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SIMULATING GLOBAL UTILITY OF DESIGN SOLUTIONS TO ELDERLY FALLS BY BUILDING RELEVANT USAGE SEGMENTATION

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1. Introduction

In the context of design for market, solution providers seek to understand how and to what extent their innovative concept could match adequately the needs of the target population. They look for quantifying the value buckets where there is an important utility to create. Hence, if the problem is diffuse, complex, and of multiple usage situations, quantification becomes difficult. The lack of knowledge about diffuse problem, adds up to the design decision making process complexity. The body of literature in design shows that no clear method has been developed for evaluating a design solution against multiple and complex usage situations.

In the study behind this paper we looked into the case of the accidental fall of elderly people, as diffuse problem. It causes nearly five thousand deaths in France per year [CepiDc 2013], almost twice the number of car accidents. Elderly fall being absolutely unfortunate, needs emergency intervention and the hospitalization that non-negligibly costly. Fall significantly decreases the person's autonomy and, as a result, the person would need home nursing and semi-intensive care. The economic overhead of fall consequences for the public state has notably increased during the last decades, and with an aging population, it speeds up continually. However, products and services solutions on the national market for such a diffuse and complex problem are insufficient and rather focused on particular niches. Moreover, the business and economic model of solutions targeting elderly is intricate because the boundary between care and welfare is narrow, and the insurance companies influence the product or service buyer with their offers and policies. Nonetheless, the fall situation and how a given product or service could prevent or limit causes should be considered as the main basis for solution evaluation. The objective behind this study is to understand how a given product satisfies the requirement of a group of users and how it is possible to measure the efficiency of a product or a service for users and solution providers. In this regards, the present paper begins with a literature review on the existing methods for evaluating a design solution for a given market, then bring the explanation to the proposed methodology. We use the elderly fall as the demonstration of methodology and consequently show the result obtained on quantification and evaluation of two fall solution in build usage scenario space.

2. Literature review on design evaluation by building usage segmentation

A usage scenario represents a segment of the whole usage space, which originates in usage contexts and users' characteristics. For the case of product-services design, Yannou et al. [2009] and He et al. [2012] define a usage scenario as a combination of variables describing users' attributes (related to user/customer characteristics) and usage contexts. Additionally, Philips [1996] as well as Hoffmann et al. [2006, 2008] have defined a usage scenario as a combinatorial process between users' characteristics and usage situations. The optimization of the user utility is reached by making compromises between product-service attributes and user/customer's attributes in usage situations. Building a database (or space) contributes to the understanding of these attributes.

Several methodologies, mostly common between marketing and design engineering approaches, advocate the building of usage scenarios space in order to, *in fine*, evaluate and compare design solutions. In the following, we focus on both design engineering and marketing approaches since available products and services on a market must be evaluated by undertaking the preferences of the users and the usage performances of the solution. In the other words, given the users' expectations, which design solution, would best "cover" the market segments?

When one designs a solution for a market, the functional analysis is one of the traditional ways to assess the expected performances of the solution by featuring the customers' preferences. This assessment aims at optimizing design solutions by their relative distance from the Pareto frontier based on the aggregated preference models [Messac et al. 1996], [Allen 2001]. However, these models are contestable to the extent that the marketing surveys and brainstorming workshops suffer from idealistic representation of users' preferences. In Design Optimization approach there are lacks of understanding in terms of users' realistic expectations and judgements while the product's performances are modelled independently from usage situations, which are multiple and complex in the case of a widespread issue. Therefore, yet the question is how to predict the market segments by using a more realistic approach?

Marketing methodologies commonly refer to analyse the market by conducting surveys on the multi-attitude usage segments. One of the major schools of thoughts is Conjoint Analysis [Green and Srinivasan 1978], which allows product and service providers to become acquainted with consumers' psychology, decision-making process and economic behaviour. Subsequently, on the basis of marketing surveys, consumers' preferences in the form of human appraisals are investigated in order to build the market and choice models [Kumar et al. 2009]. However, capturing the heterogenous customers' preferences according to the Expected Utility Value Theory (EUVT) is realised by conducting a marketing survey, which is a difficult task partuicularly when designers face such a widespread issue. Marketing surveys are costly and demand a lot of tedious field-research works to define the representative statistical samples and then to questionne them. An other drawback of this method is the fact that the radically innovative design solutions can not be modelled because the users do not have any knowledge about them [Yannou et al. 2013].

To better understand the usage segmetations and in order to answer the question of how customers transform their real intrinsic preferences into performance, Yannou et al. have proposed in [Yannou et al. 2013] a new methodology, which provides a more holistic vision of the optimization of a design solution depending on varied usage contexts and situations. This method, called Design by Usage Coverage Simulation [Yannou et al. 2013] does not only simulate the usage segments by building a database over the usage scenarios but also assesse the covered areas by the existing design solutions, mostly innovative. This method alignes with the researches done by Telenko [2012], with the purpose of modelling the usage contexts and evaluating the variability of lifetime energy usages where a PGM approach is employed to demonstrate the influence of the usage context as a set of dependent factors.

Building of performance models in [Wang et al. 2012], [Yannou et al. 2013] is conditionned upon the usage representative variables to provide a more clear vision of the usage segments and the performances of the design solutions. These simulations aim at providing predictions on engineering performances of a product-service. Subsequently, the feasible usage scenarios partially covered / or not covered by a given product or product family can result in a series of absolute usage coverage indicators (providing the usage scenarios space) and relative usage coverage indicators referring to competing products for the same need category to cover. The usage coverage model has been applied to optimizing a jigsaw product family [Wang et al. 2012].

Here, we model the usage scenarios, following a usage coverage simulations approach, for the case of fall of the elderly. Nevertheless, in the case of elderly fall different classes and different usage situations must be modelled comparing to the case of jigsaw usage. First of all, we face hazardous usage situations i.e. the design solutions are used when there is an important risk of falling among the elderly. Second of all, beyond the socio-demographic causes, the risk factors are etiological with negative consequences on the elderly's health conditions and society.

3. Method

As we aim to model the performances upon the usage contexts and situations, the usage coverage simulations presented and experimented in [Wang et al. 2012], [Yannou et al. 2013] seems the most relevant to the extent that we focus on a diffuse issue where averaging the customer's preferences or conducting tedious marketing surveys appear to be not adapted. Since, in most cases, it is not possible to investigate the whole population or even its samples, referring to experts' heuristic rules in the form of declaratives [Wang et al. 2012] and the existing literature review turns to be a relevant way of modelling user profiles as well as the usage contexts.

Figure 1 represents our research framework for establishing the link between preferences and usage contexts on the one hand, and the evaluation of solutions' performances on the other hand. It starts by building a heuristic usage scenarios space by collecting data over representative usage scenarios. Inspired by Belk's works [1974, 1975], we collect the intrinsic variables e.g. related to user socio-demographic profiles and extrinsic variables for instance over the usage situations and contexts. Subsequently, performances of design solutions are simulated based on expert heuristic rules over the product and/or services efficiency attributes. Mapping the existing design solutions with the usage scenarios space (without solution) generates a modified or a shadow usage scenarios space (with solution). Finally, the usage coverage indicators are assessed on the basis of comparison between the performances of the solutions. These indicators help us to calculate the efficiency of the design solutions as well as their potential global utility creation for the usage scenarios space (ΔU_{global}).

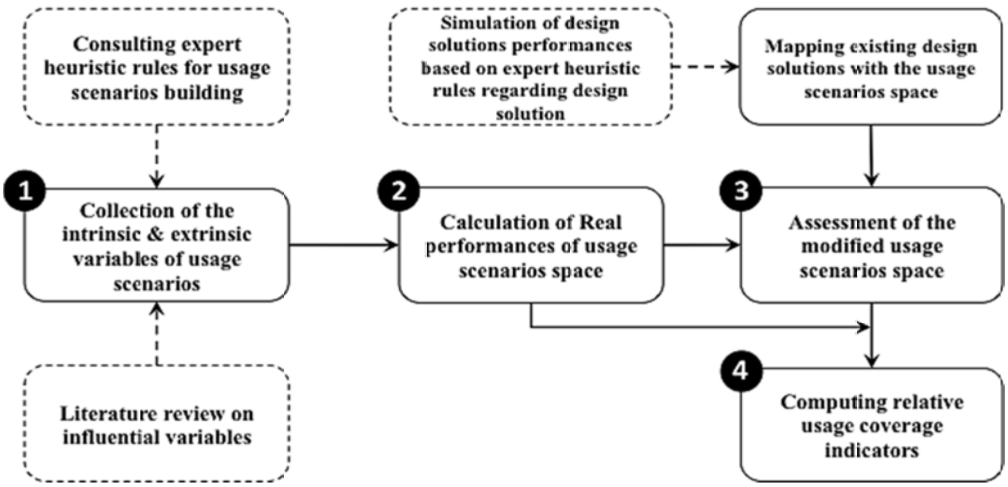

Figure 1. Usage coverage design methodology based on heuristic usage segmentation

More specifically, a Design Oracle [Awedikian and Yannou 2012] simulates a performance (or, counter-performance) vector (Y) defined for each usage scenario as well as for the overall usage scenarios space. This vector is also defined in the "without solution" case where any product or service is used: vector of the real performances (Y_{real}) and for the case "with solution" ($Y_{sol.}$). Our design oracle simulates and quantifies on a utility scale, the created utility of the existing design solutions (see formula 1) by characterizing the covered usage segments.

$$Y_{sol.} - Y_{real} = Created\_Utility \tag{1}$$

The matter of value creation potential of design solutions is of interest to solution providers since it helps to evaluate the non-covered usage segments where there are real potentials for success of new product and/or service. We call these usage segments potential "value buckets" meant to be discovered.

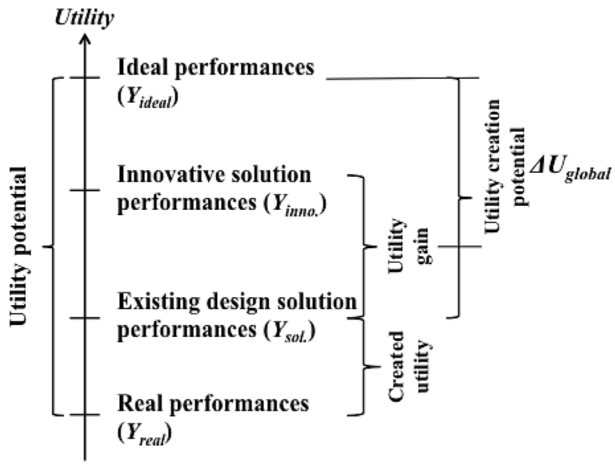

Figure 2. Representation of performances on a utility scale

The reminder of this paper focuses on presenting a summary of our results of usage simulations for two alternative product families through building heuristic usage segmentations spaces.

4. Simulation results

First of all, a brief clarification on the case of elderly fall is necessary. Then, we detail the building of usage scenarios space based on experts' heuristic declaratives and then we simulate two alternative design solutions according to usage segments. Finally, we discuss an innovative design solution, which improve the usage segments already covered by two alternative solutions.

4.1 Nomenclature

The following nomenclature list illustrates the main parameters and notations used in this rest of this paper:

D	Total number of deaths due to a fall per year	$Y_{sol.}$	Design solution performance vector
F_i	Usage variable	Y_{ideal}	Ideal performances vector
$f_{i,j}$	Usage modality	*DFLE*	Disability-Free Life Expectancy
$s_{i,j}$	Relative Size for variable i and modality j	*HLY*	Healthy Life Years
$n_{i,j}$	Relative probability of registered fall for variable i and modality j	*NYMC*	Number of Years remaining to live with a Modified Comfort
Y_{real}	Real performances vector	*FC*	Financial Costs

4.2 Fall among the elderly

Falls among the elderly are multiple and they occurs under various contextual situations [Pin Le Corre et al. 2005]. Risk factors are associated to the fall's situational variables [Rubenstein 2006], and they generate various bio-psycho-social consequences [Stel et al. 2004]. The fall among the elderly is a synonym for the loss in terms of life expectancy and autonomy and also the important financial costs for the National health system.

The target population of our study is the French elderly people (aged 65 years and older) living in the Metropolitan France in 2010 (about 10.54 million according to [Robert-Bobee 2006]). Gerontology literature emphasizes that approximately 30% of the elderly, falls at least once in a year [Campbell et al. 1981], [Tinetti 1987] (i.e. almost 3.51 million). Among these individuals, we estimate the number of registered injuries because of a fall, after [Barry et al. 2011], to be about 527,000. For this number of registered falls as injuries, according to the French Epidemiology Centre on Medical causes of Death (CepiDc), 4,954 persons died (D) because of an accidental fall [CepiDc 2013]. The financial costs of direct emergency interventions and hospitalizations (FC), based on available information [Allard et al. 1995], [Carroll et al. 2005], are evaluated around 2 billion euros in 2010.

Several products and services have been developed to deal with fall problem, with the objective of minimizing its negative effects, such as products with quick alert function (watch, bracelet or roundel) for emergency alert or fall prevention solutions. Two alternative product families of design solutions are depicted in Table 1.

Table 1. Design solutions for the fall of the elderly

Product family	Example	Description	Image
Fall prevention	Light pathway	A set of motion sensors detecting the movement at the moment of getting up from the bed and enlightening the path between bed and rest room. The solution is efficient during the night for the elderly with sleep disorders. The solution in not efficient in fully enlightened places.	
Fall detection and alert	Tele-assistance product and service	A pendant or watch connected to a tele-assistance platform service via a modem-box. The device can alert the fall manually or automatically based on a fuzzy logic calculation. The solution is not efficient when the fall is not sudden and sharp.	

Despite the important number of design solutions on the French market [DRIRE 2009], the percentage of deathly falls among the French elderly between 2006 and 2010 [CepiDc 2013] follows an upward trend. Therefore, we wonder that it is perfectly comprehensible to ask the question of adequacy and global efficiency of the French existing design solutions.

4.3 Usage scenarios space

A usage scenario is a combination of usage variables related to the context and to the person who fall.
Medical studies have identified more than 400 risk factors of the fall [Skelton and Dinan al. 1999], which are not categorized pertinently. Therefore, in order to delimit the perimeter of usage variables, we assume here that a fall has the same consequences in terms of counter-performances whatever the contextual conditions in which it occurs. For instance, the consequences are the same whatever the age and the previous health conditions. This is, of course, not true but we do not want to model different contextual failure modes but provide merely one reference failure mode for an averaged fall, characterized by a set of usage variables. In addition, we consider a linear effect of the number of falls on the consequences, for instance on the lowering of life expectancy. This is also not true since a recurrent fall can dramatically deteriorate health conditions and lead to death gradually.
Based on these assumptions, we adjust a specific filtering methodology for apprehending the most influent usage variables. Our approach for categorizing the usage variables is to define general dimensions for variables inspired by Belk's situational marketing works on usage contexts [Belk 1974, 1975]. These variables; must indicate the profile of the target population (socio-demographic variables for instance), can cause a fall and impact the fall frequency in terms of the probability of fall (e.g. health problems). Besides, they might characterize conditions under which a design solution discriminates among them (indoor / outdoor activity or lighting conditions for instance).
Therefore, we qualify intrinsic variables as related to human attributes (i.e. biological and socioeconomic variables) and/or extrinsic variables as related to usage context (i.e. behavioral and environmental variables). The review of more than 60 medical publications as well as the task of consulting heuristic experts' rules has resulted in the proposition of 31 intrinsic (including 12 health condition variables) and extrinsic variables (F_i). Here, we provide an exhaustive list of 12 health conditions usage variables in alphabetical order: *Alzheimer, Cerebral aging, Depression and Anxiety, Diabetic, Equilibrium problem and neurologic changes, Foot problem, Heart problem, Obesity problems, Osteoporosis in lower limb, Parkinson and sequel of brain injury, Under-nutrition and Vitamin D deficiency and Visual impairment* (a detailed description of the variable is available in [Bekhradi et al. 2013]. Each variable has two or several modalities, ($f_{i,j}$) (72 modalities are identified in total) and a clear definition is provided for each modality.

The size of a modality ($s_{i,j}$) represents its statistical proportion or the number of observations in the population. Modalities constituting a given variable are exclusive and discrete i.e. the whole population is totally distributed on modalities of a given usage variable. It is the same for the probability of registered falls per year ($n_{i,j}$), which is also totally distributed among the modalities of a given variable. The size and probability of fall is either retrieved from the medical literature or expert heuristic rules, for instance they heuristically declare that: “in general, elderly women fall 70% more than elderly men”.
An “instance of usage scenario” represents the combination of either intrinsic, extrinsic or both intrinsic and extrinsic usage modalities of a usage scenarios space. The size of a usage scenario is also defined as the product of the relative size of the modalities composing this scenario. For instance, the size of Sc_i is given by the following equation.

$$s_{sc_i} = \prod s_{i,j} \quad (2)$$

The probability of registered falls per year for a given usage scenario is also calculated by the product of the probabilities of probability of registered falls per year for the modalities composing a given usage scenario (see equation (3)).

$$n_{sc_i} = \prod n_{i,j} \quad (3)$$

A usage scenarios sub-space is built by choosing a set of usage variables and modalities. A set of 4 variables is illustrated in Table 2.

Table 2. Usage scenarios sub-space variables and modalities

Usage variables	Modalities
Gender (F_1)	*Male ($f_{1,1}$)*
	Female ($f_{1,2}$)
Age (F_2)	*65- 74 ($f_{2,1}$)*
	75-84 ($f_{2,2}$)
	85 and more ($f_{2,3}$)
Lighting conditions (F_{19})	*Fully enlighten ($f_{19,1}$)*
	Low enlighten ($f_{19,2}$)
	Darkness ($f_{19,3}$)
Place of living (F_{20})	*Personal residence ($f_{20,1}$)*
	Institution ($f_{20,2}$)

An instance of this usage scenarios sub-space could be for example, a “78 years old man”. Furthermore, the usage context can be characterized by “living in a health institution”. Then, we will have: “78 years old man, living in a health institution”. It is also possible to generate many other usage scenarios, either by modifying the modalities of the same variable (e.g. by replacing of “elderly man” by “elderly woman”) or by adding or removing modalities (e.g. adding the “fully enlighten”).
The identification of the consequences of falling is also based on an investigation process of systematic literature review [Stel et al. 2004]. This literature review has resulted in the selection of a total of 27 consequences defined under two dimensions: direct (bio-psycho-social consequences related to patient) and indirect (related to the use of healthcare services such as emergency services e.g. ambulance and hospital emergency department) (see [Bekhradi et al. 2013] for the exhaustive list of consequences). A matrix of consequences provides the basic probabilities of occurrence of consequences. In this matrix, we have assumed the probabilities for an “averaged reference fall” no matter which usage variables have caused the fall. In other words, a “fall” is equal to a “fall” regardless of its causing variables.

The exactitude of the usage scenarios database is validated through the help of experts' declaratives. Professor Francois Piette, the president of the scientific committee of the French Society of Technology for Autonomy and Gerontechnology, has greatly contributed to this validation step.

4.4 Performance vector assessment

Using a design oracle enables us to evaluate the alternative design solutions in various usage scenarios in terms of their efficiency. A design solution is efficient or value creator by influencing negatively the costs of consequences of a fall. Therefore, a performance or counter-performance vector (*Y*) for the usage scenarios space is defined since the design solutions act negatively on the costs of consequences. The performance vector (to be minimized) assigns the usage scenarios with 4 extensive counter-performances, which are the number of deaths (*D*), the loss in terms Disability-Free Life Expectancy (*DFLE*), Number of Years with a Modified level of Comfort (*NYMC*) and Financial Costs (FC).

The *DFLE* designates the number of remaining "Healthy Life Years" (*HLY*) that a person, with a given age and gender, expects to live, in a healthy condition and under the mortality conditions of a given period without being dependent on nursing or mobility aid for performing daily activities. Numerous statistical methods allow calculating the *DFLE* and the Total Life Expectancy (*TLE*), which represents the total number of years that a person expects to live. Among these methods, the Sullivan method [Jagger 1999] is the most appropriate to our study because of two reasons: first, the input data are available (i.e. mortality data and prevalence data over the population) and second, it is possible to calculate *DFLE* according to the age ranges that we have identified here (see "Age" in Table 2). The Δ*DFLE* calculated in Figure 3, is equivalent to the loss in terms of years of *DFLE* per usage scenario because of a fall.

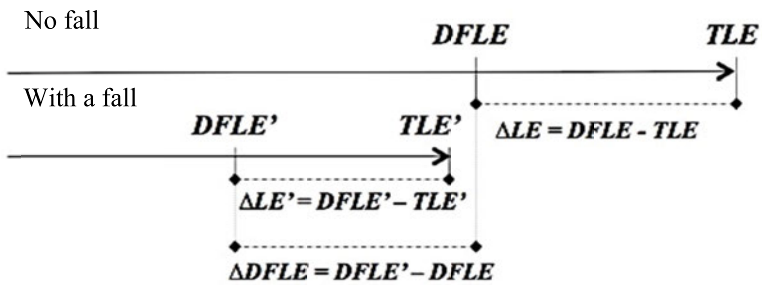

Figure 3. *DFLE* and *TLE* calculation in the case of "With a fall" and "No fall"

The loss in terms of the Number of Years remaining to live with a Modified level of Comfort (*NYMC*) is also proposed to evaluate the number of years that an elderly lives in disability conditions after an accidental fall. The loss in terms of *NYMC* per usage scenario is given by the following formula:

$$NYMC\_loss = \left|\Delta LE^{'}\right| - \left|\Delta LE\right| \tag{4}$$

Having detailed the counter-performances, the vector of real performance is given by the following matrix:

$$Y_{real} = \begin{bmatrix} 4{,}954\_D \\ 18{,}603\_DFLE\_years\_losses \\ 15{,}978\_NYMC\_losses \\ 2.10^{9}\_FC \end{bmatrix} \tag{5}$$

Where, the losses in terms of *DFLE* years and *NYMC* for the whole usage scenarios space are calculated by adding up the losses per usage scenario. The ideal performance vector is the case when all of the elements of the above matrix are equal to zero. Hence, the design solutions try to minimize the real performances.

4.5 Modified usage scenarios space by design solutions

Usage coverage simulations allow querying the usage scenarios space or sub-space. These quantitative results are useful for the design solutions providers through mapping the design solutions with the usage scenarios. This mapping is enabled by *ad hoc* queries, that are applied to usage simulations according to designers or marketers claims, including AND, OR and NOT combinations of the simple predicate-like usage scenarios as evoked in Table 3.

Table 3. Experts' heuristic rules on alternative design solution

Light pathway	Tele-assistance product and service
if ((Gender is Male)) *Then* (Efficiency is 30%)	*if* ((Gender is Male)) *Then* (Efficiency is 40%)
if ((Gender is Female)) *Then* (Efficiency is 30%)	*if* ((Gender is Male)) *Then* (Efficiency is 40%)
if ((Age is 75-84)) *Then* (Efficiency is 10%)	*if* ((Heart problem is Yes)) *Then* (Efficiency is 30%)
if ((Place of living is Institutionalized)) *Then* (Efficiency is 40%)	*if* ((Heart problem is Yes)) *Then* (Efficiency is 30%)
if ((Gender is Female) AND (Lightening condition is Darkness)) *Then* (Efficiency is 40%)	*if* ((Gender is Female) AND (Place of living is Institutionalized)) *Then* (Efficiency is 45%)

The reported efficiency percentage represents the reduction of falls for the declared usage scenario. Given the extensive properties of the performance vector elements, the overall efficiency for the usage scenarios space is given by the sum of the total design solution's performances per usage scenario.
We have compared two alternative design solutions and we have obtained the following results, as shown in Figure 4, over the total influence of the solutions on real performances.

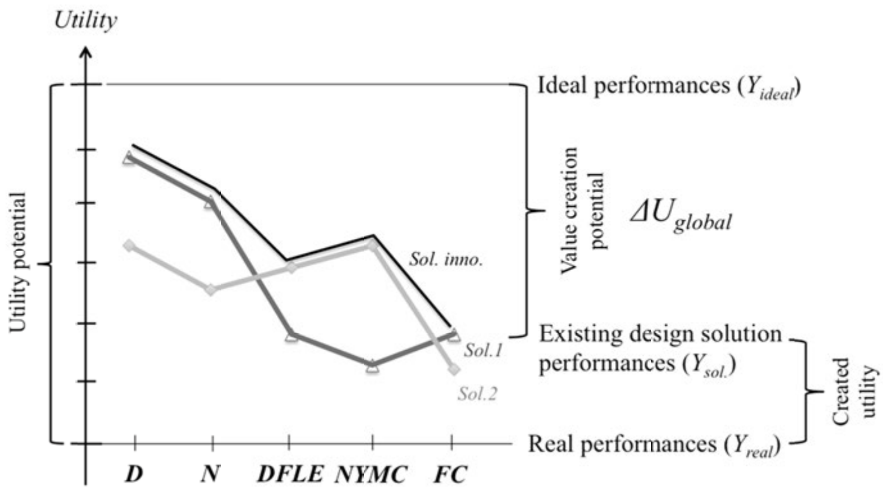

Figure 4. Comparison of two alternative design solutions

Here, an innovative concept of product or service can be also formulated by linking up the global performances of both alternative design solutions. The distance between the existing design solution performances and innovative design solution represents the value to be created. Simulating an innovative design solution based on the comparison between two alternative design solutions allows designers to quantify the efficiency in terms of different elements of performance matrix to be improved. However, it should be noted that an innovative solution such as a light pathway is not necessarily more efficient than all of the existing design solutions. This depends on the configuration of usage scenarios and also the efficiency of compared design solutions. Besides, other design parameters such as the price of product or service (not included in this model at the moment) influence the choice of customers.

In summary, the quantification of value creation potential provides useful insights to solution providers in terms of value buckets to be explored. An innovative design solution can be imagined as a solution, which covers the maximum coverage of $sol._1$ and $sol._2$.

5. Conclusion

Evaluating a design solution by considering usage scenarios in a diffuse and complex issue is not an easy task insofar as, the first task consists in building a usage scenarios space and the second task is the assessment of the influence of a design solution on usage scenarios space, which leads to a modified (or shadow) usage scenarios space. A design oracle enables to formulate queries over the both usage scenarios space with and without a design solution. The evaluation of usage segments as well as the non-covered usage segment provides useful information for design solution providers and, by doing so it contributes to their process of decision making. Consequently, they can target a more adequate market and better conduct their design solutions to the market by knowing the number of elderly characterized by a set of attributes. The latter falls within the directive lines of the blue ocean strategy [Kim and Mauborgne 2005] by detecting the value buckets with important utility potential. Forthcoming developments are studied in order to apply our model to other product families and therefore encourage not only solution providers (in terms of precise specifications on usage scenarios), but also the National health system authorities to provide and finance data collections over the diffuse case of fall among the elderly.

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