is possible to represent how they have evolved from the beginning phase up to the end of the product development process. Additionally, the case study demonstrates that a wide involvement of all company departments is required to obtain effective results, so that the evaluating procedure has to be performed concurrently; this will improve communication and mutual interactions among different company areas. Obviously, in order to guarantee a wide diffusion of this methodology in the industrial context, a more systematization is required. In future work, authors approach will be applied to a wide variety of early-stage projects, and data will be collected to validate its efficacy or lack thereof; further work is also needed to quantitatively evaluate how the use of this approach leads to a better choice. A possible evaluating methodology could be the comparison among the data estimated during the decision making phase with the ones gathered along the entire product development process, from design until the manufacturing phase. Additionally, customer satisfaction will be evaluated collecting feedbacks from the market with the help of marketing departments in order to assess if customer needs have been totally or partially satisfied.

ATTACHMENTS

Table 6. Case study u-sDSP spreadsheet.

	ASSESSED TECHNOLOGICAL SOLUTIONS											
ATTRIBUTES	Mechanical Spinning				WD drying cycle				WD exhaust drying cycle			
	P	U	P*U	P*U*k	P	U	P*U	P*U*k	P	U	P*U	P*U*k
1 Final humidity rate												
45%	1	0,150	0,150	0,011	0,25	0,150	0,038	0,003	0,25	0,150	0,038	0,003
15%	0	0,500	0,000	0,000	0,25	0,500	0,125	0,009	0,25	0,500	0,125	0,009
5%	0	1,000	0,000	0,000	0,25	1,000	0,250	0,018	0,25	1,000	0,250	0,018
0%	0	0,100	0,000	0,000	0,25	0,100	0,025	0,002	0,25	0,100	0,025	0,002
2 Drying cycle duration												
Standard+40%	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000
Standard+20%	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000
Standard (120 minutes)	0	0,500	0,000	0,000	1	0,500	0,500	0,003	1	0,500	0,500	0,003
Standard-20%	0	0,750	0,000	0,000	0	0,750	0,000	0,000	0	0,750	0,000	0,000
Standard-40%	1	1,000	1,000	0,006	0	1,000	0,000	0,000	0	1,000	0,000	0,000
3 Product placing												
Easy	0	1,000	0,000	0,000	0	1,000	0,000	0,000	0	1,000	0,000	0,000
Standard	1	0,900	0,900	0,137	1	0,900	0,900	0,137	0	0,900	0,000	0,000
Difficult	0	0,050	0,000	0,000	0	0,050	0,000	0,000	1	0,050	0,050	0,008
4 Drying cycle energy cons.												
0	1	1,000	1,000	0,101	0	1,000	0,000	0,000	0	1,000	0,000	0,000
1	0	0,750	0,000	0,000	0	0,750	0,000	0,000	0	0,750	0,000	0,000
3,6	0	0,150	0,000	0,000	1	0,150	0,150	0,015	1	0,150	0,150	0,015
5 Safety												
High	1	1,000	1,000	0,152	0	1,000	0,000	0,000	0	1,000	0,000	0,000
Standard	0	0,500	0,000	0,000	0,95	0,500	0,475	0,072	0,95	0,500	0,475	0,072
Low	0	0,250	0,000	0,000	0,05	0,250	0,013	0,002	0,05	0,250	0,013	0,002
Final User point of view - subtotal				**0,407**				**0,261**				**0,132**
5 Product complexity												
0	1	1,000	1,000	0,309	0	1,000	0,000	0,000	0	1,000	0,000	0,000
12	0	0,750	0,000	0,000	1	0,750	0,750	0,231	1	0,750	0,750	0,231
17	0	0,500	0,000	0,000	0	0,500	0,000	0,000	0	0,500	0,000	0,000
22	0	0,250	0,000	0,000	0	0,250	0,000	0,000	0	0,250	0,000	0,000
6 Mark-up												
M1	1	0,250	0,250	0,052	0	0,250	0,000	0,000	0	0,250	0,000	0,000
M2	0	0,750	0,000	0,000	1	0,750	0,750	0,155	0	0,750	0,000	0,000
M3	0	1,000	0,000	0,000	0	1,000	0,000	0,000	1	1,000	1,000	0,207
Company point of view - subtotal				**0,360**				**0,387**				**0,439**
TOTAL				**0,767**				**0,648**				**0,570**

	INNOVATIVE TECHNOLOGICAL SOLUTIONS											
ATTRIBUTES	Microwave drying				Ultrasonic drying				Mech. compression drying			
	P	U	P*U	P*U*k	P	U	P*U	P*U*k	P	U	P*U	P*U*k
1 Final humidity rate												
45%	0,33	0,150	0,050	0,004	0,25	0,150	0,038	0,003	0,2	0,150	0,030	0,002
15%	0,33	0,500	0,165	0,012	0,25	0,500	0,125	0,009	0,3	0,500	0,150	0,011
5%	0,33	1,000	0,330	0,024	0,25	1,000	0,250	0,018	0,4	1,000	0,400	0,029
0%	0	0,100	0,000	0,000	0,25	0,100	0,025	0,002	0,1	0,100	0,010	0,001
2 Drying cycle duration												
Standard+40%	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000
Standard+20%	0	0,000	0,000	0,000	0	0,000	0,000	0,000	0	0,000	0,000	0,000
Standard (120 minutes)	0	0,500	0,000	0,000	0,3	0,500	0,150	0,001	0,3	0,500	0,150	0,001
Standard-20%	0,2	0,750	0,150	0,001	0,5	0,750	0,375	0,002	0,4	0,750	0,300	0,002
Standard-40%	0,8	1,000	0,800	0,005	0,2	1,000	0,200	0,001	0,3	1,000	0,300	0,002
3 Product placing												
Easy	0	1,000	0,000	0,000	0	1,000	0,000	0,000	0	1,000	0,000	0,000
Standard	1	0,900	0,900	0,137	0,7	0,900	0,630	0,096	1	0,900	0,900	0,137
Difficult	0	0,050	0,000	0,000	0,3	0,050	0,015	0,002	0	0,050	0,000	0,000
4 Drying cycle energy cons.												
0	0,3	1,000	0,300	0,030	0,1	1,000	0,100	0,010	0,5	1,000	0,500	0,050
1	0,6	0,750	0,450	0,045	0,6	0,750	0,450	0,045	0,4	0,750	0,300	0,030
3,6	0,1	0,150	0,015	0,002	0,3	0,150	0,045	0,005	0,1	0,150	0,015	0,002
5 Safety												
High	0	1,000	0,000	0,000	0,6	1,000	0,600	0,091	0,1	1,000	0,100	0,015
Standard	0,9	0,500	0,450	0,068	0,4	0,500	0,200	0,030	0,2	0,500	0,100	0,015
Low	0,1	0,250	0,025	0,004	0	0,250	0,000	0,000	0,7	0,250	0,175	0,027
Final User point of view - subtotal				**0,332**				**0,316**				**0,324**
5 Product complexity												
0	0	1,000	0,000	0,000	0	1,000	0,000	0,000	0	1,000	0,000	0,000
12	0,1	0,750	0,075	0,023	0,2	0,750	0,150	0,046	0,2	0,750	0,150	0,046
17	0,8	0,500	0,400	0,123	0,4	0,500	0,200	0,062	0,4	0,500	0,200	0,062
22	0,1	0,250	0,025	0,008	0,4	0,250	0,100	0,031	0,4	0,250	0,100	0,031
6 Mark-up												
M1	0	0,250	0,000	0,000	0	0,250	0,000	0,000	0,1	0,250	0,025	0,005
M2	0	0,750	0,000	0,000	0	0,750	0,000	0,000	0,1	0,750	0,075	0,016
M3	1	1,000	1,000	0,207	1	1,000	1,000	0,207	0,8	1,000	0,800	0,166
Company point of view - subtotal				**0,354**				**0,207**				**0,325**
TOTAL				**0,686**				**0,523**				**0,649**

Table 5. Case study scaling constants k1, k2..k7.

Scaling constant	Value
k_1	*0,0732*
k_2	*0,0058*
k_3	*0,1522*
k_4	*0,1008*
k_5	*0,1522*
k_6	*0,3086*
k_7	*0,2072*

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