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Managing Open Innovation Project Risks Based on a Social Network Analysis Perspective

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Received: 30 March 2020; Accepted: 9 April 2020; Published: 13 April 2020

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Abstract: In today's business environment, it is often argued, that if organizations want to achieve a sustainable competitive advantage, they must be able to innovate, so that they can meet complex market demands as they deliver products, solutions, or services. However, organizations alone do not always have the necessary resources (brilliant minds, technologies, know-how, and so on) to match those market demands. To overcome this constraint, organizations usually engage in collaborative network models—such as the open innovation model—with other business partners, public institutions, universities, and development centers. Nonetheless, it is frequently argued that the lack of models that support such collaborative models is still perceived as a major constraint for organizations to more frequently engage in it. In this work, a heuristic model is proposed, to provide support in managing open innovation projects, by, first, identifying project collaborative critical success factors (CSFs) analyzing four interactive collaborative dimensions (4-ICD) that usually occur in such projects—(1) key project organization communication and insight degree, (2) organizational control degree, (3) project information dependency degree, (3) and (4) feedback readiness degree—and, second, using those identified CSFs to estimate the outcome likelihood (success, or failure) of ongoing open innovation projects.

Keywords: risk management; project management; sustainability; social network analysis; collaborative networks; project lifecycle; project critical success factors; open innovation; predictive model; project outcome likelihood; organizational competencies

1. Introduction

In today's complex, and unpredictable business landscape, if organizations want to achieve sustainable competitive advantages, they need to develop strategies that enable them to enhance performance and innovation to meet actual market needs and demands [1,2]. Innovation and performance strongly depend on how an organization´s top management drives and motivates the organization´s employees to overcome barriers such as different geographic locations, time-zones, cultures, and functions [3], as well as to have the capacity to acquire the necessary resources (human, technological) and to adopt an effective innovation model. For example, some authors argue that an organizational ambidextrous leadership style enhances the chances of gaining and holding sustainable competitive advantage. Such a style is essentially characterized by the exploitation of the present conditions in order to optimize the current business models operation and, at the same time, exploring the opportunities that contribute to redefining the business model by making decisions in a pioneering risky way [4,5]. However, most organizations do not contain, on their own, all the resources, such as brilliant minds, technologies, and know-how, just to name a few, necessary to be able to respond today´s market complex and dynamic demands. In an attempt to overcome such constraints, organizations engage in collaborative or trade-off partnerships, whereby in interacting with other organizations or individuals such as business partners, customers, universities, scientific institutes, public institutions, and even inventors, they hope to find the best methods for supporting innovation and improving organizational performance. Such collaborative partnerships are essentially characterized by an exchange of ideas, resources, and technologies in a controlled environment—enhancing synergy. The aim of these partnerships is to provide organizations with benefits such as reduced innovation costs, faster innovative processes, increased differentiation, easier access to the market, creation of new revenues streams, more diverse R&D investments, and the sharing of innovation development risks [6]. The description mentioned above—however not without criticism regarding its benefits [6]—fits one of the most popular and adopted innovation models [7–9], with an adoption rate reaching up to 78 percent of companies in North America and Europe. We can credit to Henry Chesbrough, for having coined the term "open innovation" [10] to describe the above phenomena. In fact, the literature shows that one of the key factors—if not the major key factor—in today's business landscape, including performance and innovation, is how well organizations are able to work in networks of collaboration [11–13]. Furthermore, research shows that working in networks of collaboration that are fueled with diversity and inclusion [14,15] efficiently distributed across the different organizational functions, geographies, and technical expertise domains [16] strongly contributes to the achievement of competitive advantages [11,12] and also boosts innovation and performance [17,18]. In fact, several authors and researchers argue that the network factor—working in networks of collaboration—is a higher success predictor, regarding innovation and organizational performance than individual competencies and know-how, especially if those networks of collaboration are built with positive energy, diverse problem-solving skills and reach [13,19,20]. While the benefits of working in networks of collaboration are well documented throughout the literature, in order that organizations might efficiently and effectively profit from them, these networks, must be effectively managed [21]. In fact, research shows [22] that organizations that engage in networks of collaboration and that adopt a more hands-off approach (less control from the management team) have considerably lower success rates for their projects than do organizations that adopt a hands-on approach (more control from the management team). However, it is often argued that the lack of effective models to support the management of collaborative networks—such as the open innovation model—is one of the major factors preventing organizations from engaging with more frequency in collaborative networks models such as the open innovation one [23]. Among the potential challenges that organizations may need to address when working in networks of collaboration, several authors argue that the management of three different collaborative risks dimensions—(1) behavioral risks, (2) the risk of assigning tasks to partners, and (3) the risk of uncooperative partners—represents by far the greatest challenge that organizations need to deal with [24]. The reason behind this challenge, has to do with the nature of how work in most organizations is accomplished. In most organizations work is done through internal and external networks that are usually a mix of formal and informal networks of collaboration [25]. While there do exist formal organizational hierarchies that determine how work and collaboration should be done, these alone, due their structural rigidity, seem unable to effectively respond to the actual needs of organizations, namely those regarding innovation and performance [25]. Research shows that as organizations engage in networks of collaboration, more work within and between organizations will be done through informal networks of relationships, that will emerge as the collaboration evolves, reducing to a certain extent the role of the formal organizational structure [13,26]. While organizational formal networks consists of a designed chain of authority where often are ruled by the rational-legal authority system based in universalistic principles that are understood as fair, informal networks are usually hidden behind an organizational formal chart, very hard to see with a naked eye [27], and very often not ruled by the rational-legal authority system but rather by unfair and particularistic principles, such as friendship, propinquity, homophily, dependency, trust, and so on, which are characteristic of personal and social needs of individuals [25]. In fact, it is often argued that informal networks are almost entirely responsible for how organizations find relevant information, solve problems, capitalize opportunities, and generate satisfaction well-being and retention [17,25,26]. However, several authors argue that in an organizational context, it is very difficult to distinguish whether relations between organization´s entities (employees) and between different organizations are informal or formal [28,29]. Moreover, informal relationship networks may become formal and vice-versa [29], which shows that there is a blurred line between informal and formal networks in an organizational context. It can be concluded that formal and informal networks of relationship simultaneously influence and are influenced by the behaviors of the different entities that comprise a social network. This phenomenon, in an organizational context, will influence how project tasks or activities will be executed, which to a certain extent may result in collaborative risks, such as (1) behavioral risks, (2) risks in assigning tasks to partners, and (3) risks in selecting critical partners. Several researches also show that if formal and informal organizational networks of collaboration are not effectively managed, they may strongly hinder the performance and innovation capacity of an organization and ultimately can evolve either to an overload collaborative status or to an inefficient organizational collaboration status [12,26,27]. Efficiently managing networks of collaboration has been pointed out by renowned authors, researchers, and institutes, as a major factor that influences results as for example project outcomes [26,27]. The most effective way to study, analyze, and quantitatively measure the dynamic interactions, which mirror existing and forge future behaviors of social entities that occur throughout formal and informal networks of relationships between entities in a social network, is through the application of social network analysis (SNA) centrality metrics [16,26,27,30]. Social network analysis centrality metrics or measures are developed based on graph theory—a branch of discrete mathematics structure, used to model pairwise relationships between entities such as persons, organizations, and others—which is the only effective method that enables the mapping, analysis, and quantification of relationship data between entities in a dynamic environment, contributing thus to explain how social structures evolve across time and how they impact the environment where they do exist [30]. However, due the complex nature of the subject (the application of social network analysis metrics in the organizational context)—characterized by a non-straightforward linear process regarding the understanding and the practical application in organizations, namely in the organizational managerial field, regarding the practical application of the SNA concepts and how their benefits are understood—still most organizations have not done the shift towards the integration of relational data (data from networks of collaboration analyzed and measure by the application of SNA centrality metrics) into their organizational strategic management processes [12,17,20].

In this work, a heuristic model, Open Innovation Risk Management model (OI-RM), developed on the basis of four scientific fields (Figure 1)—(1) collaborative networks, (2) project management, (3) risk management, and (4) social network analysis—has as main goal the identification of critical success factors regarding the formal and informal dynamic interactions (behaviors) between the different entities (organizations) that participated in projects characterized by a collaborative network approach, such as the open innovation one, so that they can be replicated and used as guidance in future projects characterized by a collaborative network approach.

In order to uncover and quantitatively measure dynamic interactional behaviors that will be used to identify and quantify project critical success factors, the proposed model in this work will analyze a set of successfully and unsuccessfully delivered projects that were executed under a collaborative network approach—such as the open innovation one—searching for unique dynamic behaviors between entities that participated in those delivered projects, that characterize each of the two project outcomes (success, and failure). The data that the proposed model in this work requires in order to quantitatively measure project critical success factors is to be collected through two different methods. They are (1) project meetings, where essentially the number of meetings and participating organizations in each meeting, characterized with their respective project competencies is recorded and (2) project emails, where essentially the number of exchanged emails between the participating entities, characterized according to their content and temporal timeline, is recorded. The data collected in project meetings and project emails, will then be analyzed and quantified by the application of social network analysis centrality metrics, which in turn will be used to characterize four different interactional collaborative dimensions (4-ICD) that usually occur in collaborative network projects. They are (1) key project organization communication and insight degree, which has as objective to measure how the presence of important key (function of their specific project competence) entities (organizations) in project meetings and email communication network, triggers communication dynamics (communication proactivity) between the participating entities, (2) organizational control degree, which has as objective to measure how a given organization controls the email communication network, in terms of send/receive project information related, (3) project information dependency degree, which has as objective to measure the dependency degree of a given organization or organizations, regarding project information to execute their project tasks or activities, and finally (4) feedback readiness degree, which has as objective to measure the speed of answering/replying to project information requests through the email communication network. In Table 1, a comprehensive description is illustrated that translates the integration of the individual contributions of the four scientific fields that build the foundations of the proposed model designed to quantitatively measure open innovation projects critical success factors across the different phases of their lifecycles.

Figure 1. The four scientific fields, which support the development of the Open Innovation Risk Management model (OI-RM) model.

Table 1. OI-RM Model individual integration contributions.

	Four Scientific Fields	**Individual Contributions for Proposed Model**
OI Project Lifecycle	Project management	Provides the definitions and structure of an open innovation project where the application of the proposed model will be deployed.
	Collaborative networks	Provides the definitions of the different dimensions of collaboration (networking, coordination, cooperation, and collaboration) that are used to define the four different informal collaboration dimensions (4-ICD).
	Social network analysis	Provides the tools and techniques to uncover and quantitatively measure the four informal collaborative dimensions (4-ICD), between organizations across an open innovation project lifecycle, where the 4-ICD are (1) key project organization communication and insight degree, (2) organizational control degree, (3) project information dependency degree and (4) feedback readiness degree.
	Risk management	Provides definitions, approach, and standard risk management process, to be adopted throughout the process of identifying, analyzing, measuring, treating, monitoring, and updating (continuous improvement cycle) dynamic collaborative risks, in other words, project critical success factors.

1.1. Relevance and Novelty of the Research

The proposed model in this work addresses three different collaborative risks dimensions—(1) behavioral risks, (2) risks of assigning tasks to partners, and (3) risks of selecting critical partners—that emerge as organizations engage in collaborative network models, such as the open innovation one. By doing so, the proposed model in this work aims to provide meaningful insight that contributes to answer the following three questions that together form its research question. They are

Question 1: To which extent do dynamic interactions (dynamic behaviors) between different entities (organizations) that participate in collaborative projects across a project lifecycle influence project outcome (failure or success)?

Question 2: Are there critical successful factors that can be identified associated with project success outcome?

Question 3: If there are critical success factors, can they be quantitatively measured and replicated in future projects?

By addressing the mentioned research questions, the proposed model in this work is contributing with valuable insight in three different dimensions.

First and as main objective of the proposed work, the proposed model in this work provides organizations a heuristic model that helps to manage in a holistic way (formal and informal) the networks of collaboration that emerge between the different entities that engage in collaborative networks working models, as they participate in innovation initiatives. The management of collaborative networks in innovation initiatives supported by effective management models provides organizations benefits as proved in the latest research [12,22], which argues that organizations that adopt a more hands-off approach management style (less control from the management team in the negotiation phase, as different organizations define the collaborative guidelines processes and procedures) leaving strategic, operational, or cultural incoming issues or differences to be managed as the collaboration evolves across time—a fix-it-as-you-go issue resolution approach—have considerable lower success rates than organizations that adopt more a hands-on approach (where the active involvement of top management to anticipate and resolve issues before any collaboration between different organizations begins). The proposed model in this work is in line with what is mentioned above, in the sense that it provides organizations with a structure to control innovation initiative developments, identifying project critical success factors based on behavioral patterns of collaboration uncovered in past successfully delivered collaborative projects.

Second, provides organizations a way to quantify and verify how much does a more, or a less centralized collaborative network structure—regarding communication, control, dependency and feedback degrees, measured by the application of social network analysis centrality metrics as result of the formal and informal dynamic collaborative interactions—positively, or negatively influences collaborative project´s outcome. This will enable to argument in a more data-driven way, research that defends the fundamental role for innovation and performance, of formal and informal networks in organizations [13,17,18,31] and research that points in other direction, defending that other factors—rather formal and informal organizational networks of collaboration—are of more importance for innovation and performance in organizations [2].

Third, the implementation of the proposed model in organizations is aligned with the organizational digital transformation strategy and industry 4.0 [32] to the extent that it automatizes the collection, processing, and analysis of behavioral data, associated to successful and unsuccessful project outcomes, continuously refining the process of identifying project critical successful factors through an automatized continuous improvement cycle, characterizing the proposed model in this work as a machine learning model.

1.2. The Importance of Organizational Sustainability in the Global Sustainability Context

Sustainability in organizations can be seen as holistic, consistent, and incremental growth processes (economic, social, and environmental), rather than non-constant growth processes over time. This means that these holistic and consistent growth processes over time focuses not only in the immediate important challenges of an organization but also in the long-term challenges. As organizations engage in open innovation projects, effective collaboration becomes the "neuralgic center" that strongly affects the outcome of collaborative development between the different organizations that participate in open innovation initiatives. Understanding and efficiently managing the different collaborative networks dimensions that emerge between the different organizations that engage in open innovation, such as communication, information-sharing, feedback, just to name a few, is a critical factor to better and more accurately develop efficient collaborative planning and take corrective or optimization measures, in a timely manner. By acting in this way, one is optimizing the necessary different resources associated to such actions. The application of social network analysis has in this scenario a key role regarding the identification (essentially quantitative) of such different collaborative networks dimensions that emerge as organizations engage in open innovation initiatives. Social network analysis enables to identify and quantify risks associated to dynamic interactive collaboration between the different organizations that participate in open innovation initiatives in a holistic way, such as collaborative overload and poor or lack of collaboration or information sharing between the different organizations according to the following value-chain: The identification of open innovation collaborative risks in a timely manner contributes to a better understanding of the actual and future collaborative developments, which in turn will enable a more accurate planning of effective responses to upcoming challenges. This in turn will enable optimization regarding the allocation of necessary resources to plan responses, which in turn strongly contributes to a leaner organizational and societal approach, providing organizations sustainable competitive advantages (by essentially saving resources, time, and money), which in turn, strongly contributes to the three fundamental pillars of sustainability known as economic, social, and environmental.

1.3. Structure of this Work

In this work a heuristic model is proposed to manage collaborative networks in open innovation projects, by identifying project collaborative critical success factors. The present work is divided into four distinct but interrelated chapters.

In chapter 1 (Introduction) a brief introduction to the architecture of the proposed model in this work is presented, highlighting the linkage between individual contributions to the different scientific fields that support the development of the proposed model and the motivation (reasons for the need of such model in the organizational context, namely in organizational collaborative networks perspective) to develop it.

In chapter 2 (Literature review) an extensive literature of the four scientific fields (collaborative networks, risk management, social network analysis, and project management) that support the development of the proposed model is undertaken, highlighting the most important contributions in the organizational collaborative networks context, to the development of the proposed model in this work.

In chapter 3 (Model development and implementation) the research methodology, function principles—supported by an application case—, important concepts, development process, implementation process across a project lifecycle, and ethical considerations of the proposed model are illustrated in an extensive and detailed approach.

In chapter 4 (Conclusions), the managerial implications, further developments, and benefits and limitations of the proposed model are presented and discussed in an open innovation context. The chapter finalizes by suggesting a number of aspects for further development and research.

2. Literature Review

2.1. Collaborative Networks

Collaborative networks (CN) can be defined as networks that comprise a variety of entities such as organizations, people, and so on, which are geographically distributed, autonomous, and heterogeneous regarding their operating environment, culture, social capital, and goals but collaborate to better achieve common or compatible goals, where the interactions are supported by computer network and can take several forms, such as service-oriented organizations, virtual organizations, dynamic supply chains, industry clusters, virtual communities, virtual laboratories, and so on [33]. Organizations that are members of long-term networked structures, usually result in an increase in circulation and production of knowledge within the network, contributing that to a more effective way of working of organizations, as they pursuit their objectives [18]. However, it is argued that the lack of performance indicators that identify and measure the production and circulation of knowledge in a collaborative environment make difficult to prove its relevance [18]. The concept of collaboration may often be confused with cooperation and gains a higher level of ambiguity, when the concepts such as networking, communication, and coordination are considered [34]. All the concepts mentioned above are components of collaboration but have different dimensions in the organizational field regarding the value that they offer. Therefore, it is important to identify what each one of them really represents. Their unique contribution is described as follows [33]: (1) Networking is the exchange of communication, information, and experiences for mutual benefit, where usually there is no common goal or structure that regulates timing and individual contributions. (2) Coordination, in addition to the characteristics of networking, involves aligning/altering activities for mutual benefit in order to achieve results in a more efficient way. (3) Cooperation involves not only information exchange and adjustments of activities (Networking and coordination) but also sharing resources and division of some labor among participants in order to achieve compatible goals. The sum of the individual contributions by the various participants in an independent manner, forms the aggregate value of this collaborative level. (4) Collaboration involves all the other three mentioned before and includes jointly planning, implementing, and evaluating a program of activities in order to achieve a common goal. It is a "working together" collaborative level, which requires mutual engagement in problem solving activities from the participating entities, trust, effort, and dedication. It still implies the sharing of resources, responsibilities, rewards, risks. Ultimately, it enhances the capabilities of the participating entities.

2.1.1. Open Innovation

Open innovation is an organizational collaborative model type that has been gaining increasing attention in the past years, essentially due its measurable benefits in enhancing the innovation capacity of organizations [23]. The term "open innovation" is credited to Henry Chesbrough [10] and can be defined as a model that uses a wide range of external entities (actors and sources) to help organizations to achieve a sustainable innovation behavior [23]. Essentially, open innovation means that organizations should work together in networks of collaboration, sharing ideas, experiences, know-how, and technologies, to generate value [35] that otherwise could not be achieved if organizations work in an isolated mode. Some authors argue that there are essentially three different levels of collaborative innovation, which to a certain extent are dependent from strategic, operational and structural, legal, and cultural issues or challenges [23]. They are (1) management of interorganizational collaboration process (managing the interactions between the different organizations that participate in an open innovation project), (2) management of the overall innovation process (managing all the processes, phases, and innovative breakthroughs across the timeline evolution that defines the duration of the collaboration), and (3) creation of a new collaborative knowledge (organizing, documenting, and making available critical information regarding the innovation process evolution). To better understand how the open innovation model functions, Chesbrough [10] proposes the comparison between a traditional approach to innovation initiatives (the blockbuster business model type or closed innovation model) and a new approach (open innovation model). Chesbrough [10] argues that the blockbuster business model type—also known as the closed innovation model type—is no longer economically sustainable and that organizations need to engage in open innovation working approaches if they want to survive. He argues that the open innovation model, by contrast with the traditional closed innovation model, is a new way of creating value in an organization [10]. Essentially, the open innovation model is characterized by having two different flow-types of knowledge and resources [10]. They are (1) outside-in flow type (occurs when an organization brings external knowledge or/and resources from business partners, customers, universities, scientific institutes, and public institutions to improve its innovative performance. By acting so, innovation initiatives, costs, and time can be reduced by acquiring, buying, or borrowing only those resources that are really needed. (2) inside-out flow type (occurs when organizations search for possibilities to share already available in-house knowledge or/and resources with the external environment in a way which will add value to the sharing organization such as for example out-licensing and transfers of rights, promoting spinoffs, turning to open source, just to name a few. By sharing their ideas with the external environment, organizations can create value chains (downstream chains) with other organizations or earn a royalty when others use their ideas, which very likely organizations on their own could not use, develop, or even implement. If both flow types are simultaneously adopted by an organization, they can be named as coupled flow type, where the exchange of resources, ideas, and technologies occurs trough collaborative partnerships in the form of joint researches, consortiums, and joint ventures just to name a few. As already mentioned before, the literature shows that there is a lack of effective models to support co-innovation collaborative models. Nevertheless, some models can be found in the literature [23,36], where two of them are very popular among practitioners of open innovation projects, also known as crowdsourcing [23]. The first model, the InnoCentive [36], created in 2001, runs in a web based platform and consists of six steps that start with the identification of problems and ideas, formulation of a challenge, specification of intellectual property agreements, publication of the challenge, evaluation of the solutions, and a price to end with the transfer of intellectual property. The second model, developed by Procter & Gamble (P&G), called Connect + Develop, works inwards and outwards spanning from packaging to trademarks, marketing to engineering, and commercial services to design.

2.1.2. Open Innovation Model Benefits and Challenges

One of the biggest benefits in engaging in well-managed open innovation projects, is the positive impact in economic, social, and environmental sustainability [37]. However, despite the benefits, that can easily be found in the literature [38], according to a survey conducted by Accenture in 2015 (a consultancy company) about 50% of surveyed organizations, said that open innovation don't seem to be yielding as many new products or other benefits as they had hoped [38]. Several studies show that the reason for the low adoption rate is essentially linked to two factors [22,38]. They are (1) political, and (2) cultural, but surprisingly not technical. Factors like, different cultures and different attitudes regarding sharing intellectual property, different concerns about risk sharing, multiple gatekeepers, relationship between large and small organizations, skepticism regarding anything "not invented here," [22] and disputes between organizational rival groups over organizational "territory", hold back adoption. Research in the field of open innovation, suggests three major risks that are likely to be experienced by organizations as they engage in open innovation projects [24]. They are (1) pure risk or uncertainty (related to the probability of an event occurrence that puts at stake the success of the innovation project), (2) risk of an innovation project (related to the fact that there is a substantial portion of the risks associated with estimates such as resources, duration of the task and costs. Includes also business, political or regulation, and operational risk sub types), and finally (3) collaborative risks (related to the fact that a collaborative ecosystem can be characterized by a set of relationships that are established between several entities, such as companies/organizations, knowledge, resources and tasks, and contains the risk of collaborative management, behavioral risks, risk of assigning tasks to partners, and the risk of selecting critical enterprises). Other challenges that may be an obstacle, or even hinder pursuing in to these collaborative project types include, but not only, finding creative ways to exploit internal innovation, incorporating external innovation into internal development, and motivating outsiders to supply an ongoing stream of external innovations processing ideas quickly and efficient, establishing an efficient internal structure, proper management of intellectual property issues and other legal risks, the fear of failure, the lack of incentives and critical creative resources [39]. Crafting effective strategies and models to properly address the above-mentioned risks, represents a huge challenge for organizations. Despite the benefits that are credit to open innovation, the model is not without critics or downsides. High costs in people coordination and loss of control and power over innovative processes, are just a few mentioned in the literature [6]. To better understand the advantages and the disadvantages of open innovation, in Table 2 are illustrated the differences between closed, and open innovation, which represent the benefits and limitations of both models [6,37].

Table 2. Benefits and Limitations of Open Innovation and Closed Innovation.

	Benefits	Limitations
Closed Innovation Model	• Full overall control on the innovative process and intellectual property (IP) • Less or non-dependence on external knowledge • No risk of leak of confidential information • Less faults on routine works • What one organization discover it will get it to market first	• Not all the smart people in the necessary fields to innovate, work for *us* • Higher levels of investments to supply the R&D departments • Development performs at a slower pace • Gains limited market share • Higher risk, because developed ideas may end not being supported by the organization
Open Innovation Model	• Allows to knowledge, ideas, technology flow in and out between organizations • Diversification of R&D investments • Easier market entry • Resource acquisitions advantages • Development performs at a higher pace • Broader base of ideas • Technological synergy effects • Increase of the learning capacity • Use intellectual non-own property as strategic asset • Reduced costs of innovation initiatives • Share innovation investments risks with other partners • Increase differentiation and the creative process • Create new revenues streams (Copyright- royalties)	• Increase in process coordination and implementation costs • More faults in routine workflows • Strong dependence on external knowledge • Loss of key knowledge control and flexibility, creativity, and strategic power • Lack in legacy for additional tasks • Risk of leak, of confidential information • Loss of overall control over the innovative process and intellectual property (IP)

As it can be seen in Table 2, the benefits of the open innovation outweigh by far the limitations, namely when compared with the benefits of a closed innovation system. Essentially, the major benefits can be traced in financial outcomes in two different ways. First the exchange of resources and technologies enables faster innovation processes and opens more doors to existing and different markets, wherefrom more revenues may arrive. Second, by sharing the risk of failed innovation initiatives with innovation initiative partners, may spare organizations from bankruptcy or even extinction.

2.2. Risk Management and Critical Success Factors in Project Management

A project, according to the PMI (the Project Management Institute) is a temporary endeavor with a defined start and end, that aims the creation of a unique product or service or result [40]. In order organizations successfully deliver a project, they should have support of standard structured approaches (so-called best practices standards). Such best practices on how to efficiently manage projects, are usually provided by the project management scientific field [40]. Project management can be defined as the application of knowledge, skills, tools, and techniques to project activities, to meet project requirements, across all the different project phases of a project lifecycle [40]. Very often, as organizations deliver projects, challenges in the form of risks (threats or opportunities), arise across the different phases of a project's lifecycle. Such risks, if not properly managed (usually threats), very likely will drastically reduce the chances of achieving a successful project outcome, which in other words means, deliver a project within the planned scope, quality, schedule, costs and resources (the so-called project constraints [40]). Project risk management expert David Hillson defines project risks, as the uncertainty that matters [41]. He argues that this definition aims to divide what represent real project risks, from what not represents real project risks. Hillson suggests four types of risks that may outbreak in project management. They are [41]: (1) Event risk, (2) variability risk, (3) ambiguity risk, and (4) emergent risk. In Table 3 a comprehensive description regarding the four types of risks and the respective uncertainties is presented.

Table 3. Risks and respective uncertainties types.

Risk Types	Uncertainty Types	Description	Management Approach
Event Risk	*stochastic uncertainty*	Also called event risks, are risks related to something that has not yet happened, and it may not happen at all, but if it does happen, it will impact on one or more project objectives.	There is a set of well-established techniques for identifying, assessing and managing them, based on risk management standards and best practices.
Variability Risk	*aleatoric uncertainty*	Are a set number of possible known outcomes, but one does not exactly know, which one will really occur.	Advanced analysis models such as the Monte Carlo simulation, are the actual solution to model and manage these risk types.
Ambiguity Risk	*epistemic uncertainty*	Are uncertainties, arising from lack of knowledge or understanding. Also called of know-how and know-what risks, comprise the use of new technology, market conditions, competitor capability or intentions, and so on.	Learning from experience from past, or others–lessons learned. Prototyping and simulating, before taking real action.
Emergent Risk	*ontological uncertainty*	Known as "Black Swans", these risks are unable to be seen because they are outside a person´s experience or mindset, so one doesn't know that he should be looking for it at all. Usually they arise from game-changers and paradigm shifters, such as the release of disruptive inventions or products.	Contingency planning, is the key to manage such risk types.

The model proposed in this work, addresses the ambiguity risk type, characterized as an epistemic uncertainty (according to Table 3) which essentially is characterized by a lack of knowledge and understanding regarding a given subject, which in the case of the proposed model is the extent to which the dynamic behavioral interaction—characterized by the 4-ICD—of entities in an open innovation context, influence a project outcome (success or failure). Such type of risks can be properly addressed by learning from past experiences and simulating future events (according to Table 3) which is exactly what the proposed model in this work offers, as it identifies project critical success factors from closed projects and replicate those critical success factors in future projects. Other authors and researchers in the area of project risk management, argue that project challenges (project risks) can be instead called as project critical success factors [42]. Factors such as experience of project teams, project manager's ability to solve problems, management level during the strategy formulation stage [43] are just a few of them. Notable is the work in this area done by Pinto and Slevin back in 1988 [42], as they identified a set ten project critical success factors, that change importance function of a given project phase. Such critical factors, are considered major project risks, that if not properly managed, will jeopardize the chances of a successful project outcome. They are [42]: (1) project mission not properly defined, (2) lack of top management support, (3) undetailed project schedule, (4) poor client consultation, (5) lack of necessary and proper technology, and expertise, (6) poor team skills and experience, (7) ambiguity client acceptance, (8) lack of proper monitoring and feedback of project activities, (9) poor communication, (10) non-readiness to handle crises and deviations from plan -contingency plans. In order to manage project risks, organizations have risk management standards that they can incorporate in their project management activities, provided by institutes or body of knowledge such as the PMI [40] and ISO [44], that essentially recommend— based on experience and best practices principles—a set of problem-solving strategies an methods, supported by ad hoc tools and techniques. A very popular approach to manage risk in organizations is proposed by the ISO (the International Organization for Standardization), in their standard–31000:2018 [44]. In this standard, a set of principles aim the creation of value in organizations by effectively assessing and treating risks. The standard consists in a set of well-structured six steps that essentially aim the identification, treatment, and monitoring of risk. They are [44]: (1) Establishing scope (defining the scope of the risk management activities), context (defining the external and internal context, which is the environment in which the organization seeks to define and achieve its objectives), and criteria (specifying the amount and type of risk that an organization may or may not take, relative to objectives), (2) perform a risk identification (consists in finding, recognize and describe risks that might help or prevent an organization achieving its objectives), (3) perform a risk analysis (comprehend the nature of risk, uncertainties, risk sources, consequences, likelihood, events, scenarios, controls and their effectiveness), (4) do a risk evaluation (comparing the results of the risk analysis with the established risk criteria to determine where additional action is required, (5) proceed to risk treatment (specify how the chosen treatment options will be implemented, so that arrangements are understood by those involved, and progress against the plan can be monitored), and finally (6) record and report the previous steps (continuously keep monitoring, and reviewing the evolution of identified risks and the efficacy of the applied controlled measures).

2.3. Social Network Analysis in Organizations

The beginning of the use of graph theory in analyzing dynamic relationships between entities (persons) is credit to the Romanian American psychiatrist, psychosociologist, and educator Jacob Levy Moreno (1889–1974), as his work "Who Shall Survive" was published in 1934 [45–47]. Nowadays the application of social network analysis covers a wide range of different areas such as organizational science industry, management and leadership [48], political science [49], behavioral sciences [50], communication, learning and media [51], law, national safety, criminology and terrorism [52], just to name a few. Social network analysis (SNA) is the process of studying and analyzing social structures data with a variety of measures developed based on graph theory, that contributes to explain how social structures evolve across time, and how they impact the environment where they do exist [53]. It can be more simply defined as "a specific set of linkages among a defined set of persons, with the additional property that the characteristics of these linkages as a whole may be used to interpret the social behavior of the persons involved" [54]. SNA plays an important role in bringing light to the social capital challenges [55] and has been incorporated into traditional Risk Management processes of Organizations, as a supportive tool for decision making and risk analysis [56] and simultaneously being used to study subjects such as talent shortages and retention, incompetence, innovation, network collaboration, collective and individual performance, cultural fit, values, unethical behavior, low morale, employee wellness, noncompliance with industry, and fraud [57]. The application of social network analysis to study social structures has achieved high popularity essentially due the desire to understand to which extent people´s behaviors and relationships influence others and outcomes such as performance, innovation, social cohesion, information diffusion, and so on [47,58]. Such relationships are complex by nature and cannot be entirely explained trough traditional social theory and data analysis methods but rather by methods that are based in sociology, because they consider the individual´s social context in the process of making choices [59]. In 1979, Noel Tichy, Michael L. Tushman and Charles Fombrun [60] enumerated some benefits of applying SNA in organizations, namely the potential offered by the study and understanding of organizational theory and the dynamic component of it.

2.4. The Application of Social Network Analysis in Project Management

The application of social network analysis has been expanding to several diverse scientific areas such as project management, for example, although it remains so far at a very initial stage [61]. Essentially, in project management, the identification of critical success factors concerning the dynamic of project informal networks that may contribute for a success project outcome is the principal reason for the application of SNA [62,63]. In the past years, several works that evidence the successful application of SNA in projects have been published. In 1988 Pinto and Slevin identified that a defined set of critical factors were changing the importance degree and function of the project phase. Among those identified, some are related with the interaction between entities across a project lifecycle such as top management support, client consultation, and communicating network [42]. These findings done by Pinto and Slevin [42] were revalidated by the latest research conducted in 2012 [64]. In 1993, professor David Krackhardt and Jeffrey R. Hanson, pointed out the importance of managers uncovering their informal organizational networks as being a key contributor to success. According to them, three collaborative networks are crucial to be mapped in an organizational context. They are [13] (1) advice network, which reveals the people to whom others turn to get the job done; (2) the trust network, which identifies who shares delicate information with whom; and (3) the communication network, which shows who talks to whom about work-related matters. One of the most cited ever works regarding the application of social network analysis in project management [65] is the work done by Stephen Mead in 2001 [66]. He applied SNA to visualize project teams, namely the analysis of the informal project stakeholder´s communication network [66], and after having identified central and isolated stakeholders regarding the informal communication network, he created a corrective plan to improve the performance of those that were not so well integrated in the project network. One of the most notable works regarding he application of SNA in organizations has been published by Professor Rob Cross, who in one of his most known books, "The Hidden Power of Social Networks", published in 2004, illustrates a ten-year case-study collection of the benefits of the application of SNA in organizations, namely in managing project collaborative networks [67]. Cross identified that in every organization, there is an informal type of network that is responsible for how the work gets done and coined a set of specific actors based on their location within a social structure [26,67]. They are The Central Connectors, Boundary Spanners, Information Brokers, Peripheral Experts, Peripheral Intentionally and the Energizers. In 2009, Prell et al. [68] applied SNA to identify and analyze stakeholder networks in natural resource management using the results in the selection of the important stakeholders. Toomey [69] identified four key subjects of SNA theory that play a major role in project development. They are centrality, structural holes, boundary management, and tie strength. In 2017, Mok et al. [70] applied SNA network centrality measures to identify key challenges in major engineering projects (MEPs) based on interdependencies between important stakeholder concerns, resulting in the identification of a number of key challenges that occur in those MEPs and helped to develop a set of good practices to release those challenges that could be used in future MEPs. In 2018, Michael Arena, former chief talent officer for General Motors, concluded, after years of investigation in several different organizations, that successful organizations operate in a more networked way, enjoying what he called as adaptative space [12], which is essentially a virtual place that enables proper connection between the operational and entrepreneurship pockets of an organization, were employees explore new ideas, and the most creative ones are empowered to propagate their ideas across the organization, enabling it to work in a more agile way. This adaptative space is built, managed, and maintained using SNA (social network analysis).

SNA Centrality Measures in Project Management

Centrality, in a social collaborative network, refers to the structural location of an entity, rather to the entity own inherent attributes such as age, tender, or gender. SNA researchers suggest that centrality is a measure of importance, influence, prestige, control and prominence [71,72] and that such structural locations can be quantitatively measured by the application of graph theory centrality metrics such as degree, betweenness, and closeness. According to Freeman [71], for each of these centrality metrics, a respective social direct implication exists as follows: activity (degree can be an index of potential for the network's activity), control (betweenness is an index of communication control by serving as bridge between two different subgroups of an network), and independence (closeness is an index of the potential independence from network control), respectively. Essentially, network centrality is associated to informal power in collaborative social networks [26,27,73] that will influence coordination and decision-making in project management and ultimately influence project outcome—success or failure [74,75].

3. Model Development and Implementation

3.1. The Proposed Model: The OI-RM (Open Innovation Risk Management) Model

The proposed model in this work is called OI-RM Open Innovation Risk Management and has as objective to contribute to answer the following research question:

To which extent does the dynamic collaborative interaction between different organizations that participate in an open innovation project across all the different phases of a project lifecycle influence a project outcome (success or failure)?

The proposed model in this work is divided into two parts. In part 1, the model will identify project outcome critical success factors regarding the dynamic interaction/collaboration between organizations that participated across a project lifecycle in open innovation environment projects, in closed (successfully and unsuccessfully delivered) projects, by analyzing project related data collected in project E-mail-exchange network and project meetings, throughout all the different phases of a project lifecycle. The model will analyze the collected project data, where essentially it will be looking for repeatable behaviors (RBs) regarding the dynamic interaction/collaboration between the different organizations that worked in open innovation project environment from successfully and unsuccessfully delivered projects, by analyzing four interactional collaborative dimensions (4-ICD) that usually occur as a project is being delivered. They are (1) key project organization, communication, and insight degree; (2) organizational control degree; (3) project information dependency degree; (3) and (4) feedback readiness degree. If the proposed model identifies unique RBs associated to successfully and unsuccessfully delivered open innovation projects, they are considered the critical success factors. In part two, the model will provide guidance, and estimate an outcome likelihood of an ongoing open innovation project type, by comparing the deviation between the real ongoing project evolution and the desired evolution (which is defined by the identified critical success factors in part 1 of the model) of the ongoing project. By providing answer to the above-mentioned research question, the proposed model in this work is essentially addressing two risk types previous mentioned in chapter 2 that may occur when organizations work in open innovation projects. The first one, proposed by Abreu et al. [24], concerns the collaborative risks, which are delayered into critical enterprises risk, assigning tasks to partners risk, behavioral risk, and collaborative network management risk. The second is proposed by Hillson [41], essentially addressing the ambiguity risk type, also known as ambiguity risk—also known as "epistemic uncertainty"—where uncertainties (risks) arise from lack of knowledge or understanding, and its efficient management is done with lessons learned, prototyping, and simulations. Before introducing how the model was developed and working functioning principles, the model's key concepts must be introduced. They are presented in Table 4.

Table 4. OI-RM model key concepts.

OI-RM Key Concept	Description
Open Innovation Project	For the proposed model in this work, an open innovation project is a temporary endeavor undertaken to create a unique product, service, or result.
Open Innovation Project Outcome	The proposed model assumes only two types of project outcomes. They are successful and unsuccessful project outcomes. The criterion that defines both types is not given by the proposed model.
Number of Open Innovation Projects	The model does not preview a maximum number of open innovation projects to be analyzed. However, at least two projects—one with a successful and one with an unsuccessful outcome—are required as input.
Open Innovation Project Organizations	Project organization is any organization that participated in a project, across its lifecycle, or/and is officially assigned to participate in an open innovation project. This means it is any organization that has participated in project meetings and email project information-related exchange.
Open Innovation Project Organization-Competencies	Project organization competencies are the different competencies that different organizations play as they participate in delivering open innovation projects. They can be from the most diverse fields such as engineering, marketing, sales, human resources, and so on.
Open Innovation Project phases and Lifecycle	Every project used as input for the model has a finite number of project-phases. Usually four generic phases can be used (but not necessarily four only), (phase 1—Starting the project, phase 2—Organizing and preparing, phase 3—Carrying out the work, phase 4—Ending the project). The sum of all project phases of a project is the so-called project lifecycle.
Collaborative Interaction	The dynamic collaborative interaction of project organizations, which is characterized by the four interactive collaborative dimensions (4-ICD) that usually occur as a project is being delivered, comprises the formal and informal networks of collaboration.

3.2. OI-RM Model Function Principle

3.2.1. Research Methodology

The proposed model in this work is the result of an extensive literature review and consulted case studies that are illustrated in the previous chapter, regarding the already mentioned four scientific fields that lay the foundations of the development of the proposed model. The proposed model in this work integrates the proven individual benefits of each of the four scientific fields (project management, risk management, collaborative networks, and social network analysis) in organizations, in a network collaborative context—without neglecting its limitations—which gives to the proposed model strong trustworthy basis regarding the success of its application in an organizational context. The fundamental reason for the development of the proposed model in this work essentially relies on the countless studies and researches presented in the previous chapter in the fields of the social sciences and organizations that argue and prove that there is a relationship between the dynamic behavioral interaction between entities of an organizational social network and organizational outcomes essentially translated into performance and innovation. However, there is still by far a higher number of application cases in organizations that perform to a certain extent bureaucratic or the so-called true office work such as call centers, R&D, maintenance, operations, or factory work, rather than in project environments. The proposed model in this work is aimed to project environments, namely collaborative projects such as the open innovation ones. The methodological approach follows a well-defined sequential approach based on the literature review and case studies where the application of social network analysis has been one of the key pillars that enables the identification of the influence of dynamic behaviors in organizational outcomes. Regarding the research methodology process of the proposed model in this work, the following steps have been undertaken:

The first was defining the physical and spatial environment where the action is to occur; a project (with a well-defined start and end) with a typical structure (typical project lifecycle) and a variety of different entities (organizations) undertaken in an open innovation working model.

The second was the definition of the different levels of collaboration (communication and information exchange) between the different entities that are designed to participate in the project.

The third was the selection of the collection data methods (project meetings and project email exchange) that will enable to visualize and quantify the dynamic interactions that mirror a certain dynamic behavior.

The fourth was the selection of the most effective tools and techniques (according to literature research in the application of SNA in projects) to analyze in a quantitatively way the collected data, based social network analysis centrality measures such as in-degree, out-degree, total-degree, density, and reciprocity.

Finally, the fifth was the association of results obtained to project outcomes, enabling to draw conclusions regarding the relationship between the different dynamic behaviors across a project lifecycle and project success or failure outcomes.

3.2.2. Introduction to the Functioning Principles of the Proposed Model

To understand the working principles of the proposed model in this work, a demonstrative example based on Figure 2, is presented. The presented projects A and B, in Figure 2, that aim to the demonstration of the functioning principles of the proposed model in this work were carefully selected in order to show its potentiality for the identification of a project's critical success factors regarding the dynamic behavioral interaction of different entities (organizations) across a project lifecycle. Essentially, this has to do with the process of identifying critical success factors that must obey the criteria of being unique and repeatable to one of the two possible project outcomes—failure or success. This is, for example, to be seen in two different examples. First, in phase 1 of both projects in Figure 2, the architecture of the green lines that connect the different organizations are different. In project A, which was successfully delivered, all entities are connected through the green lines, and in project B, which was unsuccessfully delivered, not all entities are connected by the green lines. The difference in the number of connecting lines between projects A and B in phase 1 is captured quantitatively by the proposed model through the application of social network analysis' centrality metrics, which enables to characterize the difference between the project that was successfully delivered (project A) and the project that was unsuccessfully delivered (project B), regarding the number of connecting lines in a uniquely measurable way. On the other hand, in phase 4 for both projects in Figure 2, although project A was successfully delivered, the number of connection lines between the entities are the same from both projects. Here, the proposed model in this work cannot find a measurable unique difference regarding the number of connecting lines, which ultimately means that the number of collecting lines in phase 4 of the analyzed project do not influence any of the two project outcomes. This phenomenon is also one of the reasons why the proposed model in this work does not only operate with one unique centrality metric but rather with five different ones, in order to capture other dynamic behaviors that may not be able to be captured by a given centrality measure.

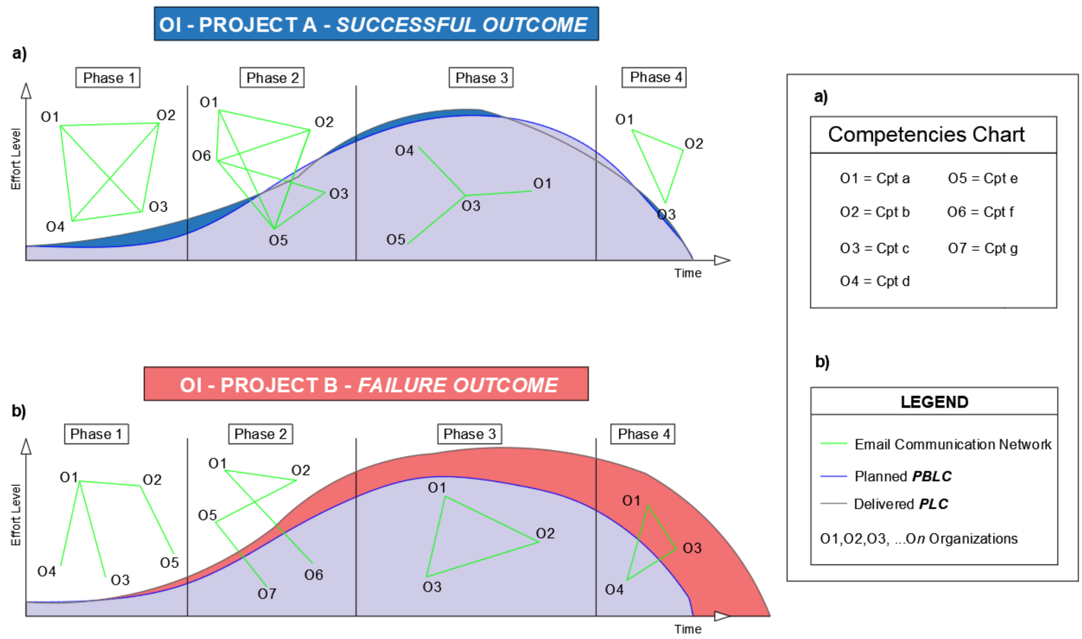

Figure 2. Project lifecycles for delivered Open Innovation Projects A and B.

3.2.3. Functioning Principle of the Proposed Model—an Application Case

In Figure 2, the lifecycles of two delivered open innovation projects are represented (projects A and B). Project A was successfully delivered, and B was unsuccessfully delivered. Both projects serve only as a demonstrative example of how the proposed model in this work functions. Organizations O1, O2, O3, O4, O5, O6, and O7 participated in both open innovative projects A and B, each with its own specific competency (a, . . . , g) according to (a) in Figure 2. The blue lines across the project lifecycles represent how the projects were planned to be delivered. The grey dashed lines represent how the projects were delivered. In each phase, on both projects, the green lines represent the email communication network direct or indirect channels between the project organizations, which result from the data collected from project-related emails exchanged. For example, in project A at phase 1, there has been an email communication channel between project organizations O1 and O2. Analyzing the email communication at the first two phases (phase 1 and phase 2) of both projects (Project A and B), it is clear to see with a naked eye that the email communication network of the project that was successfully delivered (Project A) is by far denser than the email communication network in project B. In other words, there are more email communication channels between the organizations. At this point, considering only this factor, one can conclude that a denser email communication in phases 1 and 2 of an open innovation project is associated with a project success outcome.

However, it still needs to be quantitatively measured (the difference between a denser and a less denser email network communication channel). It is at this point that the application of Social Network Analysis (SNA) turns into a powerful tool. SNA uses the graph theory metrics that can be used to measure any graph-structure like the one that represents the email communication network illustrated in Figure 2. For this case, a centrality measure, *network average total degree (degree centralization)* [45] metric, has been chosen to quantify the email communication network in the proposed model. The network average total degree is the ratio between the sum of all links attached to one organization (total degree) and is given by the formula (1) adapted from [45]:

$$ATD(pha) = \frac{\sum_{o=1}^{n}(x_o)}{n} \tag{1}$$

where:

ATD = average organizational network total degree
x = number of existing links attached to one organization *o*
n = total number of project organizations (*o* = 1, . . . , n)

Applying (1) for phase 1 of project A:

$$ATD(A,\ 1) = \frac{3+3+3+3}{4} = 3 \tag{2}$$

Maximum for $(A,\ 1)$ = *3*

Applying (1) for phase 2 of project A:

$$ATD(A,\ 2) = \frac{3+3+2+4+4}{5} = 3,2 \tag{3}$$

Maximum for $(A,\ 2)$ = *4*

Applying (1) for phase 3 of project A:

$$ATD(A,\ 3) = \frac{1+1+1+3}{4} = 1,5 \tag{4}$$

Maximum for $(A,\ 3)$ = *3*

Applying (1) for phase 3 of project A:

$$ATD(A,\ 4) = \frac{2+2+2}{3} = 2 \tag{5}$$

Maximum for $(A,\ 4)$ = *2*

Applying (1) for phase 1 of project B:

$$ATD(B,\ 1) = \frac{1+1+1+2+3}{5} = 1,6 \tag{6}$$

Maximum for $(B,\ 1)$ = *4*

Applying (1) for phase 1 of project B:

$$ATD(B,\ 2) = \frac{1+1+2+2+2}{5} = 1,6 \tag{7}$$

Maximum for $(B,\ 2)$ = *4*

Applying (1) for phase 2 of project B:

$$ATD(B,\ 3) = \frac{2+2+2}{3} = 2 \tag{8}$$

Maximum for $(B,\ 3)$ = *2*

Applying (1) for phase 3 of project B:

$$ATD(B,\ 4) = \frac{2+2+2}{3} = 2 \tag{9}$$

Maximum for $(B,\ 4)$ = *2*

3.2.4. Conclusions and Interpretation of Results

After applying (1), to all the open innovation project phases of Figure 2, it can be concluded that for the first two project phases, the ATD value of project A is almost twice the value of project B. This means that the organizations that participated in project A at the first two phases were more connected (through the email communication network) than the organizations that participated in project B, in the same project phases.

For example, in phase 1 of project B, the email communication network was much more centralized (in this case O1 has a disproportional number of links in relation to the other organizations) than in project A of the same project phase. In other words, attending only to the first two phases of projects A and B, one can conclude that a more centralized email communication network, between the organizations that participated in open innovation projects, is associated with project failure outcome.

However, when analyzing phase 4, the same conclusion cannot be taken. In fact, there is no difference between the ATD value for both projects A and B, but project B failed, and project A succeeded. This means that this metric (ATD) is no longer suitable for identifying differences regarding the interactional collaborative dimensions (the search of repeatable behaviors) between projects that were successfully delivered and projects that were unsuccessfully delivered. In this case, a new metric, based on centrality SNA metrics, should be applied.

Throughout this brief application case regarding Projects A and B illustrated in Figure 2, it is clearly demonstrated, first, how dynamic relationships (networks of collaboration) between interacting entities organized in any network form can be quantitatively measured, regardless of the size of the network, and second, how conclusions can be outdrawn regarding the association between quantitative dynamic behaviors and project outcomes (success or failure).

Furthermore, the proposed model in this work is aligned with the findings from Pinto and Slevin [42], as they stated that project critical success factors change the importance degree, according to the project phase of a project lifecycle.

3.3. OI-RM Project Success Profile and Project Failure Profile

Continuing with the example illustrated in Figure 2, if the project lifecycle of both open innovation projects A and B were the average result regarding the number of organizations, and the number of email communication channels that existed in each phase of a set of analyzed open innovation successfully and unsuccessfully delivered projects, one could say that repeatable behaviors would have been found, regarding the email communication network. In other words, the resulting project lifecycles presented in Figure 2, would not represent the email communication of one project, rather of a set of projects delivered, which would be called as OI-PSP (open innovation project successful profile—for the project lifecycle (a) of Figure 2), and OI-PFP (open innovation project failure profile—for the project lifecycle (b) of Figure 2). In this case, one could say that critical success has been identified regarding the email communication network, with a measurable value associated to them. Furthermore, function of the number of analyzed delivered projects, one could talk about a certain working open innovation collaborative culture.

3.4. OI-RM Model Application Span

The proposed model in this work (OI-RM) is not limited to a certain number of ***project phases*** of a project lifecycle. For the example of Figure 2, a four-phase model project lifecycle was adopted. However, the number of project phases of projects to be analyzed by the proposed model must be the same for both successfully and unsuccessfully delivered open innovation projects. The proposed model was designed to be applicable, regardless of ***project size and complexity***. The ***project organization-competencies*** are not limited to those mentioned in Table 4, as long they are well defined for both successfully and unsuccessfully delivered projects. Still, the model does not preview a maximum number of project ***organizations*** that take part in in the different phases of open innovation project lifecycles.

3.5. OI-RM Model Part 1 and Part 2

The proposed model in this work has two parts (Figure 3). In part 1, the model aims to identify open innovation project critical success factors, and in part 2, the model provides guidance and estimates an outcome likelihood of an ongoing open innovation project, by comparing the deviation between the real, and the and the desired evolution of the ongoing project, based on identified project critical success factor in pat 1. To be able to run part 2 of the model, part 1 of the model needs to be previously run. This means, critical success factors must have been previously found, otherwise, part two of the model has no effect so ever.

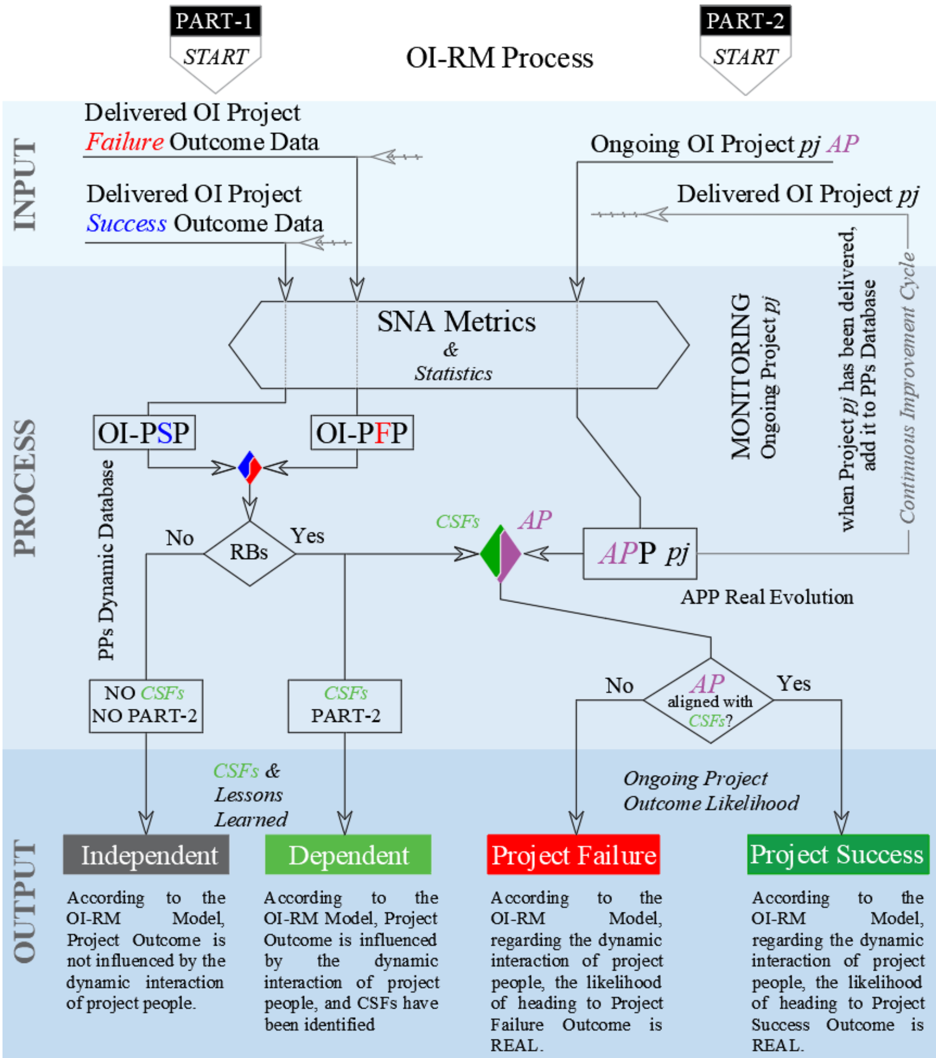

Figure 3. OI-RM model process for both Part 1 and Part 2.

A framework for both part 1 and part 2 of the proposed model is illustrated in Figure 3. To properly understand how the proposed model functions, Figures 3 and 4 should be interpreted in parallel. In Figure 3, the model process of the OI-RM model is illustrated, divided in three main blocks. They are Input (which relates to the necessary data that will be analyzed by the proposed model), Process (which relates to the mathematical and statistical operations of the proposed model), and Output (which relates to the quantitative results and conclusion provided by the proposed model). In Figure 3 on the left side (PART-1 START), the process for part 1 of the proposed model is illustrated. First, delivered OI (open innovation) failure and success outcome data—arising from project email information-related and project meetings in each phase of delivered project lifecycles (Figure 4)—is collected from a set of delivered projects and undergo a process of analysis by the application of social network analysis metrics and statistics (Figure 3). After all introduced projects have been quantitatively analyzed, they follow the average process of creating a OI-PSP (open innovation project success profile), and a OI-PFP (open innovation process failure profile), which represent in average, the repeatable behaviors of all analysis of successfully and unsuccessfully delivered projects.

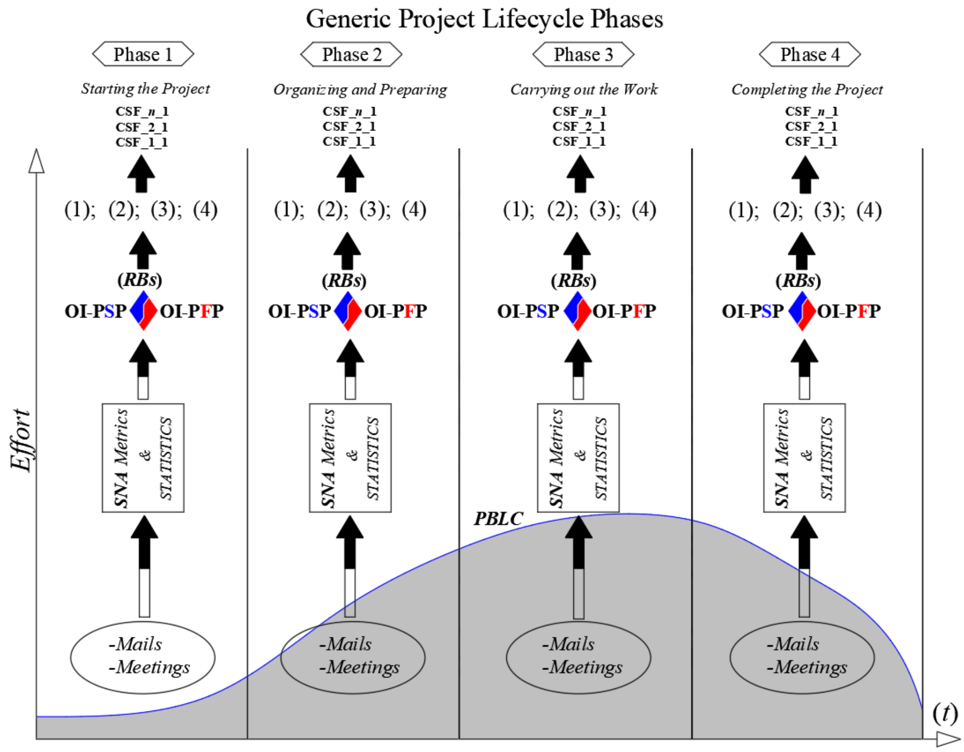

Figure 4. OI-RM Model—Part 1 and 2 Process, for Success, and Failure open innovation project outcomes. Source: Adapted from PMI, 2017 [40].

Next, the averaged repeatable behaviors from all successfully delivered projects will be compared with the averaged repeatable behaviors from all unsuccessfully delivered projects, and if unique differences between successfully and unsuccessfully delivered projects, regarding the four interactional collaborative dimensions have been found, then open innovation project critical success factors have been identified (Figures 3 and 4). If not, the conclusion to be taken is that, according to the proposed model, the dynamic collaborative interaction between the different organizations that participate across all the different phases of an open innovation project lifecycle do not influence a project outcome. In other words, they are independent. At this point, part 1 of the model is concluded. On the right side of Figure 3 (PART-2 START) part 2 of the proposed model is illustrated. At this point, it is only meaningful to go further, if previously critical success factors have been identified. In part 2 of the proposed model, the objective is to use the identified critical success factors identified in part 1 of the model to provide guidance across the evolution of an ongoing open innovation project.

First, at an ongoing project *pj*, one must to define in which project phase the ongoing project is, run the model for the collected data until the actual point that defined the present status of the ongoing project (AP), and run the comparison between the critical success factors for the respective project phase to be analyzed, and the results obtained for the AP point of the ongoing project. By the same analogy, the resulting measurable outputs for the AP point, represent an actual ongoing project profile (APP). If the results of the comparison show, that the evolution of the ongoing project at AP point, regarding the four interactional collaborative dimensions, are aligned with the critical success factor previously identified, that the conclusion to be taken is that the likelihood of heading to a successful project outcome is real (Figure 3). If not, then the likelihood of heading to an unsuccessful outcome is real, by opposition. After the project *pj*, is delivered, it undergoes once more through the all analysis process, and the results will be added to the project profiles dynamic database (PPS dynamic database), contributing for the refinement of the identification of critical success factors.

This last step is previewed by the model as the continuous improvement cycle (Figure 3). Although in the present work is not objective to demonstrate the process of estimating an open innovation project outcome likelihood, the outcome likelihood will be estimated by applying a simple averaging mathematical process, which essentially is based on the highest percentage of metrics indicating success or failure outcome. In other words, the more metric results–for an ongoing open innovation project–are aligned with the critical success factors identified in part 1 of the model, the highest is the success outcome likelihood for that ongoing project.

3.6. OI-RM Model Requirements

In Table 5, are illustrated the required open innovation projects information to be collected regarding mails and meetings projects, that are needed as input to the proposed model. Project meetings refer to any type of F2F meetings, that occur in each phase of a project lifecycle. Project mails, refers to all the project email information-related data, that was exchanged between the different project organizations, in each phase of a project lifecycle.

Table 5. Required information for input to the IO-RM model.

	Open Innovation Projects Information
Project Meetings	- Total number of project meetings occurred in each open innovation project phase, across a project's lifecycle - Total number of participating organizations in each open innovation project meeting, in each project phase, across a project´s lifecycle - Organization Project Official Competency, from each of the participating organizations across an open innovation project lifecycle
Project Mails	- Total number of emails sent/received in each phase of an open innovation project, that relate to project information data related to. - Organization Project Official Competency, from each participating organization that sent/received emails project related information. - Chronological Mail Exchange Time (send/received/answered) - Categorize emails according *: ○ Mails sent in seeking for help, or advice regarding project information related matter ○ Mails sent, providing help, or advice, regarding project information related matter

* Mails need to be identified and characterized, either by their subject or content, as being seeking mails type, or providing help mails type.

3.7. OI-RM Model four Interactive Collaborative Dimensions (4-ICD) and Respective Metrics

As previously mentioned, the proposed model in this work, will look for repeatable behaviors that are associated with successful, and unsuccessfully delivered open innovation projects, in four different dimensions (Table 6). These dimensions, named as interactive collaborative dimensions (4-ICD), that usually occur between organizations across a project lifecycle, are described in Table 6, as well as which SNA centrality metrics will be applied.

Table 6. The four interactive collaborative dimensions (4-ICD) of the IO-RM model.

(a) Key Project Organization Communication and Insight Degree	Description and Objective: How does important project organizations (function of their competency across the accomplishment of an open innovation project) present at the in-project meetings and emails networks, and to which extent their presence influences a certain project outcome. Regarding Meetings: How the presence of those important project organizations in project meetings, triggers communication and insight on what is ongoing throughout the different phases of a project lifecycle, namely at the transitional phase of the different project phases. SNA Metric: For this case, the *total-degree* (C_{DT}) [45] SNA metric will be applied, to first measure the project meetings participation degree of each participating organization in each open innovation project phase. $C_{DT}(n_i) = \sum_j x_{ji}$ Where: C_{DT} = total degree of an entity within a graph n = total number of entities within a network (graph) for $i = 1 \ldots ,$n x_{ji} = number of links from entity j to entity i, where $i \neq j$, and vice-versa. After having all the total degrees for each participating organization, a linear regression will be applied to characterize the evolution within a given project phase. There are three possible outcomes. They are 1- Negative evolution: characterizes a decreasing participation degree as a given project phase heads to its end. 2- Positive evolution: characterizes an increasing participation degree as a given project phase heads to its end. 3- Neutral evolution: characterizes a stable (continuously) participation degree as a given project phase heads to its end. Regarding Mails: How cohesively is the mail communication network? Are email communication channels open to all the organizations that participate in project activities across all different phases of a project lifecycle? SNA Metric: For this case, the *density* (***Ds***) [45] will be used, to characterize the amount of existing email communication channels that exist between the different organizations that participate in open innovation projects. $\boldsymbol{Ds} = \frac{N_{L\ REAL}}{N_{LMAX}}$ Where: Nr of Maximum Possible ties = $N_{LMAX} = \frac{n(n-1)}{2}$ n = number of entities within a graph The outcome for this metric is: (a) Full density: characterized by an email communication network that reaches all the organizations that participate in a project (b) Relative density: ratio between all possible email communication channels, and existing email communication channels.

Table 6. *Cont.*

(b) Organizational Control Degree	Description and Objective: To which extent does a given organization controls and holds "power" over the email communication network, in terms of send/receive project information related. Regarding Mails: How is the volume of mail communication between the different participating organizations in open innovation projects? Who holds the most volume of email communication related to project information data? SNA Metric: For this case, the *In-degree*, and *Out-degree* ($\boldsymbol{C_{OT}}$) [45] will be applied in order to identify which organization holds control over the email communication network. $C_{OT}(n_i) = \sum_j x_{ji}$ Where: $\boldsymbol{C_{OT}}$ = total out-degree of an entity within a graph n = total number of entities within a network (graph) for $i = 1 \ldots$,n x_{ji} = number of links from, only entity j to entity i, where $i \neq j$. The output for this metric, is: (a) Full control: organization holds completely control over the email communication network across a project phase. (b) Average control: several organizations hold control, over the email communication network across a project phase.
(c) Project Information Dependency Degree	Description and Objective: To which extent, does the project-related information, provided by one organization to other organization is recognized as important and decisive to enable evolution in project activities? What is the degree of dependency of a given organization regarding to another organization in order to accomplish project activities or tasks? Regarding Mails: How is the volume of emails sent seeking vs providing vital information to project activities? SNA Metric: For this case, will be used the *Out-degree* ($\boldsymbol{C_{OT}}$) (4) and the *Average degree* ($\boldsymbol{A_D}$) [45], will be applied, which will characterize how much a given organization is dependent on other organization to accomplish project activities. Average Degree: $A_D(n_i) = \frac{\sum_j x_{ji}}{n} = \frac{\sum_{i=1}^{n} C_{OT}(n_i)}{n}$ Where: $\boldsymbol{A_D}$ = Average degree n = total number of entities within a network (graph) The output for this metric is: 1- Total dependency: characterized by an organization that receives input from other organizations for all activities that respects an open innovation project. 2- Shared dependency: characterized by the existence of several organizations that receives input from other several organizations for all activities that respects an open innovation project.

Table 6. *Cont.*

(d) Feedback Readiness Degree	Description and Objective: To which extent, does the speed of answering emails by providing or seeking project information related, influences project outcome? Regarding Mails: How fast or how slow is the speed of answering a request from an organization to other organization? Analyze the volume of emails sent/received crossing them with the chronological time. SNA Metric: For this case, first the *reciprocity* (***R***) [45] will be used to analyze which emails were answered providing project information related, and second, the chronologic time associated to each pair sent/received. $\boldsymbol{R} = \frac{L^{<->}}{L}$ Where: $L^{<->}$ = Number of links pointing in both directions $L = total\ number\ of\ links\ within\ a\ network$ The output for this metric is: • An average value, in hours, ranging from "1" (meaning an instantaneous answer reply has been made in less than 1 h period of time) up to a maximum of the project time duration "0", for cases where feedback is not to be found, across the lifetime of a project.

3.8. IO-RM Model Implementation Process

In Figure 5, is illustrated the implementation process framework of the proposed model for both, parts 1 and 2. The framework illustrated in Figure 5, is details the implementation process for project phase 1, however the process is not exclusively of phase 1 of a project, rather is to be fully replicable for all different project lifecycle phases across the PBLC (project baseline curve), which represents the planned project evolution. In Figure 5 are represented the project meetings chronology, and emails that were exchanged within phase 1 of project-phase 1. Project meetings and emails must be documented, as previously seen, according to Table 5. At the beginning of each project phase, a formal Competencies Chart (displayed at the left side, above the first project meeting (E1) in Figure 5), must be defined, where all the organizations that are assigned to take part of the activities of an open innovation project, have well defined project competencies and responsibilities. Organizations can have different project competencies, as previously seen, such as those in Table 4. In Figure 5, are illustrated six open innovation project meetings, that did occur across phase 1 of the illustrated project. These project meetings, or events (E) are represented by E1, E2, E3, E4, E5, and Et, where Et–for the case of Figure 5–can represents the sixth project meeting.

Project Meeting E1, was the first meeting that did occur within phase 1 of the project, and project meting Et represents the last project meeting of phase 1. For example, at meeting E1 (left red marked dot in Figure 5), three organizations were present. They are O1, O2, and O3, which represent competencies a, b, and c respectively. The lines that connect the three organizations, inside each box above each project meeting (Meetings), represent the relationship degree between them, regarding the pairwise meetings participation degree across the phase 1 of the illustrate project. For example, in project meeting 1, as it is the first time that O1, O2, and O3 are together in any project meeting or the project illustrated in Figure 5, they have a line with value 1× (relationships degree box). In project meeting E4, organizations O1, O2, and O3 have degree 4×, because is the fourth project meeting that they participate together. The boxes above the Meetings boxes ($\sum$ ***Emails***), represent all the project information related exchanged emails between the period of any two project meetings. The lines represent the email communication channels. For example, between project meetings E1, and E2, organizations O1, O3, O4 and O6, are almost all connected through the email communication network, except for O1 and O6.

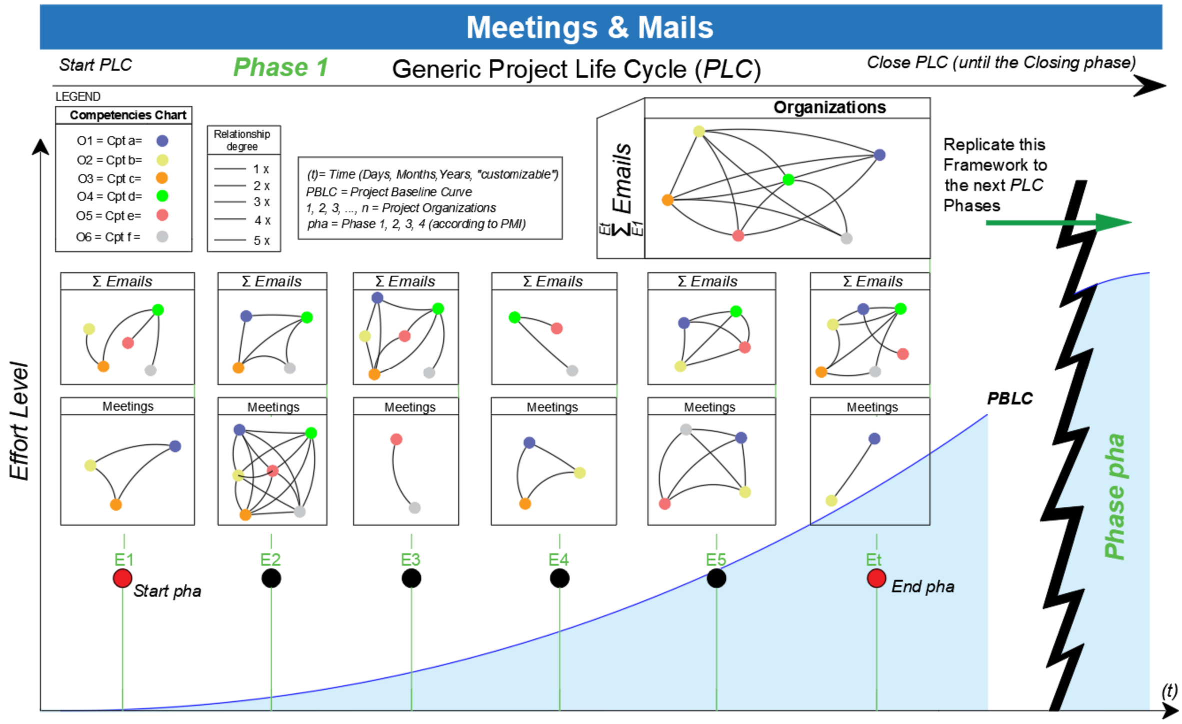

Figure 5. Implementation Timeline Framework of the OI-RM model.

At the end of each phase of a project lifecycle, all the project information related exchanged emails must be collected (∑ ***Emails***), as it is illustrated in Figure 5 at the box above the last project meeting E6 (Et). The end of a project phase may be determined by a last project meeting or by an open innovation project milestone. The process above described–related to Figure 5–is to be replicated throughout all the other project phases of a project lifecycle.

3.9. IO-RM Legal and Ethical Considerations

The proposed model in this work, accesses, and analysis open innovation project related information that flows across the different project organizations throughout the different phases of a project lifecycle. Such project information is very often considered confidential and therefore not desired to be accessible and exposed to the exterior of organizations. This aspect may represent a constraint to the implementation of the proposed model. Therefore, the effective implementation of the proposed model in this work may be dependent on the acceptance of the competent authorities at the organizational and nation level that manage the legal and ethical respective data protection issues. Nevertheless, it is expected that all the project organizations that participate in an open innovation project that will be supported by the proposed model should be informed of it, before the collaborative project starts.

4. Conclusions, Implications, and Further Developments

The proposed model in this work, aims to quantitatively identify project critical success factors regarding the dynamic behavioral interactions between the different entities that participate across the different phases of a project lifecycle in a collaborative network context such as the open innovation model. The proposed model in this work was developed based on four scientific fields: (1) Collaborative Networks, (2) Project Management, (3) Risk Management, and (4) Social Network Analysis, integrating in a holistic way the individual proven benefits for organizations from each of the four scientific fields, essentially regarding performance and innovation. Concretely the proposed model has two parts. In part 1, the model will analyze and quantitatively measure those dynamic behavioral interactions through the application of social networks analysis centrality measures, using data arriving form project meetings and project email exchange, from successfully and unsuccessfully delivered collaborative projects, searching for repeatable behaviors associated to each of the outcomes (success or failure). In part 2, the proposed model offers a framework that provides guidance to an ongoing collaborative project. Here, the proposed model measures the deviation between the real evolution of an ongoing project against a desired (planned) evolution of the ongoing project, having a criteria the identified critical success factors in part 1 of the model.

4.1. Proposed Model and Researched Literature

The proposed model in this work has as main aim to provide organizations with a model to support the management of collaborative network projects, such as the open innovation system, where the lack of such models is pointed out as the major obstacle [23] for organizations to more often engage in collaborative network project models. The model addresses two of the most important risks in collaborative network projects as proposed by [24] and [41], which are detailed in chapter 2 of this work. They are (1) collaborative risks [24] (comprised by a subset of risks such as critical enterprises risk, assigning tasks to partners risk, and behavioral risk) and (2) ambiguity risks [41], also known as "epistemic uncertainty", where uncertainties essentially arise from lack of knowledge or understanding. According to [24] and [41], both risks (collaborative and ambiguity) can effectively be managed by consulting project lessons learned and undertaking simulations to systems before implementation on the field.

The proposed model in this work provides valuable and unique insight into those dimensions by, first, identifying in a quantitatively way invisible dynamic behavioral interactions that cannot be fully understood by traditional statistical tools and techniques, which will later enable to monitor and simulate the evolution of a system, which in this case is the project social network.

Furthermore, the proposed model also addresses one of the most trendy subjects that organizations currently face—the organizational transformation through digitalization—defended by several authors [7,12,20,31] and known as well by industry 4.0 [32], which argues that organizations need to change the way they think and do work, addressing organizational processes, procedures, and mindsets transforming themselves into adaptable machine learning systems, through formal and informal networks of collaboration.

The proposed model in this work also addresses this subject as—once properly implemented in organizations—a continuous improvement cycle (Figure 3, Process) takes place, regarding the refinement of the identification of critical success factors process in collaborative projects, as it is demonstrated in chapter 3 of the present work.

4.2. Managerial Implications

In a nutshell, the key findings in this work, essentially regard the demonstration of the applicability of the proposed model in detecting (in a quantitatively way) dynamic interactive behavioral patterns associated to unsuccessful and successfully delivered projects, run under a collaborative network model approach such as the open innovation model, by essentially measuring communication and information flow exchange between the entities (organizations) that comprise a collaborative project social network, across the different phases a project lifecycle.

The proposed model in this work, provides organizations with a valuable historic picture regarding how collaboration between the different organizations that did participate in collaborative network projects occurred, across the different phases of a project lifecycle. In other words, the model provides organizations with a dynamic lesson-learned knowledge- base, which enables them to learn from past experiences (failures and successes) regarding which dynamic behavioral interactions are associated with success or failure project outcomes.

From a macro perspective, the continuous application of the proposed model in this work in organizational collaborative network projects, such as open innovation, will help organizations to identify and quantify different collaborative working cultures that emerge as they work in collaborative network models, enabling thus to identify which collaborative working culture is more effective regarding organization performance and innovation.

There are still other advantages that the proposed model offers from a micro perspective, compared with other HR people analytics models, where the data to model and analyze organization performance is usually collected through pulse survey or 360° questionnaire approaches. In this dimension, the data collecting method of the proposed model in this work is almost completely bias-free and eliminates organizational down-time as organization members do not need to answer performance and quality pulse surveys regarding how collaboration occurred when they worked in an open innovation project environment.

The identification of project critical success factors is a mathematical process, with quantitative outcomes. From a management perspective, where managers need to take decisions most of the time based on quantitative approaches expecting to improve the quality of results (performance and innovation), the proposed model in this work, by outputting quantitative results regarding the interactive dynamic behavior of the different entities that participate in collaborative network projects, enables organizations to quantitatively understand the effect of such dynamic behavior in organizational outcomes and to craft strategies and take actions in a more data-driven way, rather than traditional approaches essentially based on gut feeling and key influencers' opinions.

Still, from a managerial perspective, the model provides the organization with another benefit related to the actual trend, working through collaborative networks. By quantitatively analyzing the influence that the blur of formal and informal networks of collaboration in successfully and unsuccessfully delivered projects, it provides managers with a unique insight into the real importance of essential informal networks of collaboration, enabling them to take appropriate action in order to support, maintain, or even foster collaborative network dynamics that are associated with successful outcomes.

Finally, the proposed model in this work aims to provide organizations with a much clearer insight regarding how organizations can benefit from the integration of relational data (data that quantitatively mirrors the dynamic network relationships between entities in collaborative network projects) into their organizational strategic management processes or frameworks, where an effective implementation of the proposed model in organizations will enable them to do more with less, thus contributing to the achievement of sustainable competitive advantages.

This means that, as the proposed model in this work enables organizations to better plan and manage their organizational collaborative networks (by understanding and identifying the critical factors that drive successful project outcomes), organizations reduce or eliminate risks associated with collaborative projects (collaborative risks), which in turn optimizes resource usage, orienting organizations towards being leaner, which ultimately will contribute positively to economic, social, and environmental sustainability.

4.3. Suggestions for Future Research

The implementation of the proposed model in organizations can be a challenge to them. This may occur essentially because organizations need to access to the right technology and the employment of a working culture, as they work through collaborative networks, that enables necessary data to the proposed model in this work, to be recorded as previewed in Table 5. Creating and implementing an automated process that collects the necessary data to the proposed model demands appropriate technology that may not be at reach for most organizations.

Here, further research should be undertaken, in order to develop a system that can be efficiently implemented in organizations where data can be properly collected and the impact to the working culture be minimized as much as possible so that the collected data mirrors as much as possible how really collaboration occurs.

The proposed model in this work only collects data from project meetings and emails. However, much project related information flows through other communication and collaboration channels such as phone calls, instant messaging, corridor meetings, and so on. Essentially, due legal constraints, the collaboration done thought these other mentioned channels is not captured by the actual proposed model. Here, further research should be undertaken to develop new data collection methods in order to be able to filter personal from professional interactions as entities participate in collaborative projects, so that collaboration done through those other channels mentioned should be able to be captured and analyzed.

Finally, it is suggested that research should be continuously undertaken regarding the development of new social network analysis metrics that can complement existing metrics to better identify, measure, and understand dynamic behavioral patterns that occur as organizations engage in collaborative network projects.

Author Contributions: Author M.N. carried out the investigation methodology, writing—original draft preparation, conceptualization, the formal analysis, and collected resources. Author A.A. contributed with the conceptualization, writing—review and editing, the supervision, and final validation. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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