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How should requirements be defined to have real innovation?

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Abstract

People are generally influenced in their purchasing choices by diverse stakeholders and these influences are often not related only to "use situations". Learning processes, product diffusion dynamics and externalities in fact frequently complicate innovation processes. "Design for Innovation" means considering that design cannot focus only on buyer's preferences and on "product use" because this could limit diffusion of products, besides bounding in general innovation opportunities. The "Design for Innovation" approach drives to study "beyond use situations" and the influences among the actors involved in the innovation processes. This paper describes through two different case studies how a more original list of needs that would have not emerged with more traditional approaches for the requirement management, can be generated with this approach.

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Keywords: requirement capture, multystakeholder analysis, customized and personalized product development.

1. Introduction

Innovating means designing something good not only from a technical point of view, but also because it makes business sense [1]. Really, designing increasingly means a more complicated process than simply making sure that a single buyer and a seller will find mutual benefit from a transaction, so that the former will buy a product from the latter.

Often in fact the innovation process is complicated by learning processes [2], diffusion dynamics [3] and externalities [4] as well as depends on social and organizational pressure [5] that determines mutual influences between market actors. Hence, for instance, the actors who have not adopted products yet are usually influenced by the actors who have successfully done so, as well as buyers and users are not necessarily the same person or the actor(s) that will ultimately benefit from the product might be different from either the buyer or the user.

In the case of buses for public transport, for instance, the buyer is the purchasing department of the transport authority, the users are its employees, such as bus drivers and maintenance crews, and the direct beneficiaries are the passengers who ride the bus.

The reasonable consequence of this thought is that diverse stakeholders influence people in their purchasing choices and therefore design by focusing only on buyer’s preferences could limit the diffusion of products, besides bounding generally the innovation opportunities. The concept of “Design for Innovation” is widely described in [6] and definitively that paper questions on traditional design approaches that mainly focus on the “user” though it is useful to consider all the phases that constitute the innovation process and the specific decisions made by the actors in all the phases.

These situations are called “beyond use” situations; failing to consider them may lead to designing products that might be used, but will never really be if they are not adopted first, or to products that will be bought, but then will not be properly used, and so on.

While many scholars debate about the importance to study the multi-faceted aspects of needs ([7], [8], [9]), as well as some efforts exist to define design specifications with multi-stakeholders lists of requirements ([10]), there are still no models supporting inter-actor representations of needs and their

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mutual relationships. Cantamessa et al. ([11]) suggest studying the individual perspective of each actor besides the influences that are reciprocally cast among the needs of actors.

Two consequences for designers result. The former is that designers find themselves consider a wider set of needs as the basis for the requirement definition, which are the result of an "interpreted or expected impact" of these influences ([12]). The latter is that designers can investigate the way with which influences among actors impact on the importance of these needs. From now therefore needs, which would have not been considered if the influence had been missing, are studied, as well the importance of a need for an actor can increase or decrease because his experiential context.

This approach is by now tested in a variety of cases, from industrial machinery to medical devices. This paper describes two of them that distinguish for structural elements (the former is in a startup, the latter in a more structured company) nevertheless have several similarities for the purpose of the method application.

The following Section 2 reviews the theoretical model of the "Design for Innovation" problem and details the method for tackling it. Section 3 describes the applications while the paper then concludes with some reflections on the results.

In our model, needs are the issues on which actors focus their attention. Needs are native if they are of direct concern to the actor itself, and reported if they are perceived because of other actors' influence. Consequently, reported needs are needs that would not have been considered had the influence been missing. Moreover, the external influence can modify the importance or the perception that an actor assigns to a native need.

Some needs are well known, either because they are obvious, or because they are established by external entities (e.g. regulatory institutions), or because they reflect common sense or general interest. However, the intensity with which each actor perceives the need and bases his or her decisions on it, is likely to depend on mutual influences.

Referring for instance to medical devices, it is obvious to assume that – all the rest being equal - hospital management will prefer a product that minimizes discomfort to the patient, even without receiving direct influence from patients themselves. However, the importance that management will attach to this need may be altered if patients do cast such an influence (e.g., through a patients-rights association) or, if by purchasing a less invasive device, managers consider that this choice might attract a higher number of patients.

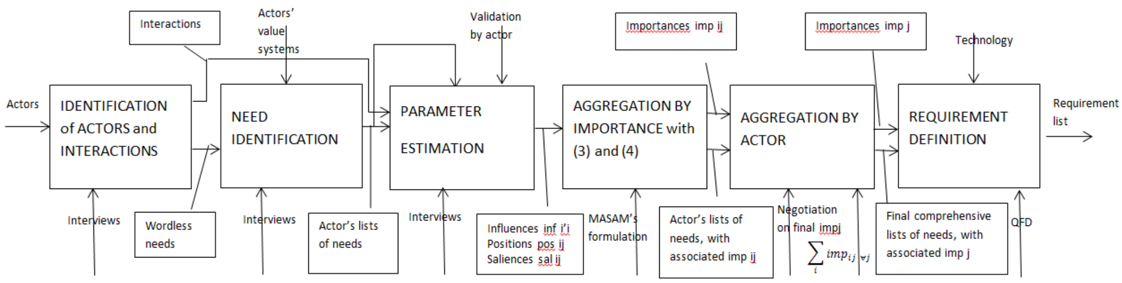


Fig. 1. Diagram that describes the methodology

2. The methodological approach

Methods coming from Social Network Analysis and Actor Network Analysis usually study influences between actors. The use of such methods in product design and development however is not very common, with [13] being one notable exception. The approach here proposed for the analysis of inter-actor influences is inspired by social influence network models ([14]) and by the Multi-issue Actor Strategy Analysis Model ([15]). Both these approaches are successfully applied to a variety of situations and usually used for strategic analysis and negotiation problem. The method proposed in this paper integrate these approaches with the QFD procedure as the basis for the definition of multi-actor requirements in product development.

2.1. The considerations underlying the theoretical model

Both the approaches for the analysis of inter-actor influences, whose this model refer to assume that an actor's present opinion on an issue results from the combination of that actor's original opinion and the influences that other actors have exerted on him or her.

For the designer who is developing the medical device, the ability to understand and proactively work on these influences is integral to defining the product and its go-to-market strategy. The path to investigate these influences between actors on needs is made by several steps as represented in Fig. 1. The analyst's work starts from the study of the purchasing process, attempting to identify all the actors involved and the influences between them. Each of the actors has his/her own needs that must be identified, besides the importance they attribute to them. This importance is determined by the stance an actor has with respect to a certain problem as well as by the relevance he/she attributes at the need for his/her life. These elements define the essential variables on which the model is built and are mainly collected by interviews. Identified them, beside the weight influences can have in changing the opinion of an actor, the analyst knows the importance of each need for each actor. The further step, as some needs may to be common among actors, is to derive a single list of needs whose importance is aggregated by actors. This list will be the input to the QFD matrix for the definition of the requirements.

2.2. The four main formal constructs of the model

Four constructs constitute the theoretical model presented in this paper:

- The opinion of Actor i on Need j. It is related to the importance $imp_{i,j}$ attributed by actors to their native needs and depend on position and salience the Actor i has on Need j. This importance is defined as:

$$imp_{ij} = sal_{ij} * pos_{ij} \quad (1)$$

  Where, position ($-1 \le pos_{i,j} \le 1$) indicates the direction towards which an actor perceives his or her own goals with respect to the need, while salience ($sal_{i,j} \in [0,1]$) represents the degree with which the realization of the favourable outcome is relevant to the actor's overall objectives. So, if an actor i who has posi,j=-0.5 and sali,j=0.2 on need j, will have a weak interest for a preferred outcome that is slightly oriented to negative values. This will result in impi,j = -0.1. Two actors may perceive the Need i with the same salience, but have opposite positions on them, which will lead to the necessity of finding trade-off solutions.

- The attitude and capability of one actor to influence other actors. It can be expressed defining the degree of influence $inf_{i,i,j}$ that an actor actor i' can exert on actor i with respect to issue j. It is set along a linear continuum between 0 and 1 ($0 \le inf_{i',i,j} \le 1 \quad \forall i, \forall i', \forall j$) and is such that the total influence cast by other actors is either nil, or equal to 1. Considering all the influences between all the actors involved, it is possible to construct the NxN matrix of potential direct influences among the N actors on the issue j, defined as:

$$\overline{\overline{\boldsymbol{inf_j}}} = [inf i', i,]_j \quad \forall j \quad (2)$$

- The susceptibility ($0 < a_{ii,j} \le 1 \; \forall i, \forall j$) of an actor to interpersonal influence on the issue j. At each occasion in which influence among actors occurs, potential influences become effective only if actors are susceptible to receive them. The effective influence an actor is subject to is given by a blend of: a) the potential external influences receivable by the other actors ($inf_{i',i,j}$) weighted by his or her susceptibilities ($a_{ii,j}$) and b) the "internal conviction" (given by the complement to 1 of susceptibilities). Considering all the actors, the matrix form is required and the new matrix that describes the *effective* influences is:

$$\overline{\overline{\boldsymbol{INF_j}}} = \overline{\overline{\boldsymbol{A}}} * \overline{\overline{\boldsymbol{inf_j}}} + \boldsymbol{I} - \overline{\overline{\boldsymbol{A}}} \quad \forall j \quad (3)$$

- The recursive progression of the influence process over time. This implies that the opinion an actor has at time t will depend on his/her opinion in the past, since the beginning of the process. The initial opinion of actors is named $\overline{\boldsymbol{IMP^{(1)}}_j}$ and will remain the same when weighted by "internal conviction"; the rest is the part that is influenced according the own susceptibility. Hence, this latter will be given by the opinion at the previous moment multiplied by the influences weighted by the susceptibility. Considering a group of N actors, the influence process is therefore defined through:

$$\overline{\boldsymbol{IMP^{(t)}}_j} = \left(\boldsymbol{I} - \overline{\overline{\boldsymbol{A}}}\right) * \overline{\boldsymbol{IMP^{(1)}}_j} + \overline{\overline{\boldsymbol{A}}} * \overline{\overline{\boldsymbol{INF_j}}} * \overline{\boldsymbol{IMP^{(t-1)}}_j} \quad (4)$$

where, $\overline{\boldsymbol{IMP^{(1)}}_j}$ is the Nx1 vector of initial importance attributed by the i actors, $\overline{\boldsymbol{IMP^{(t)}}_j}$ is the Nx1 vector of importance at step t, $\overline{\overline{\boldsymbol{INF_j}}}$ is the NxN matrix of the effective influences on need j, and $\overline{\overline{\boldsymbol{A}}}$ is the matrix of susceptibilities. Assuming that the influence process reaches the equilibrium to infinity, if one looks at the single $imp_{i,j}{}^{(\infty)}$ equation (4) leads to (5):

$$imp_{i,j}{}^{(\infty)} = \left(1 - a_{ii,j}\right) * imp_{i,j}{}^{(1)} + \sum_{i' \neq i} a_{ii,j} * INF_{i',i,j} * imp_{i,j}{}^{(\infty)} \quad \forall i, j; t = 2,3, \ldots \quad (5)$$

It represents the importance attributed by each actor i to a need j at the end of the process.

Having determined the importance of each need and for each actor, the further step is the aggregation of the different actor's views in order to create a single list of requirements that may be used – for instance –as an input to a QFD matrix. This point is crucial in the analysis, since it would be misleading to simply compute an average of the importance levels. This would "cover up" the potential contrasting views that actors may have on a given need, and would lead to developing a product that does not really satisfy any specific actor, would easily be vetoed by one or more of them and therefore would not be adopted at all.

Conflicts, in fact, will emerge if two actors i'and i on the need j have:

$$\mathrm{imp}^{\infty}_{i',j} * \mathrm{imp}^{\infty}_{i,j} < 0 \quad (6)$$

and the degree of potential conflict arising on the need could be represented by a measure of the discord in each pair of actors, given by (7):

$$\sigma_{i'i} = (\mathrm{imp}^{\infty}_{i',j} - \mathrm{imp}^{\infty}_{i,j}) / \left[(\mathrm{imp}^{\infty}_{i',j} / \left|\mathrm{imp}^{\infty}_{i',j}\right|) * (\mathrm{imp}^{\infty}_{i,j} / \left|\mathrm{imp}^{\infty}_{i,j}\right|)\right] \quad (7)$$

being $\mathrm{imp}^{\infty}_{i',j} = max_k \overline{\boldsymbol{IMP}}^{\infty}_{\boldsymbol{k,j}}$ and $\mathrm{imp}^{\infty}_{i,j} = min_k \overline{\boldsymbol{IMP}}^{\infty}_{k,j}$.

In order to frame the problem, designers can therefore distinguish among situations in which actors substantively agree form situations in which actors highly disagree. In this latter case, especially if the need is important for the actors, the level of conflict will be high and designers will have to tackle it. Ideally, one would like to have all stakeholders together so that it would be possible to negotiate requirements finding a compromise between the stakeholders' positions (e.g. make a product that "costs a bit less but is a bit harder to use" being careful in driving towards a result such as no sales and no usage at all). However, it may often be the case that stakeholders do not act contextually the purchasing process, and/or negotiation on the issue is not viable. In these cases, stakeholders could assume veto positions, so that no technical compromise would lead to a positive outcome. The only path that can be taken in these cases is to act at organizational level, by formalizing the conflict and trying to solve contradictions. In practice, this may include modifying the mutual influence process and/or involving third parties that may do so.

Once each importance is aggregated and eventual conflicts managed, each need j has its importance and, consequently, the list of needs is ready to feed the QFD matrix. This last passage from need to requirement by the QFD matrix is quite standard and does not need to be further discussed.

3. Two case studies from different industrial sectors

The multi-stakeholder method has been tested in a variety of cases, from industrial machinery to medical devices. In this paper, we present two of them: the former, MEDALLCARE, an Italian start-up company that is proposing a new line of products KITOSMART® and the latter, a company that produces gear-shaving machines for the automotive industry and for precision mechanics. These two cases are completely different for structure and market conditions but surprisingly have some similarities.

Working with a start-up company in the medtech industry came out to be an ideal testbed for new methods. Being a startup, the firm really felt the need to make sure its products could be well received in the market, organizational procedures and processes were not yet structured and there was no inertia in adopting a new method for requirements capture. Moreover, the acceptance of medical devices does not only depend on the merits of technology, but also on the firm's capability to understand and interact with a complex purchasing process, in which the firm must interact with multiple actors.

The second case instead concerns a well-organized company that has customers with very diverse needs to meet worldwide, since shaving represents nowadays an effective way to solve diverse manufacturing issues in production. Since the company had already used procedure for the requirement capture, they have been interested in exploring the effective potentialities of the approach through a pilot application case constructed in collaboration with their marketing and technical offices. Diverse reasons have led to the interest of the company to acquire the proposed new methodological tool. First, the organizational procedures and processes were formalized, but not standardized yet and therefore new approaches could be assimilated and processes easily reviewed. Then, the influence of many actors in the purchasing processes is intrinsically quite evident and the company immediately realized the potentialities of the approach proposed. Finally, also machine tools as the medical products need of good business practices besides specialist technological knowledge in order to be market-attractive.

In both cases, the analysis has made use of a heavy data collection, provided through interviews. They have been composed by two different sections: initially, a semi-structured interview aimed at gathering potential needs and identifying the influences between actors; then, a structured interview in order to elicit values for position, salience and susceptibility to listed needs.

3.1. KITOSMART®: a biomedical product

KITOSMART® is a line of innovative products that could replace the existing bandages, gauzes and dressings to cure several pathologies (domestic or hospital ones).

Designers of MEDALLCARE before our work had already begun to identify the customer needs to feed the QFD matrix. Table 1 shows the needs they had identified and each importance they had attributed from their own experience.

The firm purchasing process appeared to be well structured and strictly defined since the beginning. When a supply contract for dressings expires, the purchasing department appoints a committee of doctors and nurses, who compile a written document defining the specifications that the dressing must satisfy. The specifications are then inserted in a tender document to which companies can apply. Firms are required to send specimens of their products, which are then tested by another committee that shortlists the preferred ones. At this point, the purchasing department decides which one to buy based on economic convenience and negotiates a 3-5 year contract. Within this process purchasing department, ward management, doctors, nurses and patients were the five actors identified and interviews were carried out to understand the needs and the pattern of influences between actors.

Table 1. Original list of needs

id	Description	Impj
1	Cheapness	1,00
2	Reduce length of hospital stay	0,80
5	Prevent losses and bleeding	0,71
6	Reduce infection risk	0,81
8	Feels comfortable (not annoying)	0,87
9	Pain relief	0,88
10	Correct positioning and adherence	0,53
11	Breathable	0,60
12	Good resistence if soaked	0,20
13	Easy to apply and remove	0,60
14	Fast application	0,50
15	Ensure long effectiveness	0,60
18	Encurage good cicatrization	0,70

The interviews were carried out on 20 individuals in 5 different hospitals, with sufficient experience and leadership roles. Doctors were plastic surgeons and operating in departments specialized in severe burns; nurses were mostly head nurses and/or experts in applying bandages on bedsores and burns. Almost all doctors and nurses had been included at least once in a committee for the evaluation of bandages and dressings. It was chosen not to include relatives of patients, since their needs were almost the same as the patients' and they were recognized to be detached from the decisional process.

For each need collected, there were position, salience, influence degree and susceptibility identified. Just to have an idea, Table 2 shows these parameters collected for the nurse. Similar tables we generated for each identified actor.

The second step of the study consisted in analyzing inter-actor influences on the needs. As an example in Table 3, you can find the results of the formal analysis on the influences made for the need "feels comfortable". Similarly have been made for all the other needs.

Made the analysis for all the needs, the firm have attempted to aggregate importance by actor. Conflicts have been solved by looking at importance derived from the analysis of the influences and facing the contradiction behind. For the other needs free by conflicts, merging the different lists of needs in a single one has been performed without any particular problem. In the end, a final list of needs shared among the stakeholders have been drafted and Fig. 1 shows the derived House of Quality for the QFD procedure. There is possible to look at the final list of the requirements accepted by the firm and then definitively validated by the panel of experts interviewed. Some of the need identified have been confirmed but other ones have emerged only because of the direct investigation of multi-actor analysis. For instance, shortening the air exposure of the injured body areas is an obvious need and represents a key element of the product's value proposition, because it leads to low risks of infection, ease of positioning and use, faster medical treatment. Other requirements, such as the anatomic pre-conformation of the components, the compression modulation that hinders potential bleedings and blood-serum storage over the wound, the possibility of in situ pharmacological preparations and medicaments or the impact on the resource usage have emerged because the analysis of the multiple actor perspectives.

Table 2. Collected parameters for the nurse.

Nurse	Pos ij	Sal ij	mpij (1)	aii, j	Who? i'	Pos i'	Sal i'	infi'i
prevent losses and bleeding	1	0,8	0,8	0,5	Doctor	1	0,8	0,6
			0		Patient	1	0,6	0,4
reduce infection risk	1	0,7	0,7	0,5	Doctor	1	0,9	1
simplify further analysis	1	0,8	0,8	0,8	Doctor	1	0,6	1
easy to apply and remove	1	1	1	0,8	Patient	1	0,65	1
fast application	1	1	1	0,8	Patient	1	0,6	1
ensure long effectiveness	1	0,65	0,65	0				
feels comfortable (not annoying)	1	0,7	0,7	0,6	Patient	1	1	1
allow to use wrong dimensions	1	0,4	0,4	0				
pain relief	1	0,7	0,7	0,5	Patient	1	1	1
adapt to different body parts	1	1	1	0				
good resistence if soaked	1	0,6	0,6	0				
breathable	1	0,9	0,9	0,3	Doctor	1	1	1
correct positioning and adherence	1	0,9	0,9	0,4	Doctor	-0,6	0,25	1
effectiveness of treatment	1	0,6	0,6	0,4	Doctor	1	1	1
reduce healing time	1	0	0	0,3	Doctor	1	0,6	1
encurage good cicatrization	1	0	0	0,5	Patient	1	1	1

Table 3. Influence analysis for need 8.

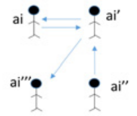
Cases	Morfology	Occurence	actor	imp (1)	Imp (∞)
need 8: feels comfortable (not annoying)		D and M have a reciprocal influence, but D influences also N and is influenced by P	M	0,75	0,76
			D	0,70	0,71
			N	0,06	0,08
			P	0,80	0,80

Fig.1 moreover shows how requirements importance after the influence analysis are different from the original ones derived by the evaluation, although based on experience, of the designers whose judgments could be subject to inaccuracy. Importance of the requirement in the QFD represent instead, at this point, really the expression of the importance that each actor attaches to the different aspects of the product.

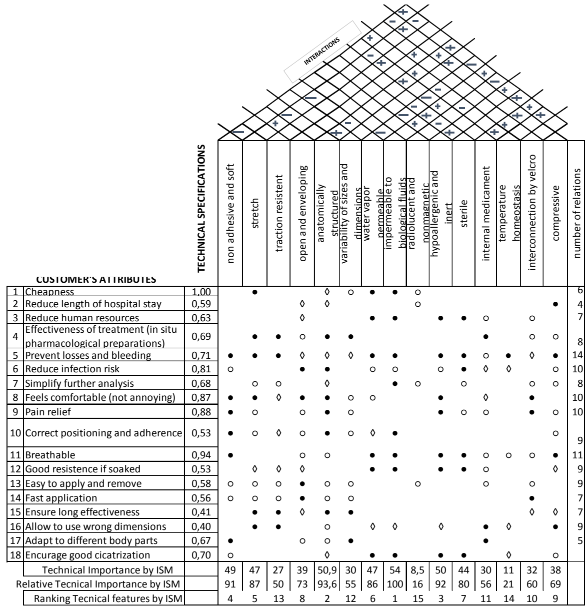


Fig. 1. House of quality for Kitosmart® products.

3.2. The case of gear shaving machines

In the second case, the multi-stakeholder model has been applied in a company that produces gear-shaving machines for the automotive industry and for precision mechanics. The pilot application case has been constructed in collaboration with their marketing and technical offices that has identified six actors to consider as "the customer". Three of them are involved in the innovation process because they interact with machines (i.e. machine workers, maintenance technicians and factory supervisors) the other ones, plant managers, product designers and quality managers, are involved because make decisions that indirectly impact on the production process.

Even in this case have been conducted 15 interviews, considering the relevance of the different roles in the process and using those data collected, the analysis has been performed as for the med-tech case, following the path described in Fig.1. In this paper, the intermediate tables are not reported for reason of space, but Table 4 aims to show the difference between the list of needs before the analysis and after, highlighting the effects of the method.

Again, among the needs identified, some are more obvious because they would have anyway emerged also with more traditional approaches and others are more original as not strictly related to the structures of the machine tool. The approach in fact leads technicians to consider together design issues such as machine flexibility (considering general-purpose machineries or specifically developed ones for a single step of the process plan) as well as the architecture of the parts to produce, that can be more or less characterized by integral architectures and strict interdependences among the functional elements. Moreover, needs related to maintenance such as “easy to disassemble” have been introduced with a high value of importance. Hence, designers have moved from considering issues related specifically to the machinery design towards issues related also to the product design or maintenance needs.

Table 4. Original and derived lists of needs for gear shaving machines

original needs			needs after the analysis		
id	description	impij	id	description	impij
1	cheapness	90%	1	cheapness	90%
2	increase productivity	85%	2	increase productivity	80%
3	safe for the operator	100%	3	safe for the operator	100%
			4	immediate maintenance	80%
			5	effective training	68%
			6	reduce in floor space	60%
7	adattability in movements (e.g. insertion, orientation, etc.)	70%	7	adattability in movements (e.g. insertion, orientation, etc.)	76%
			8	optimize logistic flows	70%
9	fast retooling	65%	9	fast retooling	76%
10	operative flexibility	60%	10	operative flexibility	80%
11	reduced energy consumption	50%	11	reduced energy consumption	55%
			12	reduce needed personnel	62%
13	reduced use of consumables	70%	13	reduced use of consumables	70%
14	reduced waste and scrap	80%	14	reduced waste and scrap	88%
16	high automation	80%	16	high automation	80%
17	friendly UI	60%	17	friendly UI	70%
			18	simple and fast training	80%
19	high reliability	85%	19	high reliability	89%
20	easy/quick setup	80%	20	easy/quick setup	85%
21	increased precision in machining	100%	21	increase precision in machining	100%
22	assure quality standards	90%	22	assure quality standards	90%
			23	easy to disassemble	90%
			24	replaceable parts	100%
25	long autonomy	80%	25	long autonomy	70%

4. Conclusions

The paper aims at contributing to the debate about needs identification and requirements specification, by introducing an explicit representation of different stakeholders’ needs and their reciprocal influences in these activities. The rationale behind the method is that – failing to do so – products will be designed quite narrowly around the perspective of a single stakeholder, which is generally the user. Apart from very basic products, characterized by a very simple purchasing process, a product will be able to successfully penetrate the market only if all relevant stakeholders agree on its adoption.

The paper describes a new methodology for the analysis of needs from a multi-stakeholder perspective by examining the impact of inter-actor influence. The methodology has been tested in several cases but the paper concerns two of them: the former in a startup of the medical sector, the latter in a company that produces gear-shaving machines for the automotive sector. These two companies are completely different for organizational structure and market conditions but surprisingly have some similarities. Results obtained have been very interesting and allowed the firms to develop a set of products that have been quickly accepted for a distribution partnership by an established industry player.

The presented approach has two main consequences for product development. First, designers must consider a wide set of needs deriving from multiple stakeholders as the basis for requirements definition. Requirements must take into account these stakeholder needs in such a way that all stakeholders who are involved in the adoption decision agree to the innovation.

The second consequence is that the firm developing the product should investigate the mutual influences among actors and their impact on native and reported needs. Specifically, it should consider actors’ native needs together the reported needs resulting from the explicit and implicit influences that actor is subject to. These influences have an obvious impact on the importance of a specific need and, consequently, on the weight that designers may give it in the QFD.

The quantitative model proposed in addition leads to negotiate compromise solutions, as well as to highlight conflicts between actors’ needs to be leveraged as a hint to guide the generation of solutions.

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