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Crowd Engineering: Manage Crowd Contributions for Design and Manufacture of Innovative Products

Agostino Villa and Teresa Taurino

Politecnico di Torino, DIGEP – Department of Management and Production Engineering
Corso Duca degli Abruzzi 24,
10129 Torino, Italy
{agostino.villa, teresa.taurino}@polito.it

Abstract. The increasing complexity of designing and manufacturing products as well as the growing speed required for their innovation is pushing large and medium-small companies to an ever-broader search for new ideas and for a wide availability of experts, able to provide timely contributions. Existing approaches mainly address the early phases of the product lifecycle in the frame of “open innovation”. The crowd engineering approach is to organize an efficient and effective utilization of the “crowd”, i.e. a wide set of persons, from students to private experts, and to start-ups and smart SMEs, which could be involved in the creation of innovative products. The first purpose of the paper is to give a presentation of Crowd Engineering in terms of a logical frame where crowd-workers will contribute into an informal collaborative network to fulfill technical and social needs. Then a schematic model based on an analogy between Crowd Engineering and Supply Relationship Management, will be outlined thus offering, on one hand, suggestions for a real implementation, on the other, some hints for a research agenda.

Keywords: Crowd Engineering, Combinatorial optimization model.

1 Introduction

A collaborative network is a network consisting of a variety of entities (e.g. organizations and people) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals, and whose interactions are supported by computer networks [1]. In the last decades, the growing complexity of the design of new products, the increasingly shorter time-to-market required to market new products, and the spread of the so-called "augmented products" [2], i.e. products with constantly increasing services, is pushing companies, both large and medium-small, to an ever-broader search for ideas and innovations, through a wide availability of experts, able to provide timely contributions.

Consequently, companies need to re-engineer the design and production process, since many experts, companies, interested persons, associations, etc., which provide them with the many contributions that are usable, form a real "crowd". The Crowd

Engineering builds social solutions of design and production of innovative products, by “empowering companies to turn the force of their crowds (suppliers, customers, partners and also employees) into business advantage” (<https://www.definitions.net/definition/crowdengineering>).

It is evident that such a re-engineering problem involves a careful selection of both the “Contributors” and the contributions themselves for the new product creation or production. This problem has been tackled with multi-criteria decision analysis approaches (MCDA), such as Analytic Hierarchy Process [3, 4] Analytic Network Process [5], Goal and Mixed-Integer Programming [6], Data Envelopment Analysis [7], and the Fuzzy Set theory [8]. However, little information is given about some feedback from practitioners and from implementations of such approaches, which are still few. In practice, as recently observed in some particularly innovative Mid-Small Enterprises (SME) registered in the PMInnova Program [9], the ongoing trend toward the individualization and even personalization of products results in new additional challenges for industrial enterprises in the frame of “open innovation” [10], i.e. with wide supports from externals.

To this scope, Crowd Engineering must set the following objectives:

- Establish new design approaches, strategies, methods and tools for the co-creation of innovative, individualized products by opening the product creation to the “crowd”;
- Enable crowd-based product creation by next generation product data exchange, based on standards and open source;
- Realize an efficient procedure to collect, select, integrate contributions, such to obtain a good overlapping of the set of collaborative selected contributions and the desired scheme of the innovative product.

These three objectives can be achieved by developing the Crowd Engineering approach in a user-centric way, i.e. with a strong direction of the multi-dimensional design process implemented by an institution, institute or company, having a clear idea of the innovative product to be obtained and a considerable ability to define a “call for innovation creation” to a set of potential contributors.

The organization of the paper will be as follows. Section 2 is dedicated to give a preliminary logical overview of the Crowd Engineering concept and an outline of its structure. Section 3 first describes a schematic model of Crowd Engineering, based on the analysis of its analogy with the Supplier Relationship Management. Section 3 will present a schematic model of Crowd Engineering, by outlining the theoretical methods for supporting the multi-dimensional selection. Finally, Section 4 will present some hints of a research agenda, based on a Crowd Engineering work-flow scheme.

2 Preliminary Logical Overviews of Crowd Engineering

The Crowd Engineering procedure aims to focus, structure and translate into practice new ideas dedicated to collaborative co-creation. It is obtained from a process of collecting contributions from various sources (people, associations, SMEs, etc.), their selection and their integration for the purpose of conceptual and detailed design, the

development of the necessary production operations, the production of new products oriented to the user. Crowd Engineering is based on the advancement of the well-known triple helix towards a quadruple helix for innovation systems (see Fig. 1). The classic triple-helix from 1995 knows only three actors. But emerging innovations do not necessarily match consumer demand, so the helix has to be extended by a by a »user« component, involving end users/consumers in the innovation process. Therefore, additional attention has to be paid to community-based approaches, originated by “collaborative network”, that appears to be powerful social frames for value creation [11].

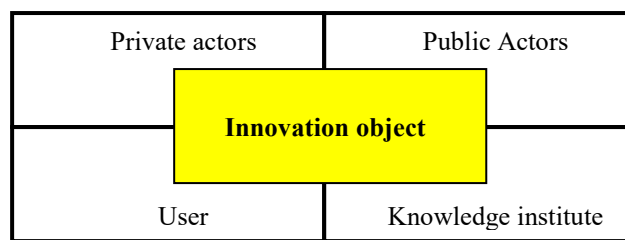


Fig. 1. Quadruple helix for innovation systems

Therefore, the Crowd Engineering project is stated by a “call for innovation creation” with the scope of searching and collecting contributions from many "Contributors" in order to integrate them so as to obtain a product (system or object) with characteristics of total novelty, structure and forms that allow production, all set by the Crowd Engineering Project Management (named in the following simply as "Manager"). The goal of the Crowd Engineering problem, as defined above, is advertised by the Manager in a broad way, in order to be able to receive contributions from many Contributors. Each Contributor proposes his own contribution, without knowing the contributions of the others or their participation in the research launched by the above mentioned “call”. Therefore, the Contributors are potentially competitive. The Manager must have a "measure of usefulness” in order to verify if a contribution provided by an actor can be useful for the solution of the Crowd Engineering problem, in the sense that it can contribute to the achievement of the Crowd Engineering project objective. To this end, the Manager must evaluate each individual contribution obtained by each Contributors, and perform a multi-dimensional selection such as to collect only contributions with the following characters:

- A contribution must be “active” i.e. such to give rise to information/data that are coherent with some part of the innovative product or some operations that can contribute to the innovative product creation; this first attribute of a contribution can be evaluated according to the adopted measure of usefulness, above mentioned;
- Two or more contributions must be “collaborative”, i.e. such to be usable in collaboration with other contributions, thus generating a more effective and active action in the design and production process; this further attribute of a pair of contributions can be evaluated by adopting a

"measure of similarity" between the two contributions, with respect to the result of the "problem", that is to some part of the innovative product or to some innovative operation necessary to produce it.

From a simplified point of view, the Manager, once evaluated as useful the contribution will be, could consider a second different contribution to understand if the two contributions are collaborative: their joint use facilitates the achievement of the Crowd Engineering goal in a more efficient and effective way with respect to the individual ones. Once recognized a pair of collaborative contributions, the Manager will evaluate to support the couple with a third contribution, by estimating the joint use of the three in terms of an increasing - if any - of the measure of collaborative utility. Progressively, the Manager can reach a complete set of contributions, all complementary, such as to express an admissible solution for the Crowd Engineering project. The logical Crowd Engineering overview briefly described above, has the sole purpose of illustrating in a simplified way the concepts and methodology of the problem. Indeed, it makes evidence of the combinatorial nature of the contributions' selection problem.

3 Schematic Model of Crowd Engineering

A schematic model of the Crowd Engineering approach can be obtained by the analogy between the Crowd Engineering and the Supply Relationship Management (Section 3.1). This first analogy suggests taking also into account the evident links between Crowd Engineering and Crowdsourcing, as well as with "Collaborative Networks" (Section 3.2).

3.1 Analogy between Crowd Engineering and Supply Relationship Management

An enterprise performance, especially of small and medium-sized, largely depends on the relations with its suppliers, often belonging to different value chains, as in several industrial districts analyzed in [12, 13]. Then, a good enterprise-suppliers relationship is a necessity for any industrial organization, to be able to respond to dynamic and unpredictable chains of the final products demand [14, 15]. Therefore, a Supplier Relationship Management (SRM) is a methodology that organizes all the interactions of the enterprise with third-party organizations, which supply goods and services in order to allow the best possible product creation [16]. The evaluation of a supplier is then the process of measuring the performance of the suppliers itself, as well as of its capability to meet the buyer (i.e. the enterprise) demands. Tacking now into account the above logical description of the Crowd Engineering approach, it is possible to identify a strong analogy between the two processes, as shown in Table 1. Therefore, it is to use the SRM approach to give a schematic illustration of the Crowd Engineering procedure.

Table 1. Correspondences between Crowd Engineering and Supply Relationship Management.

<i>Phases and Actors of Crowd Engineering</i>	<i>Phases and Actors of Supply Relationship Management</i>
<i>Actors:</i> Contributors Manager (with clear view of the innovation)	<i>Actors:</i> Suppliers Producer (with clear view of the final product)
Phase 1. Identify contributions	Phase 1. Specify the purchase strategy
Phase 2. Select the useful contributions	Phase 2. Evaluate the supplier performance
Phase 3. Integrate the selected contributions into the innovative product description	Phase 3. Make collaborative-integrated the Suppliers with respect to the final product
Phase 4. Evaluate the global set of contributions. IF necessary, iterate	Phase 4. Evaluate the feedback from the producer IF necessary, iterate

3.2 Relations of Crowd Engineering with Crowd-sourcing and Collaborative Networks

In order to make evidence of the strict relation between Crowd Engineering and Crowd-sourcing, the definition of the latter as reported in [17] is here referred to: “Crowdsourcing is the act of taking a job traditionally performed by a designated agent (usually an employee) and outsourcing it to an undefined, generally large group of people in the form of an open call.” [18].

In practice, Crowdsourcing is a powerful tool because it describes collaborations both in research and in design actions which can significantly enlarge both the group of (potential) scientific partners, and the team of designers. With regards to the scientific context, Crowd sourcing implies to first clearly identify the problem to be solved by the crowd, and then to plan a reasonable balance between natural antagonisms of contributors. Therefore, Crowdsourcing makes evidence of some important, and also critical aspects, of Crowd Engineering that, with respect to the former, now it appears to be the operative practical version. Referring now to relations between Crowd Engineering and Collaborative networks, among the different variety that the latter assumes in industry and services (see [19]), its aspect of “collaborative engineering” is concerning teams of technicians and engineers belonging to different companies and cooperating together on a common significant project, thus sharing skills and experiences, thus moving towards the creation of a “virtual community”.

Therefore, the existence of a collaborative network is a very useful prerequisite for a company intending to start a Crowd Engineering project. In fact, the Collaborative network can become the area of first and fundamental diffusion of the "call for innovation creation", providing the most favorable environmental conditions for the launch of the Crowd Engineering project itself. A verification of this occurs in the

next Session, where the operational scheme of a Crowd Engineering project is outlined, especially in the selection phase of the contributions and acceptance of the new ideas, two key phases of such a project.

3.3 Crowd Engineering Operational Scheme

As for SRM, also in case of Crowd Engineering, for an effective collaboration, Manager and contributors (i.e., suppliers of contributions for the innovation required by the Manager) need to share profits in order to achieve a win-win situation. To come to an effective and profitable collaboration/integration of contributions, a Crowd Engineering operational scheme is mandatory [20, 21, 22]. Such a scheme is illustrated in Fig. 2. It is just the representation of the Table of correspondences, being derived by SRM scheme illustrated in [3], but specifically adapted to the Crowd Engineering concept.

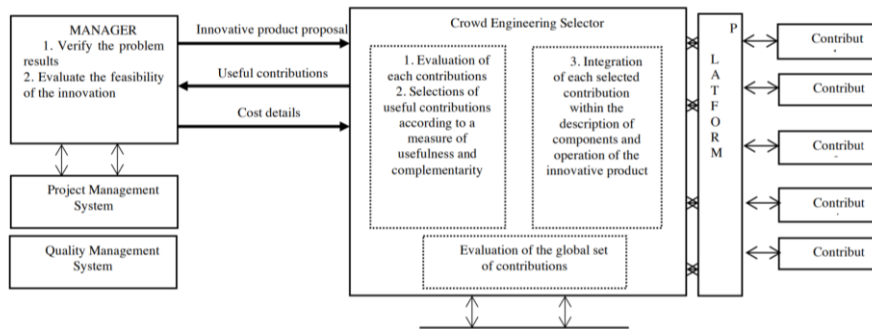


Fig. 2. The SRM-based scheme of the platform specifically adopted to the Crowd Engineering model.

The scheme is self-explanatory. The scheme inputs are the contributions sent by the "crowd", that is from the various types of suppliers of innovative ideas, in large numbers. The "heart" of the Crowd Engineering scheme is the Selector which, in accordance with the steps shown in the previous table, consists of the following parts:

- (1) evaluation of each contribution and selection of each one useful among them by evaluating an associated “*measure of usefulness*” that represents the coherence of the contribution with the project goal and a “*measure of complementarity*” for each couple of contributions, as defined in Section 2;
- (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 the parts and all the operations of the innovative product.

The Manager is operating in the final block of the scheme, with the following aim:

- (4) verifying the problem result, that is an admissible global correspondence among the selected contributions and all the parts and all the operations of the innovative product;

- (5) evaluate the real feasibility of the hypothesis of an innovative product obtainable from the integration, bearing in mind that different additions (with different uses of the contributions) are possible even though they obtain the same final product.
- (6) evaluate costs and revenues in each case produces an innovative product among the feasible ones;
- (7) evaluate the usefulness and the cost of every useful contribution received, to offer a profit to those who have helpfully responded to his call.

To implement its functions, the Manager receives as input:

- selected useful contributions;
- proposals for innovative products developed by the Selector.

It also interacts with the Warehouse Management System, for the needs of components, and with the Quality Management System, to estimate the performance of the resulting innovative products.

4 Some Hints for a Research Agenda

The development of the Crowd Engineering approach to select the best possible set of contributions from the “crowd” for innovative products creation, is one of the more challenging lines of evolution for smart enterprises.

To offer some considerations that could be utilized by experts when the needs for innovation become so important and critical for the survival of the enterprise, some ideas for the application of the Crowd Engineering approach is now presented, as a sequence of Work Phases (i.e. a Work-flow), summarized in the following Table 2. Indeed, a Manager needs to have a detailed description 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.

Table 2. Outline of the Crowd Engineering workflow.

<i>N°</i>	<i>Scope</i>	<i>Description</i>	<i>Documentation</i>
Work Phase 1	Call-for-contributions, referred to the a-priori selected consumer goods type.	Definition of a descriptive framework of the a-priori selected consumer goods type, to be used as a reference by: potential contributors, i.e. people or organizations - as above - who intend to participate in the call, sending their contributions.	Document with clear unambiguous presentation of the consumer goods type.
Work Phase 2	Strategies to manage the crowd of contributors, by creating a	Policies, strategies and initiatives in order to leverage the crowd, that means to gradually create	(A)Communication protocols, managed by Crowd Engineering

	“community innovators”.	of a	“community of innovators”. Who will send their proposals (data, suggestions, project indications)?	Manager B) Rules to which participants must satisfy in defining and formulating contributions (C) Clear rules on the refusal of contributions.
Work Phase 3	Methods for accepting and selecting contributions depending on their usefulness	for and	(a) Formulation and presentation of the structure of the "Crowd Engineering Selector" to guarantee an accurate, clear and unambiguous acceptance (or refusal) of the contributions.	(A) Documentation of the structure of the "Crowd Engineering Selector"
Work Phase 4	Organizational platform denoted Crowd Engineering Selector, for the integrated management of all strategies, and initiatives and tool utilizations		<i>Development of the Platform dedicated to managing all the activities that will be done for selecting, evaluating and integrating contributions.</i>	(A) Documentati on of the Platform, functionality (B) Authorizations of all contributors to include their data, info's and contributions in the Platform
Work Phase 5	Impact evaluation of the Crowd Engineering application		Analysis of the Platform applications to pilot case, such as their correspondence with the product tree graph nodes and links.	(A) Data and information gradually gathered and cataloged in order to describe the result.

This simplified workflow suggests some hints for future research lines in which a comprehensive view of the Crowd Engineering, Crowd-sourcing and Collaborative network could contribute to a real innovation of the creation process of new products.

According to [17], some main research lines can be envisaged, for assuring a useful and significant development of Crowd Engineering and its practical implementation in industrial and service frames:

- a) identification of robust methods to identify and select fruitful contributions for a given innovation project goal, such to be clearly transferred to the crowd and understood by each potential contributors; this will characterize the communication power from the innovation project Manager and the wide

- range of individuals and entities that could give really new ideas, in a form to be recognized and integrated by the Manager itself;
- b) selection and clear communication of incentives (or earnings) for the individual contributors, clearly related to the usefulness of the contribution and its integration with the rest, and finalization to the goal of the project;
 - c) promotion of healthy competition among contributors, while preserving the anonymity of contributions and guaranteeing their ownership, especially as the project takes shape and the integration of contributions will become increasingly evident (as is the exclusion of contributions of little value or not useful);
 - d) the correct evaluation (above all in economic terms) of the theoretical contributions and their validation, especially in the case of particularly innovative contents; similar considerations apply to the evaluation of contributions with a rapid practical impact;
 - e) Finally, the organization of a structure for managing the interactions of the Manager (or project team) with the crowd, through a structure that manages the center-contributor relations clearly but preserving the privacy of each one.

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