Crowd-Engineering: Managing Innovative Product Design by Widening Collaborations

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Abstract: Global contest has overwhelmed enterprises by the eager demand for products and services with high-tech features, along the entire product life cycle. Several companies reacted by developing the cooperation with high-tech firms. However, in the last decade, another revolutionary asset is emerging together with the worldwide networking evolution, namely the "Crowd-Engineering" (C-E): A huge, flexible and diversified human capital-made of individuals and consultants-available for companies to create their products and services. Together with these advantages, however, this asset calls for companies to face the complexity in the crowd management, selecting among competitive contributions and making all of them work effectively and efficiently. Therefore, there is an emerging need for methods and tools to manage C-E processes. This study presents a theoretical framework for managing and selecting crowd contributions along the whole New Product and service Development (NPD) project. Pros and cons of C-E applications are discussed.

Keywords: Crowdsourcing, Crowd Engineering, Collaborative Design

Introduction

The tremendous competition in New Product and service Development (NPD) has pushed companies towards a growing demand for Research and

Development (R&D) activities far beyond the internal capabilities. Since more than half a century large companies resorted to outsourcing R&D activities for non-strategic components and product services, thus turning to large Original Equipment Manufacturers (OEMs) for items previously guarded as part of the core business. The re-arrangement of the business has allowed large companies to concentrate their efforts on a limited number of R&D activities, related to strategic components (e.g.,: The powertrain, or the body in white for automotive industries). Only a limited number of OEMs (First Tier suppliers) were asked to collaborate on product co-design and contracted to supply complete sub-assemblies to be assembled into the final product (e.g.,: Radiators, valves, shock absorbers, bumpers, tanks, interiors, panels, instruments, SW and HW components and so forth among vehicles components). Consequently, only a limited number of OEMs that could afford their own R&D efforts could exploit this market and grow up. Those OEMs, in their turns, have concentrated the efforts on R&D activities for their "core business" products by phasing-out non-strategic coponents, or sub-assemblies, purchased from smaller suppliers (Tier 2, 3, …). In general, most of Small and Mediumsized Enterprises (SMEs) could not afford the R&D effort required to exploit the edgy technologies involved and, as a result, they have been phased-out from the virtuous spiral of innovation processes embraced by final producers, thus experiencing a gradual reduction in the added value of their activities.

However, about fifteen years ago a revolutionary asset named crowd sourcing-enabled by the digital network evolution-dawned in the business world. Thanks to the network (internet, social media, smartphone apps, etc.) companies could obtain ideas, expertise, quality assessments, or market sentiments from a large group of people (experts, researchers, users, …) anywhere in the world. This revolution allowed companies to draw on the skills from a wide range of people, without incurring the high costs of in-house employees, or external experts. They could turn to a crowd of individuals-i.e., an "undefined (and generally large) network of people" -able to respond more effectively than employees, or any other outsourcing agency, to calls for disruptive ideas, development of cutting-edge technologies, design product features, analyze the market and so forth. This "knowledge asset" could easily chase market trends and exploit advanced technologies, instead of settling on consolidated ones, already exploited by affirmed manufacturers and disseminated across competitors.

Despite these benefits, the crowdsourcing approach may show severe drawbacks over the project management, particularly when NPD involves deeper engineering activities made of several structured tasks. Starting from the call for contributions, up to the integration of usable works into a coherent product, the crowdsourcing management of engineering developing activities faces a higher level of complexity, asking for new tools and methodologies to turn the "knowledge resource" flows into successful businesses.

On Crowdsourcing and Crowd-Engineering

A crowdsourcing project may include several kinds of activities. E.g., before the implementation of new features in a product (mobile phones apps, etc.) companies can turn to the crowd and farm for marketing data, or opinions from focus groups, including a variety of cultural and socioeconomic backgrounds.

Besides, a relevant aspect of crowdsourcing concerns the crowd motivation and cost. People can be involved in crowdsourcing work as paid freelancers.; in other circumstances, people prefer to perform small tasks on a voluntary basis. Even if some authors express some doubts about the reasons that pushes people to contribute to crowdsourcing, some other authors (Tran *et al*., 2012) pinpoint a variety of incentives, such as the economic reward, the reputation, the job opportunity, or the desire to contribute to a valuable project. Most of the time, however, a token for the participation in the call, even in case of rejected contributions, has been considered.

In particular, this is the case of Crowd-Engineering (C-E), where "call-for-solutions" to engineering problems are issued and crowd tasks may be burdensome. Application fields can range from software development-including website creation and/or transcreation-to manufacturing, machines and product design (Mao *et al*., 2015; Ketonen-Oksi *et al*., 2014).

An evident distinction is needed between the "call for-ideas" and the "call-for-engineering". To solve for several engineering problems-with reference to advanced sectors such as space exploration, or health care-challenging ideas are needed first, usually relying on a large number of scientists and designer, internal or external to the organization (Stöhr, 2003). Only when ideas are explored, chosen and settled, effective engineering solutions can be expanded and detailly checked, together with costs, lead times and supplier availabilities. To this purpose, a consistent set of "calls-for-engineering" should be issued to exploit the ideas and develop the new product/service.

Even traditional organizations-where human actors are assumed to cooperate face to face-require a strong effort to manage engineering activities involved in NPD, so that heuristic management approaches have been developed for specific sectors. As an example, aerospace industry has adopted formal methodologies based on System Engineering (described in ISO TR 14062 standards) that split the whole process in six phases, at least: Planning, Conceptual Design, Detailed Design, Testing, Production Launch and Product Review. The practitioner-oriented management standards usually emphasize the importance of the multidisciplinary domain and the need for defining a clear Work Break-down Structure (WBS) of the NPD process well in advance, by re-iterating trial and error steps to fix sub-optimal design specifications at each development phase and minimize divergences among Work Packages.

Also, several IT and math tools have been developed to integrate engineering-management theoretical models (e.g.,: Engineering Design, System Engineering, Concurrent Engineering, Simultaneous Engineering, Project Management, Knowledge Management, etc.) within the legacy IT environments – i.e., Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM), Computer Aided Assembling/disassembling (CAx), Product Data Management (PDM), etc. – thus resulting in a suite of collaborative-software applications that support the NPD management across the whole product life, from the cradle to the grave, i.e., the Product Lifecycle Management (PLM).

In case of C-E, the process management complexity increases furtherly, because of both: The need for attracting many competitors and selecting the actual contributors among them, from one side; as well as the cultural barriers preventing from contributors to cooperate straightforwardly, as they are not necessarily trained to work together within a unique methodological framework and the same legacy IT environment.

According to Burnap *et al*. (2017), in C-E projects the C-E Managing quality may strongly affect the overall result.

Every engineering problem involves a careful selection of both the "Contributors" and the contributions themselves for the NPD, whose parts/components/concepts have been presented in the "call for contributions" by the C-E process Management Center (herewith denoted C-E Managing).

To avoid a confused presentation of the project objective to be achieved with the help of many contributors, the call for engineering process must have a clear formulation, along with some basic characteristics (Villa and Taurino, 2019).

As an example, let's assume that a company takes the decision to restyle and introduce innovative features into an existing product, properly described in terms of functions and components. To identify and assess alternative ideas and manufacturing processes, the C-E Manager is asked to disseminate a "call for contributions", according to the following rules:

i. Establishing the organization to manage the new design approaches (i.e.,: Types of ideas, concepts and/or suggestions the company is seeking for the co-creation of the focused product features)

ii. Enabling the exploitation of new data and concepts for the next generation products, through exchanges based on new standards and open-source tools
iii. Defining and organizing an efficient set of procedures to collect, select, integrate contributions and obtain a good match between the selected contributions and the desired scheme of the innovative product features

Criteria for C-E Contribution Selection

As outlined above, the C-E managing activity is defined as a set of techniques and procedures for searching and collecting a large variety of contributions from the "crowd" and organize them into the product. To this purpose, the C-E manager needs:

- To solicit an adequate set of contributions from the crowd
- To evaluate and select the contributions
- To integrate the selected contribution/s into the more detailed set of features for the new release of the developing product

Therefore, the C-E manager is required to organize and sequentially implement the steps, or development phases, necessary to pursue these three conceptual objectives. In the first step, the C-E manager must disseminate a clear piece of information on the project goals to a suitable set of potential contributors. Such a piece of information must include the declaration of the evaluation metrics for expected contributions made of different indicators (Villa and Taurino, 2019), as listed below.

a) A "measure of novelty", to assess the potential "disrupting" outcomes from the contribution, as well as the possible breakthrough features that could be included in the NPD. As it is one of the most critical assessments, the C-E Manager must clearly point out what does the company expect in terms of "new ideas and concepts" and what is to be considered acceptable, or not
b) A "measure of usefulness", to assess the usefulness of the contribution related to both the Engineering problem to be solved and the project objective to be achieved
c) A "measure of coherence", to assess the capability of the contribution to generate information/data/or product features that are consistent with other product elements and/or manufacturing constraints included in the NPD process
d) a "measure of similarity", which is needed in case of two or more contributions with similar concepts, ideas, organization hints, etc. Obviously, duplicated ideas are not useful at all for the E-C Manager, who should select only some parts, or none of the duplicated contributions
e) A "measure of complementarity", which occurs when two or more contributions present ideas or concepts that can be easily merged. In such cases, the E-C Manager should merge the contributions, or part of them, by redefining a unique one, possibly shared among the proposers
f) A "measure of the reward", to assess the rewards for the participants. The rewards will be different in the case of an innovative, active and even complementary contribution and-provided that not all the contributions are accepted-a fixed token for the rejected ones is also suggestable to encourage the participation of the crowd. Conversely, to avoid many useless contributions and not to pay for them, sometimes, a preliminary selection of the participants could be useful. Nevertheless, the selection should rely on the unbiased assessment of potential contributors. To include/reject a potential contributor a priori within/from the pool of participants, the C-E Manager should also rely on some objective rules: A very simple one is based on the number of times that a participant provided unsuccessful works in previous calls

Upon receipt of the works from each contributor, in the second Phase the C-E Manager shall start the evaluation and select the contributions, adopting criteria from (a) to (e). In theoretical terms, this problem could be approached as a multi-criteria decision analysis one, such as Analytic Hierarchy Process (Saminathan and Hemamala, 2017), Analytic Network Process (Schniederjans and Garvin, 1997), Goal and Mixed-Integer Programming (Meade and Presley, 2002), Data Envelopment Analysis (Selen and Hott, 1986) and the Fuzzy Set theory (Cooper *et al*., 2011).

A Practice-Oriented Crowd Engineering Model

As a matter of fact, the pool of C-E potential contributors can be thought of as a set of suppliers able to provide the required materials and services to a "make-to-order" manufacturer. In this perspective, a parallelism between the pool of C-E participants and the pool of material/service suppliers can be easily seen, where the performance of the enterprise largely depends on supplier performances. In our case, a methodological approach-similar to the Supplier Relationship Management (SRM)-is needed to organize all the firm interactions with third parties, providing engineering services that support the NPD process. By digging into the similarity, a lot of analogies could be found in the management of potential suppliers, including the evaluation of their performances and the capability to meet the manufacturer demand.

To this purpose, the SRM model presented by Saminathan and Hemamala (2017) could be usefully adopted and reformulated as a Crowd Engineering practical scheme. Consequently, the following relations respectively hold (with reference to Table n° 1) between involved actors, as well as between the set of NPD phases and the corresponding set of SRM selection and ordering steps.

Like SRM, also C-E requires an effective collaboration between the C-E Manager and all involved contributors (suppliers) by sharing profits and achieving win-win results. This collaboration can be obtained by adopting the C-E scheme represented in Fig. 1 that is just the representation of the correspondences in Table 1.

This scheme is self-explanatory, even if some considerations and comments could be useful.

Inputs to the scheme are the contributions sent by the crowd, the large number and types of pre-selected actors, able to supply innovative ideas and/or solutions.

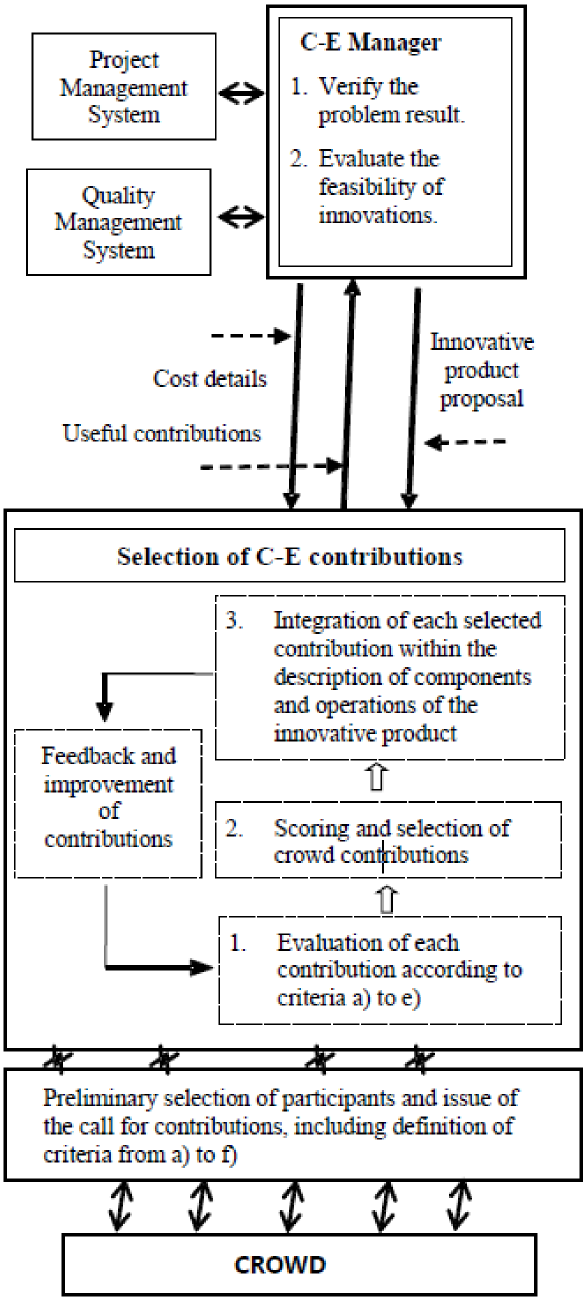

Fig. 1: The SRM-based scheme of C-E

Table 1: Relation between C-E and SRM selection.

C-E selection	*SRM selection*
Actors:	*Actors*:
Contributors	Suppliers
Manager (with clear view of the innovation)	Producer (with clear view of the final product)
Phase1. Identify contributions	Step 1. Specify the purchase strategy
Phase 2. Select the useful contributions	Step 2. Evaluate the supplier performance
Phase 3. Integrate the selected contributions into the innovative product description	Step 3. Make collaborative-integrated the Suppliers with respect to the final product
Phase 4. Evaluate the global set of contributions. IF necessary, iterate	Step 4. Evaluate the feedback from the producer. IF necessary, iterate

The "*heart*" of the C-E Management framework is the Selection of Contributions made of three main steps:

(1) Evaluation of each contribution and selection of each one useful by associating it a "measure of usefulness" that represents the coherence of the contribution with the project goal and a "measure of complementarity" for each pair of contributions (as defined above)
(2) Integration of each selected contribution within the description of the parts (components) and operations (of production) of the innovative product to be created
(3) Evaluation of the overall correspondence among the selected contributions and all parts and all operations of the aforementioned innovative product

The C-E Manager will operate, as shown in the final block of the scheme, with the following scope:

(4) Verifying the problem result, that is an admissible global correspondence among the selected contributions and all parts and all operations of the innovative product
(5) Evaluate the real feasibility of the ideas of innovative product obtainable from the aforementioned integration, having clear in mind that different utilization of the contributions are possible even though they will give rise at about the same final product
(6) Evaluate costs and revenues in each alternative of contributions' sets to produce the innovative product, among the feasible ones
(7) Evaluate the usefulness and the cost of every useful received contribution, to give some profit to Actors who have helpfully responded to the call

To really implement his/her functions and take the necessary decisions on the received contributions, the C-E Manager will use the following inputs: The useful contributions from crowd, already selected; and proposals/ideas for developing the final product, innovative, both coming from the Crowd Engineering Selector.

To make this scheme the core of a platform that could manage many contributions from the crowd, the operations/decisions of the C-E Manager play the most critical role. Then, any C-E Manager needs to have a detailed view of the sequence of phases to be applied, starting from the definition and description of the innovative product desired, up to the Crowd Engineering organization and use, as shown in the following outline of the *C-E workflow*:

Phase 1: Call for Contributions

Scope: Definition of a descriptive framework of the product type to be used as a reference by potential contributors.

Documentation: Clear un-ambiguous presentation of the desired innovations.

Phase 2: Method for Accepting and Selecting Contributions

Scope: Rules and criteria to accept or refuse a contribution received by the crowd.

Documentation: Tables of rules and selection criteria.

Phase 3: Organization of the Crowd Engineering Selector

Scope: Development of the procedures and algorithms for selecting and evaluating contributions.

Documentation: Tables describing procedures and algorithms; authorizations for contribution submission.

Phase 4: Strategies to Manage the Crowd of Contributors

Scope: Criteria and rules to gradually create an "innovators community"

Documentation: Protocols and format for contribution submission; rules to refuse bad communications, etc.

Phase 5: Evaluation of the Crowd Engineering Application Impact

Scope: Analyzing applications to pilot cases.

Documentation: Catalogue of contribution; integration of useful contributions in an innovative product.

Conclusion

NPD in high-tech sectors presents a complex challenge, both for large organizations and for smart companies that want to provide innovative technologies to the large ones.

The C-E approach offers the opportunity to leverage much broader professional ideas and expertise, tapping into swaths of experts, researchers, start-ups, etc. and thus providing a major boost to product innovation. With the ability to integrate NPD activities with a broader base of technical and technological information, C-E represents a disruptive methodology that can reinvigorate the investment capabilities of small and large companies and maximize their ability to create value.

However, the many elements of complexity contained in C-E projects represent a large obstacle that risks drowning the sketched benefits in management inefficiencies. The traditional methods and tools for managing NPD activities are not suited to dealing with C-E problems that involve-in distinct ways and with different intensity-various people and technologies belonging to external organizations. The types of relationships and engagement between actors involved in C-E activities must be based on contractual tools and management methods that are appropriate for this new operating environment.

A key factor in ensuring the effectiveness of operations is the structuring of the entire NPD process into a series of phases for the request and selection of contributions, alternating with phases for the development and consolidation of intermediate results (milestones) of the project. This requires, on the one hand, new organizational models, open and transparent, to safeguard the efforts and the intellectual property of the proposers; on the other hand, there is the need to manage projects characterized by greater ramifications and uncertainties, evaluating the different proposals objectively and selecting the alternatives in a manner consistent with the strategic lines of the project.

Often, the greatest obstacle lies not in defining the strategic direction of the project-the responsibility of the lead firm-but in the difficulty of maintaining it, defining a-priori the specifications to be achieved, the evaluation metrics and the decision-making criteria to be used in selecting proposals.

In this study, the authors have presented a methodological model to deal with this specific selection phases, i.e., those phases in which the leading firm requests participants to formulate different ideas, project proposals, or technological solutions and then selects them in a way that is consistent with the strategic objectives of the project and the stated a-priori decision criteria. In particular, the paper proposes a systematic procedure, derived in analogy with the supply-chain management methods. The key factor of this procedure is the consistency between the specifications to be met, the evaluation criteria and the proposal selection methods, guaranteed by explicit and transparent communication tools and paths. Through theoretical references and logical considerations presented in support of the proposal, the authors have highlighted criticalities and uncertainties that characterize the decision-making phases, outlining the fundamental aspects that should inspire the criteria to be adopted for the evaluation and selection of proposals.

The decomposition of the entire NPD into alternating phases of selection and actual development is not linear: First, because the phases are not defined statically, but dynamically, as each intermediate milestone is reached. Second, it may take several iterations before a valid outcome is achieved, aligned with the strategic goals of the project. One aspect that is not addressed in this study relates to the incorporation of interim outcome review activities into the project. In traditional methods, the review activity is usually placed towards the end, at the achievement of important milestones. On the contrary, for C-E projects a greater number of design reviews is needed, together with a greater capacity for critical review, preferably delegated to third parties, or to bodies of the leading company not directly involved in the project. While this undoubtedly represents a management burden, on the other hand, the greater number of reviews can be exploited strategically, to assess more carefully the consistency between the strategic objectives and the added value generated by the different options possibly developed in parallel up to given milestones, to ensure the success of the project.

The analysis of different decision-making situations observed within the *PMInnnova Program* led to the consideration that some problematic elements are quite common and can be resolved with more effective communication between the leading company and the participants, aimed at clarifying the objectives and constraints of each intermediate stage for which contributions are sought. However, it has also become apparent that other types of uncertainties and divergences are inherent in the individual behavior of participants, namely environmental and cultural factors related to the different geographic areas to which they belong. These divergences cannot be eliminated but, if they are incompatible with the purposes of the project, they can rather be anticipated and managed in the pre-selection phase of participants.

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Author's Contributions

Agostino Villa: Conceived the work, drafted the article, analyzed the bibliography, gave final approval to the submitted version and the revised one.

Franco Lombardi: Discussed and expanded the article, wrote revisions, analyzed the bibliography, gave final approval to the submitted version and thr revised one.

Alberto Faveto: Revised the work, contributed with intellectual content, and gave final approval to the submitted version and the revised one

Ethics

The authors recognize the great importance of scientific and technical research, which affects the quality of life around the world. For this reason, as researchers and professors of the Politecnico di Torino (i.e., the academic community), they adhere to the principles of research integrity and are committed to respecting the highest ethical and professional standards of conduct

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