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# Managing Collaborative Risks of Integrated Open-Innovation and Hybrid Stage-Gate Model by Applying Social Network Analysis—A Case Study

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**Abstract:** It is often argued that efficient collaboration is the key to success. However, research shows that if collaboration is not properly managed, collaborative risks may emerge, threatening business success. Furthermore, research shows that there is a lack of models to support the management of collaborative initiatives in organizations. To address this lack, presented in this work is a model to manage collaborative risks in organizations that work under the open innovation and the hybrid stage-gate development frameworks (two of the most popular collaborative frameworks in product and process development). The model presented in this work is a novel approach to manage collaborative risks in the open innovation and the hybrid stage-gate frameworks, and was developed based on network graph-theory to be used to identify informal collaborative interactions that may lead to the emergence of three major collaborative risks: (1) partner choice risks, (2) task assignment risks, and (3) behavioral risks. The results of the application of the proposed model in a real organizational collaborative context illustrated in the case study show that such collaborative risks can be identified in a timely manner, enabling an organization to efficiently and preventively act to minimize or eliminate the undesired effects of the mentioned collaborative risks.

**Keywords:** collaborative risks; open innovation; sustainability; network graph theory; product development; stage-gate; project management; case study

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## 1. Introduction

In today's disruptive business landscape, achieving and holding sustainable competitive advantages—even in well-established firms—can be very challenging. Nevertheless, there seems to be a way to increase the odds of success. Much research shows that effective collaboration within and between organizations is the key that leads businesses to success [1,2]. However, factors such as inadequate market analysis, lack of commitment, lack of models to manage collaborative risks, poor leadership, or poor marketing strategy may lead collaborative initiatives to fail [2].

Although there are many well-known factors that may lead an organization to achieve success, such as the adoption of one or more of the generic strategies ((1) leadership cost strategy—low costs of production, offering the lowest prices in the target market segment; (2) differentiation strategy—offer different, unique, and added-value products or services to customers that distinguish them from competitors; and (3) hybrid strategy—combining leadership cost and differentiation strategies to answer the increasing competition brought by turbulent and disruptive changes in industries and markets) [2–4], the adoption of an ambidextrous organizational leadership style [5–7], and innovation boosted by diversity and inclusion [8,9], there is one factor that overweighs all the mentioned ones—the ability to work in networks of collaboration (also known as the relational dimension, which includes both intra- and inter-collaboration); in other words, the ability to efficiently collaborate within and between different organizations [10–12]. Much research shows that the ability to work in collaborative networks is a higher success predictor than individual competencies, skills, and know-how, especially if fueled with positive energy and diverse problem-solving skills efficiently distributed across different organizational functions, geographies, and technical expertise domains [13–15]. Such relational dimensions, that include communication, internal and cross-boundaries collaboration, creating and diffusing know-how and know-what, problem-solving networks, informal key people, and the interactions between a changing project team set, are of greater importance to achieve success than, for example, non-relational factors such as work planning, budgeting, client consultation, experience, accountability, urgency, clear responsibilities, or the availability of human resources or even lessons learned. Because organizations alone very often do not have the necessary resources to execute innovation initiatives, they engage in collaborative networks, such as public institutions, universities, development centers, individual experts, and even competitors (usually known as coopetition), to generate and develop disruptive ideas and, thus, increase the chances of successful innovation initiatives [11,13,14]. In fact, history shows that working in collaborative networks is the key for success. For example, in one of the most inventive eras in the history of humankind—the Renaissance—the Medici family in Italy brought together people from a wide range of disciplines, such as sculptors, scientists, poets, philosophers, painters, and architects, to promote the exchange and development of new ideas, resulting in breakthrough innovations, in fields such as humanism, arts, science, navigation, and technology, just to name a few, which ended up spreading across Western Europe and the world [16]. Another example comes from one of the greatest inventors of all time—Thomas Edison—where the majority of inventions credited to him and his achievements were in fact the result of long hours of tenacious work and development from a cohesive and diverse group of people which Edison coined as "muckers" [16].

Research shows [15,17,18] that organizations that effectively work in collaborative networks achieve better and more sustainable results across the whole innovation process than those that do not. These results include benefits such as the reduction of innovation costs, faster innovation processes, an increase in differentiation, and easier access in different markets, just to name a few [18]. Such a collaborative approach is characteristic of an innovation model known as the open innovation model [17]. Furthermore, research in physical product development (PPD) [19–22] suggests the integration of the Agile methodology into the most widely used control process in new product development (NPD), the stage-gate framework –, resulting in the hybrid stage-gate model [23–25]. This integration brings additional benefits to the open innovation model such as faster product releases, better response to customer change requirements, and improved team communication and morale across the innovation process [25].

However, research also shows that the lack of models to support and guide collaborative initiatives drive organizations away from engaging more in collaborative networks, hindering them from profiting from the potential benefits such an approach may offer [17,19,20]. Research also shows that collaborative initiatives may be threatened by three very popular collaborative risks if these are not properly managed by an efficient model. These include: (1) partner choice risks, (2) task assignment risks, and (3) behavioral risks [19–22,26]. In fact, this is in line with recent research [21,22] that shows that organizations that adopt a more hands-off approach in open innovation projects (less control over collaborative networks due to the non-application of a collaborative management model) achieved lower success rates than those that adopt a more hands-on approach (the use of a collaborative management model).

The objective of this work is to propose a model to manage the mentioned collaborative risks that may emerge as organizations engage in collaborative initiatives under the open innovation and hybrid stage-gate frameworks and, thus, contribute to bridge the gap of the lack of proper models to manage organizational collaborative initiatives. The approach proposed in this work materialized by the model below presented has its foundations in three major dimensions. First, the adoption of the hybrid stage-gate framework (from the family of the waterfall project management methodology) to structure the different phases of the joint work (innovation initiatives) represents today's most adequate approach to manage work progress and monitoring of the deviation between planned work and achieved work for a given time frame, namely in physical projects (2, 12, 21). Furthermore, the hybrid aspect of the framework already includes the adoption of some aspects of the Agile methodology, namely the interactive working mindset aspect, which has been credited as the major factor of a high project success outcome (12, 21, 23). Second, the adoption of the open innovation model as the approach that enables the controlled emergence of dynamic interactions between different parties that take part in a joint work initiative (innovation initiative) is one of the most efficient models to promote and boost a collaborative mindset between the involved parties. Although there are some known limitations of the model, if properly managed, the model promotes the generation of combined ideas and facilitates communication, the exchange of necessary information in a timely manner, the share and acquirement of necessary resources, and the share of risks and benefits for the involved parties (13, 18, 20, 24, 25). Finally, the use of graph-based theory (SNA for short) is the only efficient tool that is able to map dynamic interactions between elements that work together within a time frame (1, 2, 12, 14). This is because the graph-based theory is the model that better represents the way entities, such as people, organizations, countries, animals, and so on, interact (communicate, exchange information, exchange know-how and know-what, provide professional and personal support, and so on) by laying out in a mathematical dimension both the sender and receiver (the entities) and the respective channel (interaction) whereby the message is conveyed. This enables efficiently understanding how the interaction between any two entities occur and as consequence of this, how to develop strategies to manage such interactions; in other words, what can be measured can be managed!

The proposed model in this work quantitatively identifies trends in the interactions of project stakeholders that may lead to the emergence of such mentioned collaborative risks by the application of social network theory using graph-centrality metrics [11,14,21], such as in-degree, out-degree, betweennesses, reciprocity, density, and average degree. The proposed model in this work (Figure 1) named 4-Open-Innovation (4-OI) is divided into four parts (P1, P2, P3, and P4). The model enables a holistic management structure type of the whole typical collaborative innovation process that results from the integration of the hybrid stage-gate model (recognized in Figure 1 by the several stages between gates (G) across the parts 2, 3, and 4) and the open innovation model (recognized in Figure 1 by the use of internal and external technology base sources in part 2 (blending), and the outcomes that may occur across the process in part 3 and 4).

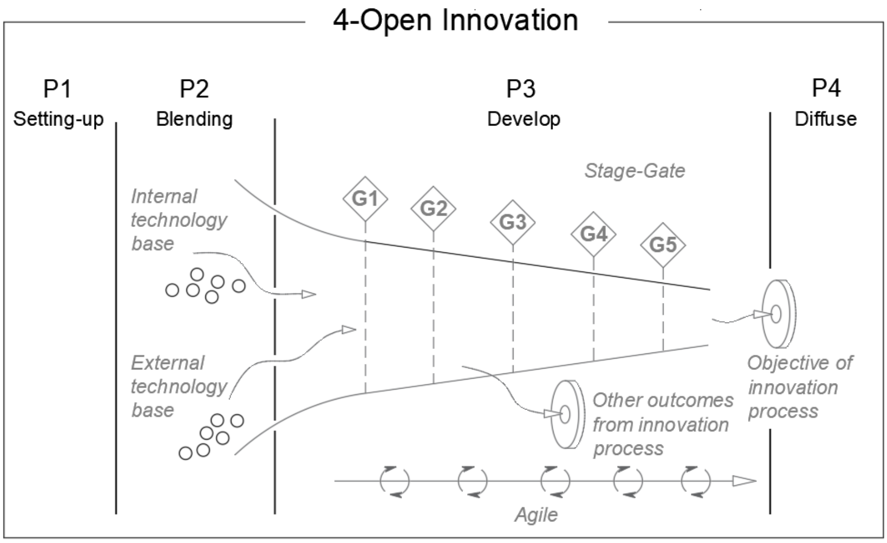



**Figure 1.** The 4-Open-Innovaiton model integration.

The 4-OI model is divided in four parts. They are: part 1 (P1, setting up), where the innovation dimensions and partners are selected; part 2 (P2, blending), where legal aspects and task assignment to the selected partners are agreed and defined; part 3 (P3, developing), where the core innovation development takes place; and part 4 (P4, diffusing), where the adoption rate of the resulting product or process is forecasted. Table 1 illustrates the relationship between the different parts of the 4-OI model, the three mentioned innovation collaborative risks, and the SNA centrality metrics used for each of the four 4-OI model parts.

**Table 1.** The 4-OI model- innovation parts, collaborative risks, and SNA centrality metrics.

| | Parts | Risks | Brief Description | Centrality Metrics |
|---|---|---|---|---|
| 4-OI | Part 1: Setting-up | (1): Partner choice risks | Concerns the risk associated with choosing the right partners to engage in innovation initiatives regarding their credibility, competencies, or skills. | In-degree |
| | | | | Out-degree |
| | Part 2: Blending | (2): Task assignment risks | Concerns the risk associated with the assignment of innovation process tasks to chosen innovation partners. | In-degree |
| | | | | Betweenness |
| | Part 3: Developing | (3): Behavioral risks | Concerns risks associated with the intra- and inter-cross-functional communication, information-sharing, and control across the innovation process. | In-degree |
| | | | | Reciprocity |
| | | | | Density |
| | | | | Average degree |
| | Part 4: Diffusing | | Concerns the forecasting of the adoption rate of the resulting product or process. | Out-degree |

For each part of the 4-OI model, the quantity and types of graph-based centrality metrics vary in the function of the type of the collaborative risk. For example, in part 1, the associated collaborative risk type is the partner choice risk. This risk type will be managed by the application of two graph-based centrality metrics, the in- and out-degrees. The data that will be analyzed by the graph-based centrality metrics will be collected in strategic surveys conducted in online platforms and in the open innovation project email communication networks.

The present work is divided into five chapters. Section 1 introduces the motivation and objectives of this work, framed in the context of the importance of collaborative initiatives in organizations. In Section 2, the main four areas that support the development of the model presented in this work are described, highlighting their importance in organizations and major contributions to the development of the proposed model. Section 3 presents the development that led to the proposed model in this work—the 4-OI model. Section 4 illustrates a real case application of the 4-OI model, demonstrating the application process and highlighting the benefits for organizations. Finally, Section 5 presents the major conclusions, the research and managerial implications of the proposed model, and enumerates some suggestions for future research.

## 2. Literature Review

### 2.1. Open Innovation

The word innovation comes from the Latin word "innovare", which means new, or the introduction of a new idea, methodology, product, or process [27,28]. Innovation can be defined as a response to an organizational change [29], and usually, is not a single action, rather a total process of interrelated sub processes, such as the conception of a new idea, the invention of a new device, and the development of a new market [30]. In fact, not every invention is innovation. An invention is a solution to a problem, and an innovation is the successful commercialization of that solution [31,32]. More concretely, an invention is turning money into ideas, and innovation is turning ideas into money [33,34]. There are several ways to characterize innovation types, such as long-term vs. short-term, research vs. advanced development, leap vs. stepwise, and so on. Though there is no consensus regarding the different dimensions of innovation [34,35], in this work, innovation is categorized in three different dimensions. They are: (1) outcome, (2) geographical, and (3) degree. They are illustrated in Figure 2.

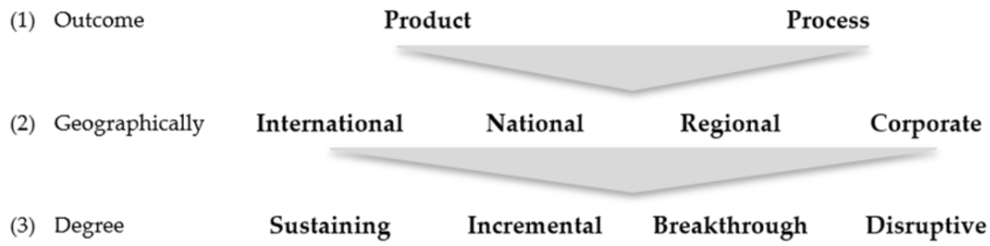



**Figure 2.** Innovation generic dimensions.

Innovation can result either in a product (new ideas, technologies, goods, services, or business models) or a process (the steps through which a given result is achieved, such as improvement of organizational internal processes, new production techniques, new marketing strategies, and so on) [32,36,37]. Innovation can be done at international (working with external markets or with international network communities for the development of products and services of international markets), national (working with national institutes or partners for innovation development of products or services for the domestic market), regional (working with local regional clusters partners for the development of local or regional innovative products or services), and corporate (specialized organizational innovative departments or management bodies that determine organizational innovation strategies) levels [37]. Innovation can be defined as sustaining or regular (significant improvement on a product or process aiming to sustain an existing market position, targeting demands of high-end user customers by delivering better performance than the previous product or process), which is often invisible, but has huge effects on product or process cost and performance, being probably the most common innovation in the business world. Incremental innovation (occurs more or less continuously in any industry or business, although at a varying rate over different periods of time) is the result of well-defined improvements proposed by users or developers such as engineers or scientists. Breakthrough or bold innovation (discontinuous events resulting from delivered research and development in universities or government laboratories, which usually involves a paradigm shift) are unevenly distributed over sectors and across time, and often, arise by the arriving of newcomers which provide a different vision over a problem or challenge. Finally, disruptive innovation (disrupts and turns established technical and production competencies into obsolete ones), usually associated with small companies or startups that outperform large established companies, essentially by discovering ways to deliver more-suitable products functionalities at a lower price, is very difficult to spot because one does not know until they see it and most of the time, its value it is not immediately understood [38–41]. Innovation models are a description of how an organizational innovation architecture is designed to deliver innovative solutions that create and deliver value to their customers and the organization itself [35]. Innovation models can be divided into two major types [42–44]. They are: (1) linear and (2) interactive. Linear models were first developed in the in the late 1950s and aim to understand the relationship between science, technology, and the economy [45]. Linear models have been quite successful across many decades and are still today the object of many discussions regarding their benefits in today's business landscape [45]. However, linear models are incomplete and can even be misleading due to their simplicity in the way they describe and structure how innovation occurs [45,46]. Essentially, the linear model ignores the many feedbacks and loops that occur between and within the different stages of the innovation process, as it happens in real innovation [45,46].

Interactive models on the other hand, postulate that innovation comprises complex systems of disruptive and discontinuous events that involve networks of actors and sources [43]. Interactive models are characterized by non-linearity processes of innovation, which more accurately mirror how real innovation occurs. Interactive models are characteristic of the open innovation model working under the umbrella of the hybrid stage-gate framework. Table 2 illustrates the evolution of the different innovation models since the late 1950s until today [43,46–48].

**Table 2.** Evolution of models of innovation across time.

<table>
<tr><th>Model</th><th>Period</th><th>Type</th><th colspan="2">Description</th></tr>
<tr><td>Linear or Technology Push</td><td>1950s–1960s</td><td>Linear</td><td colspan="2">Simple linear sequential process. Emphasis on R&D and science exclusively. Innovation is essentially pushed by technology and science. No feedbacks (loops), no market attention, no networked interactions are included.</td></tr>
<tr><td>Market Pull or Need</td><td>1960s–1970s</td><td>Linear</td><td colspan="2">Simple linear sequential process. Emphasis on marketing. The market is the source of new ideas for the R&D. Characterized by having no feedbacks (loops), no market attention, no networked interactions.</td></tr>
<tr><td>Coupling</td><td>1979</td><td>Mixed</td><td colspan="2">Combines push and pull models. Feedback and interaction of different elements are important to R&D and marketing. It has feedback between the different phases.</td></tr>
<tr><td>Interactive</td><td>1985</td><td rowspan="2">Interactive</td><td colspan="2">Combines push and pull models. Emphasis on external connections. Interactions take place with research institutions and markets (external connections).</td></tr>
<tr><td>Integrated or Networked</td><td>End of 1980s</td><td colspan="2">Simultaneous process with feedback loops also known as "Chain-linked Model". Emphasis on knowledge accumulation and external connections (extensive networking).</td></tr>
<tr><td>Networking</td><td>1990s</td><td>Interactive</td><td colspan="2">System integration and networks (SIN). Emphasis on effective communication with the external environment.</td></tr>
<tr><td>Open Innovation</td><td>2000s</td><td>Interactive</td><td colspan="2">Collaboration and multiple exploitation paths. Internal and external ideas can be combined to boost the development of new technologies and paths to market.</td></tr>
<tr><td>Extended Innovation Network</td><td>Under development</td><td>Not well defined</td><td>Interactive</td><td>Combines network models and open innovation. Complex network models applying SNA. Includes crowdsourcing and free innovation.</td></tr>
</table>

The move from linear to interactive models is in line with the importance that networks of collaboration have in the innovation process, as suggested by the literature [8–14,49]. In fact, this trend can be seen in actual forms of innovation such as crowdsourcing and free innovation, which have been gaining attention across the scientific community [50–52], and fits in the extended innovation network innovation model according to Table 2. Other models, such as the triple helix model [53] (Figure 3a), which eventually evolved to the quintuple helix (Figure 3b), have drawn particular interest in recent years because they integrate three different high-level actors (universities, industries, and government), with the aim that by a synergy effect, their combined value and performance will be greater than the individual sum of each one. The model advocates that the proximity between key actors in an innovation system increases collaboration between the different actors and is important for knowledge transfer, this being a major factor for successful innovation [54]. The triple helix model can be considered an open innovation model, as it captures the interactions between different innovation actors, transforming the university into one key actor in the innovation process on an equal footing with industry and government.

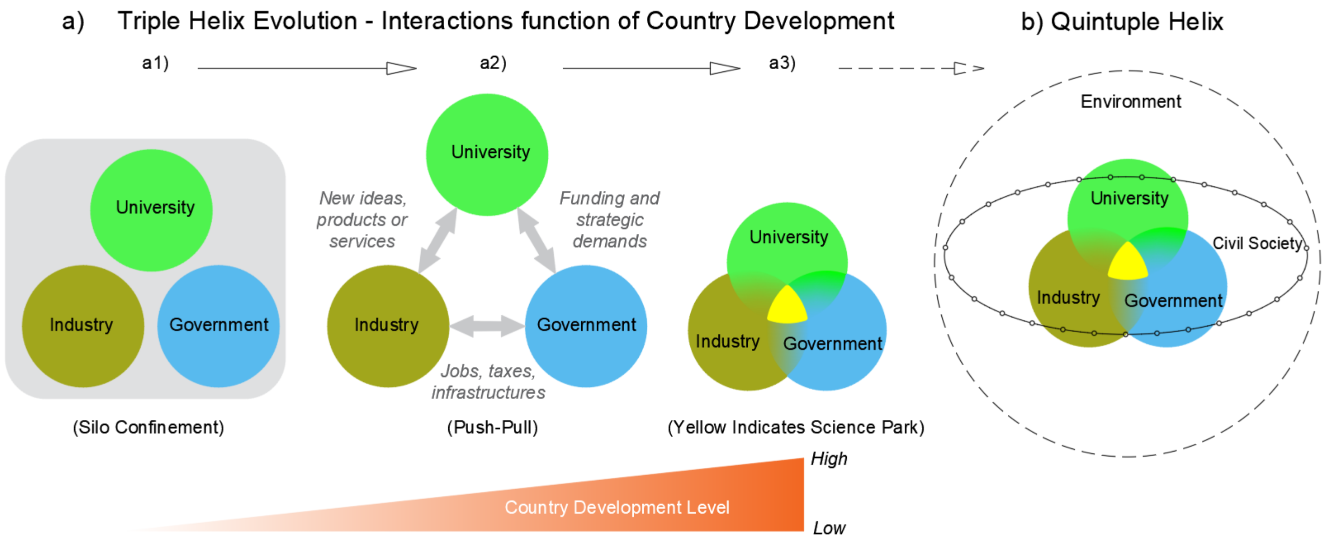



**Figure 3.** Triple Helix evolution across time (**a1**–**a3**) and Quintuple Helix (**b**) of Innovation.

Open innovation (Figure 4) is defined as the use of purposive inflows and outflows of knowledge and resources to accelerate internal innovation and expand the markets for the external use of innovation, respectively [18,55]. The idea behind the concept of open innovation is that we live in a landscape of abandoned knowledge and organizations should work together in networks of collaboration to share ideas, experiences, know-how, and technologies to generate value [56] that they could not generate if they worked isolated. Open innovation uses a wide range of internal and external entities to help organizations to achieve sustainable innovation behavior, benefiting organizations in two main dimensions: financial and competencies [19]. In Figure 4, the funnels (1) and (2) are the representation of an organization's generic R&D process. At the beginning of the funnel, there are many ideas and projects to be initiated, supported by the knowledge base of an organization (the intellectual capital of an organization). However, as the process goes from the laboratory to the market (at the end of the funnel), some ideas begin to be thrown away and projects become discontinued, usually resulting in a very small subset of outcomes (products or services) from what was initially started.

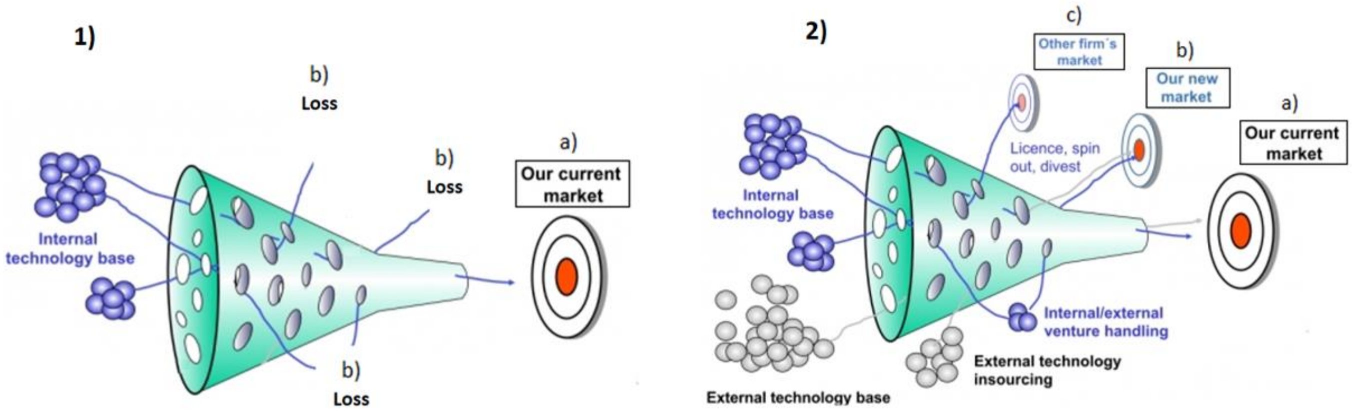



**Figure 4.** Closed innovation (**1**) vs. open innovation (**2**), adapted from [18].

In Figure 4(1) is represented a closed innovation model. In this type of model, only an internal technology base is used to the innovation process, holding organizations by themselves accountable to control the innovation process and intellectual property (IP) and *intermediary* discoveries (loss b in Figure 4(1)) that are not aligned with the objective of the innovation process which considered losses [55]. In Figure 4(2) is illustrated the open innovation model. In this model, an internal and external technology base is used, and the *intermediary* discoveries will be analyzed regarding the commercialization viability, either by creating new markets or making it available for other organizations markets. In this model there are two resources flow-type directions. They are [18]: (1) outside-in (an organization captures external knowledge or resources from business partners, customers, universities, scientific institutes, and public institutions to improve its innovation capacities or solve a problem), where the collaboration can occur through purchasing (buying intellectual property such as patents, copyrights, or trademarks from external partners), licensing-in (obtaining a right to exploit intellectual property), joint ventures with other organizations, joint development with external partners such as universities or other companies, contract R&D (outsourcing services from other organizations), venture capital (investing in promising ventures), mergers and acquisitions of organizations such as start-ups or competitors, customer involvement (involving customers in innovation processes), and external networking (collaborating with external partners to acquire new knowledge and technologies or human capital) initiatives; and (2) inside-out (organizations search for possibilities to share their already available in-house knowledge or resources with the external environment in a way which will add value to the organization that it is sharing with, such as, for example, out-licensing and transfers of rights, promoting spin-offs, turning to open source, etc.), where the collaboration can occur through selling intellectual property, licensing out to external partners to explore internal technologies, spin-offs (crate new organizations based on internal knowledge supported by the parent organization), and open source (revealing internal technology financial rewards) initiatives.

The outside-in flow type is still, by far, the most attractive for organizations, essentially because organizations are afraid that if internal ideas or technologies go outside and turn successful, it becomes embarrassing and may cause reputational damage [18]. If both flow types are simultaneously adopted by an organization, it is called a coupled flow type [18], where the exchange occurs trough a mix of the mentioned outside-in and outside-out activities. To better understand how the open innovation model works, in Table 3 are illustrated the benefits and limitations of traditional innovation (closed innovation model) and open innovation [18,57–59].

**Table 3.** Benefits and Limitations of Open Innovation and Closed Innovation Models.

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

As can be seen in Table 3, the benefits largely outweigh the limitations of the open innovation model when comparing it with the closed innovation model. However, according to research, there is still a lack of proper models to manage collaboration in open innovation models, and the existing ones seem not to be efficient [17].

### *2.2. The Hybrid Stage-Gate Model*

The hybrid stage-gate model (Figure 5) integrates the stage-gate process and the Agile methodology [60–62]. The hybrid stage-gate model is a conceptual and operational roadmap for moving a new product project from idea to launch [63,64]. The system breaks the innovation process into a discrete and identifiable number of stages, where in each stage, through a set of prescribed best-practice and critical success factors, cross-functional and parallel activities are defined and undertaken by the project team. In the hybrid stage-gate model, each stage is cross-functional. This means that there is no "R&D stage" or "Marketing stage"; rather, every stage is marketing, R&D, production, engineering, and so on, which contributes to an effective integrated risk management across the innovation process [63,64].

In Figure 5, the idea generation phase (also called the fuzzy front end) is characterized by a proactive idea search (represented by the blue circles) undertaken by the basic research type. In gate 1 (idea screen), a gentle screen is made under the qualitative criteria, such as project alignment and feasibility, that analyzes the ability to leverage the firm's resources and fit with company policies. The project is born at this point. In the scooping stage, detective work is undertaken, making a preliminary market, technical, and business assessment. Gate 2 (second screen) is a re-evaluation (qualitative and a first financial return is assessed) of the project's potential. In this stage, some ideas may be rejected (red circles in Figure 5). The build business case stage opens the door to product development. In this stage, a detailed investigation is conducted, analyzing product attractiveness, prior to heavy spending. It includes activities such as voice-of-customer (VoC), competitive analysis, feasibility and design analysis, and a detailed business and financial analysis. The final result in this stage is a business case which includes product definition, project justification, and a detailed project plan. In gate 3 (go to development), a rigorous review of each of the activities in stage 2 is conducted, subjecting the project to the must-meet and should-meet criteria used at gate 2. It is the last point at which the project can be killed before entering heavy spending. The development stage is essential to the implementation of the development plan and the development of the product, characterized by a spiral development (represented by the blue and black arrowed circles in Figure 5) which consists of a back-and-forth or iterative cross functional process (build, test, feedback, revise, and repeat) and customers for assessment and feedback. The spiral development is to be performed in all the stages. Gate 4 (go to testing) is a post-development review that checks on the progress and the continued attractiveness of the product and project economics via a revised financial analysis. At stage testing and validation, the entire viability of the project is tested. In this stage, the product itself, the production process, customer acceptance, and the economics are tested. In this stage, usually, trials and pilot productions are undertaken, and it is likely that there is a need to go back to stage 3 to make improvements. Gate 5 (go to launch) opens the door to full commercialization of the product or service, focusing on testing and validation, and is the last gate where the project can still be killed. The final stage (launch) involves the implementation of both the marketing launch plan and the production or operations plan. Finally, after a period of commercialization of the product or process (represented by the letter P in Figure 5), a performance review is usually undertaken in order to compare the latest data on revenues, costs, expenditures, profits, and timing with gate 3 and 5 projections to gauge performance. According to [64,65], the major benefits of the hybrid model include much faster product releases, a better response to changing customer requirements, and improved team communication and morale. However, some modifications to the Agile model are required for physical products. By the introduction of the Agile methodology in the stage-gate framework, a dramatic increase in the interactions between stakeholders takes place, leading to a potential natural increase of the emergence of the three most common collaborative risks (partner choice risks, task assignment risks, and behavioral risks) [64,65]. Therefore, the need of a proper model to manage such collaborative risks is critical.

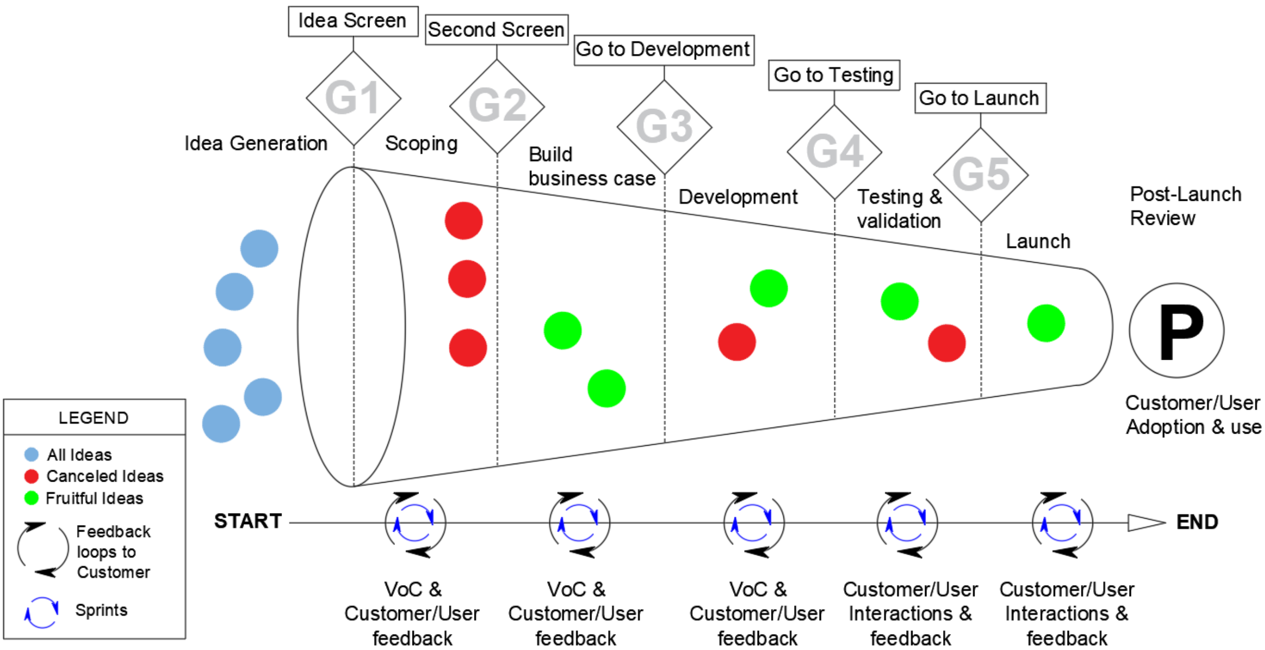



**Figure 5.** The hybrid stage-gate system (adapted from [64]).

### *2.3. Open Innovation and Collaborative Risks*

Collaborative risks are types of risks that usually emerge when collaborative initiatives take place, such as the performing of joint work between different organizational departments, between different institutes, between different organizations, or even between competitors [26,66]. According to much research, among the many collaborative risks that may be identified when a collaborative initiative is ongoing, three major collaborative risks have shown to have major importance and a major impact on how such collaborative initiatives evolve across time [26,66]. They are: (1) partner choice risks, which include the risks associated to with choosing the right partners to engage in innovation initiatives regarding their credibility and exclusive competencies or skills; (2) task assignment risks, which include risks associated with the assignment of innovation process tasks to chosen innovation partners; and (3) behavioral risks, which include the risks associated with the intra- and inter-cross-functional collaboration, such as communication, information-sharing, control across the innovation process, and the adoption rate of innovation results.

Figure 6 illustrates the open innovation iceberg, showing the typical dynamic architecture of an open innovation environment. At the upper side of the iceberg are the high-level interactions between the different organizations that engage in collaborative initiatives and the respective benefits. The arrow sizes represent the different contributions (intensities) from different organizations. At the bottom of the iceberg are the detailed interactions between the different organizations that engage in collaborative initiatives. These interactions represent how different stakeholders form different organizations interact in networks of collaboration. This is also the area where the three common collaborative risks may emerge and evolve across time.

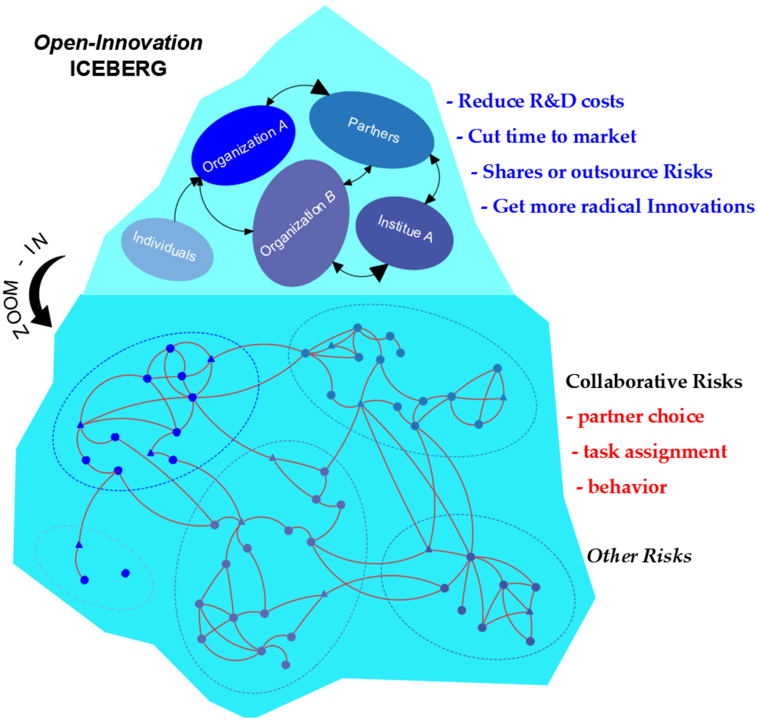



**Figure 6.** The Open Innovation Iceberg.

At the bottom of the open-innovation iceberg, the circles and triangles within the dashed ellipses may represent different organizational hierarchical levels and the lines between them represent dynamic relationships that may represent communication, information exchange, advice, and so on. It is in this part of the iceberg that the proposed model in this work will act in the identification and measurement of the three major collaborative risks (partner choice, task assignment, and behavioral risks). This will be done by the application of network graph-based centrality metrics that quantitatively measure formal and informal dynamic relationships between different actors from the different organizational areas or different organizations as they engage in collaborative initiates.

### *2.4. Social Network Theory*

The application of graph-based theory (also known as SNA—social network analysis) has gained exponential interest within recent years [67,68] and covers a wide range of different areas such as agriculture [68], organizational science industry, management and leadership [69], and political science [70], just to name a few. The dynamic relationships within a social structure are complex by nature and cannot be entirely explained through traditional social theory and data analysis methods, rather by methods that are based in sociology that consider the individual's social context in the process of making choices [71,72].

Network graph-based theory studies and analyzes social structure data with a variety of measures (usually centrality metrics such as in-degree, out-degree, density, closeness degree, betweenness degree [73]) developed based on graph theory—a mathematical structure used to model pairwise relationships between entities such as persons, organizations, or others –that contribute to explain how social structures evolve across time and how they impact the environment where they do exist [74,75].

In organizations, the application of graph-based theory has gained high popularity across recent years [21,70,76], essentially because it enables mapping informal collaboration networks such as communication (who, and with what frequency, communicates with who regarding personal and professional subjects?), information flow (how information flows within and across functional departments), problem-solving or advice (who goes to whom for advice or expertise and know-how on work or personal related matters?), know-how (who knows what and how?), access (who has access to whom?), and trust (who trusts whom?), just to name a few.

In an organizational network, an informal actor can be an identified function of their location in the network structure. These include [21,70,76,77]: central connectors or hubs (actors that surprisingly or not are much more central than anyone had imagined and are a vital part in the network or a threat, usually by turning into a bottleneck holding the entire group and organization back), information brokers or boundary spanners (vital actors to the integrity and viability of the network who usually make connections across hierarchies, business units, locations, or other silos, acting as intermediary actors who facilitate transactions between actors lacking access to or trust in one another), peripheral people (usually overlooked and not properly connected with the other members of the organization), energizers (create energy and excitement in their interpersonal interactions, very often responsible for triggering motivation, creativity, and innovation across the organization). By analyzing each of the mentioned informal networks and their entities, graph-based theory enables the identification of dynamic behavioral patterns of employees in a quantitatively way, which then can be used to match those behaviors with individual and collective outcomes, such as performance, innovation, social cohesion, information diffusion, talent shortages and retention, incompetence, network collaboration, cultural fit, unethical behavior, employee wellness, noncompliance with industry, fraud, decision-making power, or even generate forecasting models to predict learning performance, just to name a few [74–77]. Very often, graph-based theory is associated with the identification of informal networks (a designed chain of authority, ruled by the rational-legal authority system based in universalistic principles that are understood as fair; however, several authors argue that in an organizational context, it is very difficult to distinguish whether relationships between an organization's entities or between different organizations are informal or formal [77–79].

Moreover, informal networks may become formal and vice-versa [80], which shows that there is a blurred line between informal and formal networks in an organizational context. The mix of formal and informal networks of relationship simultaneously influences and is influenced by the behaviors of the different entities that comprise a social network. This, in turn, will influence how stakeholders interact as they execute project tasks or activities, which, in turn, may explain the emergence and evolution of collaborative risks.

Much research also shows that if the mix of formal and informal organizational networks of collaboration are not effectively managed, they may strongly hinder the performance and innovation capacity of an organization, which can evolve either to an overloaded collaborative status or to an inefficient organizational collaboration status [77,78,81].

According to research, efficiently managing networks of collaboration is as a major factor that influences results such as, for example, project outcomes [78,82]. The most effective way to study, analyze, and quantitatively measure the dynamic interactions which mirror existing, and forge future, behaviors of social entities as they interact throughout the blur of formal and informal networks of relationships is through the application of graph-based theory centrality metrics [77,78,81]. In collaborative initiatives, network graph-based theory plays a fundamental role in mapping the mix of formal and informal organizational networks such as an advice network, problem-solving network, communication network, or trust network, just to name a few, which will then enable understanding if these will potentially lead or not lead to the emergence of the mentioned collaborative risks [79,83,84].

## 3. Methodology and Materials

The proposed model in this work is the result of extensive literature research conducted to identify the state-of-the-art regarding models, approaches, tools, and techniques that are being used to support organizational innovation initiatives. The model was designed based on the major four different phases of the innovation process, and lays between the boundaries defined by the TR1 (technological readiness level [85]) and TR9, as displayed in Figure 7.

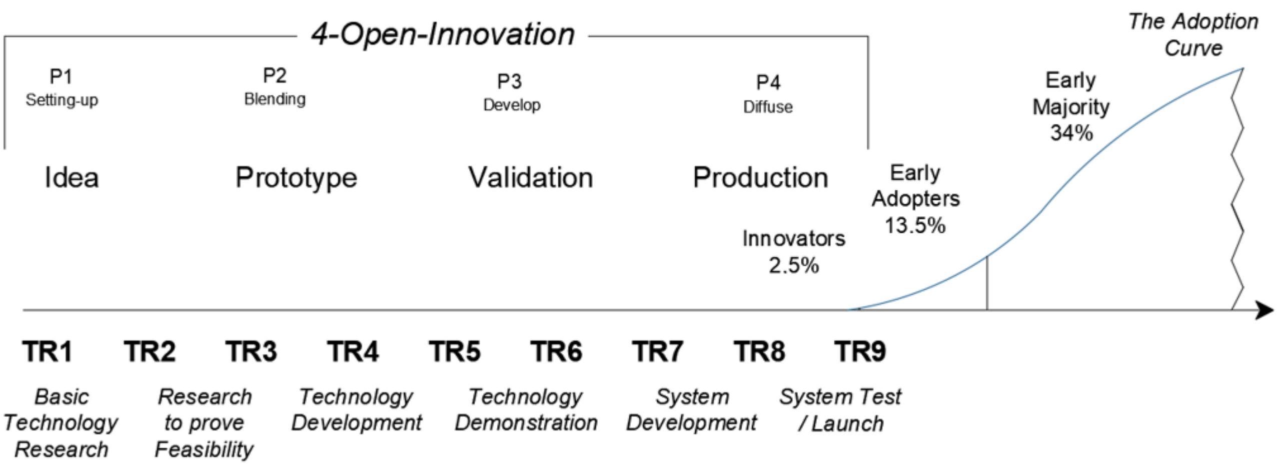



**Figure 7.** Technological readiness and 4-Open-Innovation model.

The proposed model in this work targets the collaborative ecosystem (stakeholders from different organizations) that engage in innovation initiatives under the pen innovation umbrella managed by the application of the hybrid stage-gate framework. There are three data sources. These include strategic surveys (SNA surveys) conducted online (F2F), consulting online records (internet), and analyzing a dedicated collaborative initiative email exchange network. The proposed model in this work has four parts. In part 1, the model defines the major aspects of the collaborative process in the open innovation and hybrid stage-gate frameworks. It clearly states the innovation target and the partner choice. In this part, the model aims to clarify the type of innovation to be conducted and who will be the partners to take part in the process. Regarding the partners that take part in the process, strategic data need to be collected. Data are collected through strategic surveys (SNA surveys) online and/or F2F to a potential candidate to become a partner, and include dimensions such as key competencies, trust, engagement, skills, experience, and so on. It is also possible for voice of customer data to be collected. Strategic surveys may include questions that are addressed to potential partners to rate other potential partners regarding the mentioned dimensions. This will enable creating a collaborative ecosystem map by the application of the network graph theory and highlights those potential partners that are better or worse candidates to be part of the collaborative process. Part 1 of the proposed model addresses the partner choice risks. In other words, in this part, the model aims to minimize or eliminate the risk associated with choosing a wrong potential partner to the collaborative process. Strategic survey questions may include: *have you ever worked with potential partner x? What was like to work with potential partner x? Does the potential partner x have the necessary skills and knowledge? How was the trust level within the ecosystem in previous collaborative initiatives?* In part 2, the model analyzes the intellectual and property and legal aspects and the task assignment process. Regarding the task assignment process, the proposed model conducts a strategic survey to identify key stakeholders, which, by the informal position these have within an organizational social network, are in better conditions to leverage the OI network social capital. In other words, the model will look for strategically positioned key stakeholders within the mix of formal and informal organizational networks from potential partners that can better bridge the different pockets of the innovation ecosystem. Part 2 of the proposed model addresses the task assignment risks. In other words, in this part, the model aims to minimize or eliminate the risk associated with attributing a given set of tasks or activities to stakeholders that may not effectively have the capacity to execute them in the most efficient way possible. This means that the attribution of tasks will be based on measurable collaborative data rather than simply relying on self-argued experience. In this part, strategic key questions may include: *whom do you turn to when you need to get information from another department or business unit or external organization? Whom do you like to have more access to in order to improve the way you execute your work? Whom do you turn to get efficient support regarding task or activity x?* In part 3, the model analyzes the dynamic interactions across the collaborative process. It can be understood as follows: in part 1 and 2, the model addresses the first two common collaborative risks, and in part 3, the model addresses the behavioral risks that may emerge as the collaborative initiatives take place. The necessary data to map the networks in this part may arrive by the application of strategic surveys, as in the previous two parts, or by assessing the dedicated email network communication across a collaborative ecosystem. In this part, strategic key questions may include: *whom do you turn to when you have a problem you need to be solved? Do you have enough feedback from the other partners you work with? Do other partners exchange information with you in a timely manner? Does the information you receive to proceed with your work comes entropy free?* In part 4, the model aims to identify how likely it is that a result of an ongoing innovative process will be accepted. This includes the collection of data to map the necessary networks to identify the set of key innovation diffusors. In this part, strategic key questions may include: *how likely would you adopt this idea? Do you think that this idea could benefit someone you know? To whom would you recommend this (ongoing or planned) invention?*

Figure 8 illustrates the four parts of the 4-OI model and the respective sub-parts that range from _a to _b. They are: part 1 (P1, setting up), where step _a defines the innovation dimensions and step _b selects the innovation partners; part 2 (P2, blending), where step _a defines the legal aspects and step _b assigns the innovation tasks to the selected partners; part 3 (P3, developing), where the core innovation development (research, build, test, feedback, revise, and repeat) takes place; and part 4 (P4, diffusing), where the adoption rate of the innovation process results (usually a service or product) is to be forecasted.

For each part of the 4-OI model, a timeslot (defined between two black diamonds) is illustrated on the right side of Figure 8. These timeslots represent the temporal space where each 4-OI model takes place related to the hybrid state-gate model, which is considered the core innovation development part in the 4-OI model.

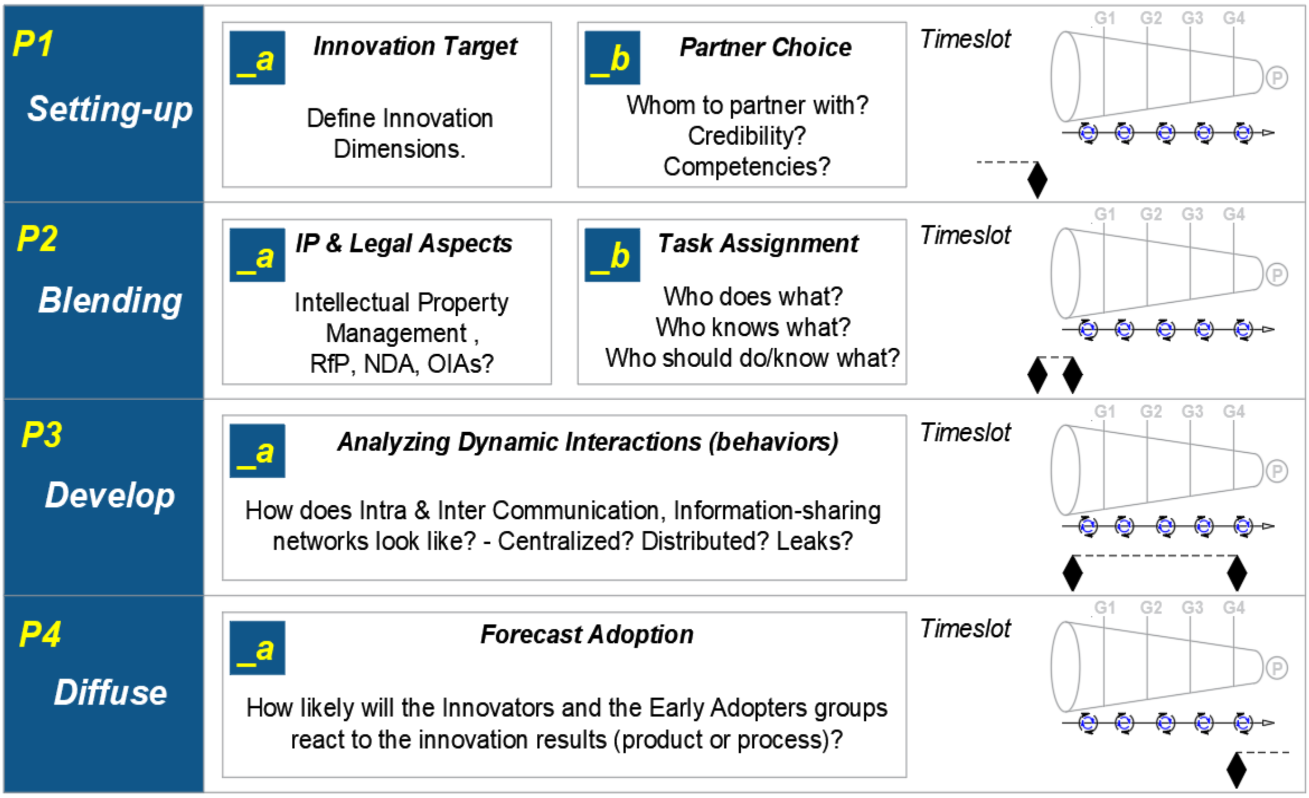



**Figure 8.** The 4-Open-Innovation Model.

Table 4 illustrates the four parts of the 4-OI model. A detailed description of the objectives for each part is provided, as well as the six different graph-based centrality metrics that will be used to analyze collected data in strategic surveys and dedicated email networks (in-degree, out-degree, betweenness, reciprocity, density, and average degree) and to identify the potential three common collaborative risks already mentioned.

**Table 4.** The 4-Open-Innovation parts and graph-based centrality metrics.

| Parts | | Objectives | SNA Centrality Metrics |
|---|---|---|---|
| Part 1 | _a | Clearly define the problem or idea to be addressed by an open innovation approach. Define innovation dimensions and who will contribute with what competencies (R&D fields, HR, marketing, sales, and so on) as main organizational competency. | N/A |
| | _b | Which possible future partners have the highest nominations, links (directed or undirected (who speaks/writes good or bad from whom)), and exclusive competencies or skills (what they are really good, not so good, or bad at). | -In-degree [73] $$C_{ID}(n_i) = \sum_j x_{ji} \quad (1)$$ where: $C_{ID}$ = total degree of an entity within a graph; $n$ = total number of entities within a graph for i = 1 . . . , n; $x_{ji}$ = number of links from entity $j$ to entity $i$, where $i \neq j$, and vice-versa, function of directed or undirected graph |
| | | Who nominates whom (who speaks/writes good or bad from whom) regarding exclusive competencies or skills (what they are really good, not so good, or bad at). | -Out-degree [73] $$C_{OD}(n_i) = \sum_j x_{ji} \quad (2)$$ where: $C_{OD}$ = total out-degree of an entity within a graph; $n$ = total number of entities within a network (graph) for i = 1 . . . , n; $x_{ji}$ = number of links from, only entity $j$ to entity $i$, where $i \neq j$, function of directed or undirected graph |

**Table 4.** *Cont.*

| Parts | | Objectives | SNA Centrality Metrics |
|---|---|---|---|
| Part 2 | _a | Treat legal aspects such as RFIs (request for information), RfP (request for proposal), management of IP (intellectual property) (essentially regarding IP contamination such as IP background (any IP that is created by the owner before the date of the open innovation agreement)), IP foreground (is all the knowledge or intellectual property (assets) produced within the collaborative venture or open innovation project during the project's tenure?), IP side-ground (is knowledge or intellectual property (assets) relevant to an open innovation project but produced outside the project by any of the partners during the project's tenure?), and IP post-ground (knowledge or intellectual property (assets) that is relevant to a collaborative venture or open innovation project that is produced by any of the partners after the project ends). Signing NDAs (non-disclosure agreements), setting of OIAs (open innovation accelerators), writing of a JDA (joint development agreement), and planning innovation jams (structured brainstorming activities which include reward-based incentives, where elements from all divisions of an organization should participate, usually ending up with the writing of RfPs). | N/A |
| | _b | Who are the informal innovative-mindset key people that, by the advantage of their location within the open-innovation ecosystem network, better leverage the OI network social capital? | (1) |
| | | Who are the informal innovative-mindset key people that connect different pockets (silos) of the organization or between different organizations that aggregate different know-hows and perspectives (diversity and inclusion principle)? | -Betweenness [73]<br>$C_B(n_i) = \sum_{j<k} \frac{g_{jk}(n_i)}{g_{jk}}$ (3)<br>where:<br>$g_{jk}$ is the number of geodesics (shortest path between any two entities) linking two actors that contain actor $i$<br>$n$ = total number of entities within a network (graph) for i = 1 . . . , n<br>Alternative calculation is analyzing the location of a node regarding how betweenness is from two different entities (organizations, organizational departments, and so on) from a visual perspective. |
| Part 3 | _a | Who has a disproportionate incoming request from the innovation ecosystem? Who is less or more dependent on vital information to accomplish open innovation activities or tasks? Are there signs of bottlenecking within the OI network? Peripherical people—feeling aside from the process? | (1) |
| | | Who is dependent on whom regarding information to push further the open innovation tasks and activities? | (2) |
| | | Are requests, questions, or information regarding open innovation vital information being timely answered or provided among the participants within the innovation ecosystem? Is the communication done one-way or is there feedback? | Reciprocity [73]<br>$= \frac{L^{\langle - \rangle}}{L}$ (4)<br>where:<br>$L^{\langle - \rangle}$= number of links pointing in both directions<br>$L$ = total nr of links in a graph |
| | | Is the open-innovation email network exchange communication too centralized? Does the information flow through all the participants in the open innovation initiative? Is there enough reach regarding the "spreading of the news" concerning new developments or findings that can be used for other purposes, as illustrated in Figure 4(2), which characterizes the three possible targets in an open innovation scenario (other firm's market, our new market)? | Density [73]<br>$\boldsymbol{Ds} = \frac{N_{L\ REAL}}{N_{LMAX}}$ (5)<br>where:<br>$nrofmaximumpossibleties = N_{LMAX} = \frac{\boldsymbol{n(n-1)}}{\boldsymbol{2}}$ (5a)<br>$n$ = number of entities within a graph |
| | | Another measure to countercheck the density measure, regarding how centralized the email communication network is. | Average degree [73]<br>$\boldsymbol{A_D}(n_i) = \frac{\sum_j x_{ji}}{n} = \frac{\sum_{i=1}^{n} \boldsymbol{C_{TD}}(n_i)}{n}$ (6)<br>where:<br>$\boldsymbol{A_D}$= average degree<br>$n$ = total number of entities within a network (graph)<br>$\boldsymbol{C_{TD}}$ = total degree = $\boldsymbol{C_{ID}} + \boldsymbol{C_{OD}}$ |
| Part 4 | _a | Who and how many are nominated in a positive way regarding the adoption of the result of the innovation initiatives (product or service)? From those nominated at the in-degree, who would they likely further recommend the adoption to as the result of the innovation initiatives (product or service)? | (2) |

## 4. Application of the 4-Open-Innovation Model—A Case Study

The following case study took place at a multinational food and beverage market leader organization (named MNE1) while deciding on a project to improve a final food-product transferring process from place A to place B (distanced about 200 m long) in one of its factories. The usual transfer process has been performed manually in all the factories of MNE1 due to a lack of available technology to address the high dry matter content of the final food product to be transferred. Pressured by economic and hygienic reasons, MNE1 decided that the transfer process should become automatic. However, until then, available processing technology was not able to solve the problem. Facing this challenge, organization MNE1 decided to contract the services from a multinational plant solution expert company (named MNE2). After several tries, MNE2 found no solution for the problem. MNE2 suggested to MNE1 that they should engage in an open innovation approach to develop a solution for the problem. Both agreed to engage in an open innovation approach, adopting the 4-OI model to support the open innovation initiative. The agreed open innovation initiative was characterized as a coupled flow type, where the customer (MNE1) perspective is seen as an external networking and joint development collaboration type, and the customer partner's perspective is seen as a customer involvement and selling or licensing out collaboration type. Further information regarding the company and the process were not disclosed due to commercial protection reasons.

### *4.1. P1, Setting Up, P1_a—Innovation Target*

In part 1 step _a, MNE1 and MNE2 defined the innovation dimensions (Table 5) according to Figure 2. The objective of the open innovation initiative is the development of a breakthrough process which will have an organizational international reach—as MNE1 includes its implementation across all the factories around the world—that will be developed in combined physical (a laboratory in one of MNE1's factories to conduct pilot tests) and virtual (online shared platform to support email exchange, reporting, and communication) spaces under an inter- and intra-cross-functional organizational collaborative network (innovation partners) approach of both engineering and R&D departments.

**Table 5.** Case study: P1_a—setting up the innovation target.

| | **Product** | | **Process** | |
|---|---|---|---|---|
| | International | National | Regional | **Organizational** |
| | Sustaining | Incremental | **Breakthrough** | Disruptive |
| | Virtual | Physical | Combined | |
| | Intra-Org. | Inter-Org. | Experts | World-Wide |
| R&D | X | X | | |
| Engineering | X | X | | |

Defining the innovation dimensions, as illustrated in Table 5, does not mean that they remain unchanged until the end of the development. Instead, it is a high-level innovation requirement structured guide that helps to framework (visualize) the whole innovation development process dependencies, which, in turn, helps to better estimate the allocation of the necessary innovation resources in a more accurate approach.

*4.2. P1, Setting Up, P1_b—Partner Choice*

Part 1 step _b initiates the open innovation partner selection process. MNE1 and MNE2 conducted pre-research to define five key competencies necessary to the innovation process, based on which, the open innovation partners were pre-selected. They are: C1 (food technology), C2 (plant solutions technology), C3 (mechanical installation technology), C4 (instrumentation and laboratory technology), and C5 (mechanical equipment technology). The pre-selected partners result from an extensive research based on awareness, best practices, recommendations, performance, and references from past collaborations regarding the necessary five key competencies. The pre-selected open innovation partners and the relationship between them (customer vs. service provider) are illustrated in Figure 9. The red line between two organizations means that they have a competitor relationship, and the line with an arrow symbolizes the relationship between customer vs. service provider. For example, MNE1 is a customer of MNE2.

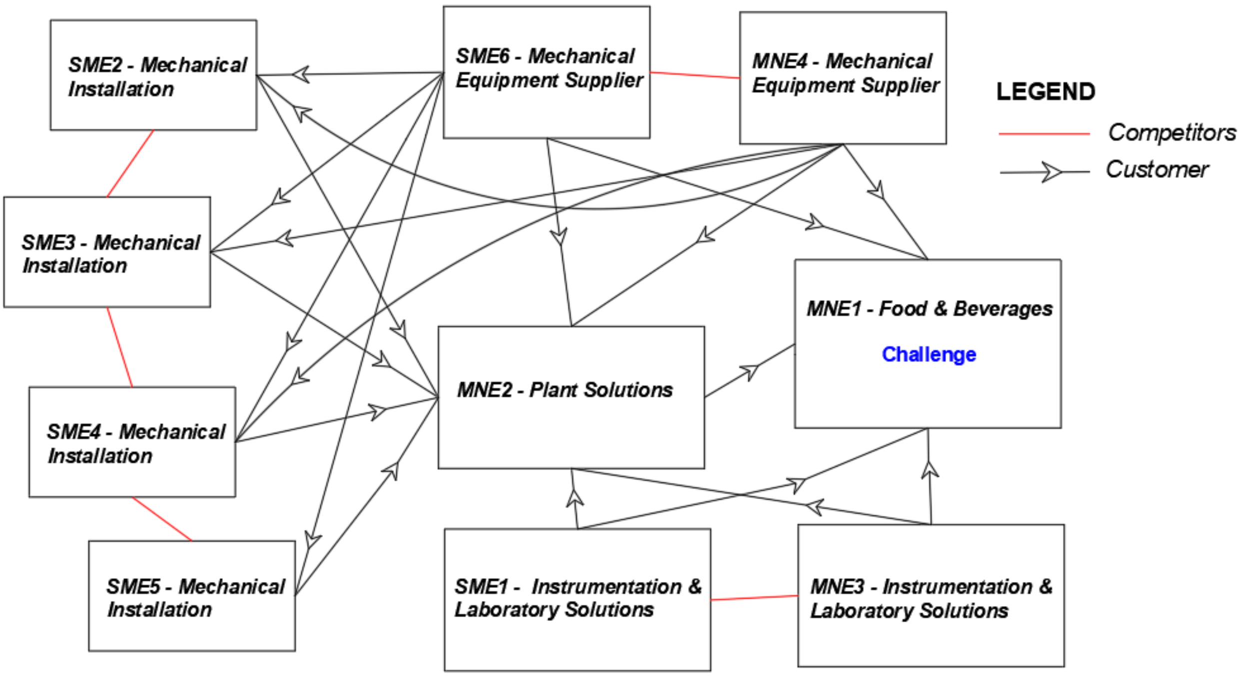



**Figure 9.** Case study: pre-selected partners for open innovation.

In Figure 9, the pre-selected partners are: four small or medium organization experts in mechanical installations (SME2, SME3, SME4, and SME5), two expert organizations in instrumentation and laboratory (MNE3 and SME1), and two expert organizations in mechanical and plant equipment (MNE4 and SME6).

MNE1 and MNE2 deepen research in social media channels (online information), (2) personal networks (conducting internal SNA surveys), and (3) organizational official logs (logs of previous collaborations of pre-selected partners) and selection criteria (reliability, deliver time, engagement, support, performance) and define a rating scale, as illustrated in the legend of Figure 10.

As an example, MNE1 R&D and engineering departments rated MNE4 R&D and engineering departments with a 2, meaning that regarding competence C5, MNE4 has a good classification. SME5 was rated as a very good candidate partner in open innovating; however, they declined the invitation. Applying (1) and (2) according to Table 4, the results of the innovation partner selection are illustrated in Table 6.

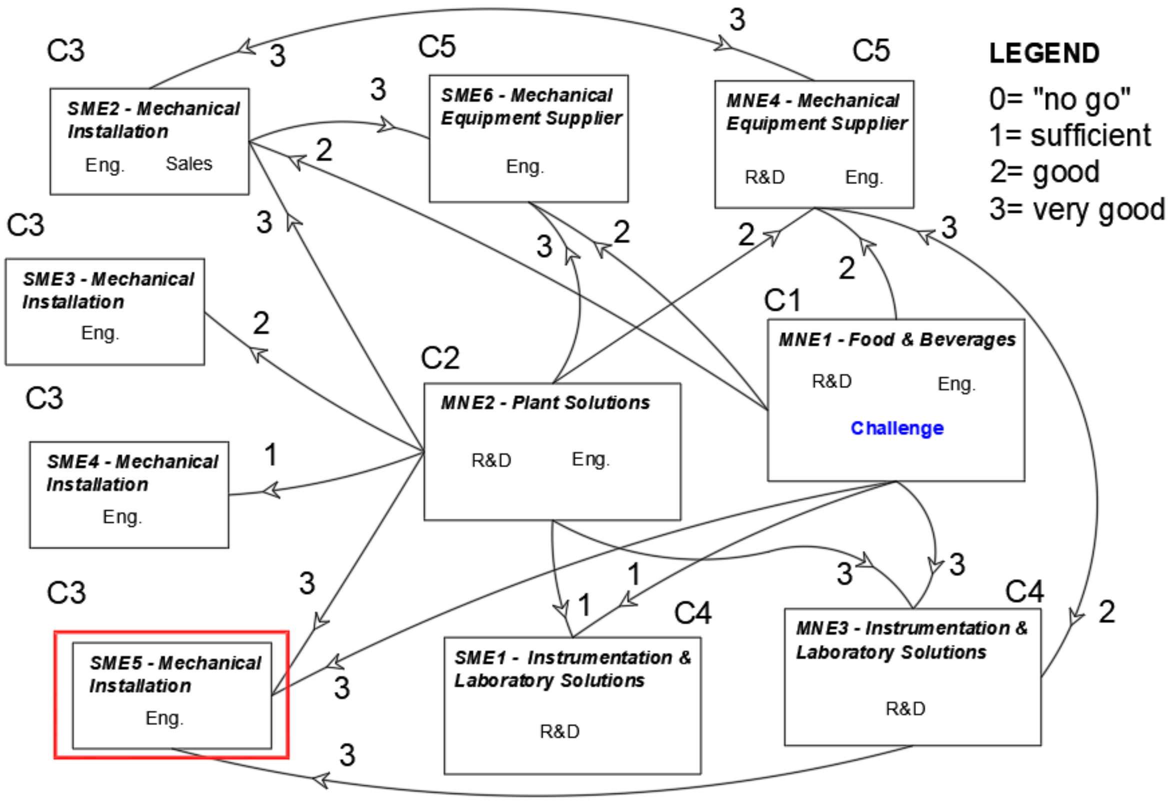



**Figure 10.** Case study: pre-selected partners for open innovation rating.

**Table 6.** Case study: in-degree and out-degree for P1_b.

| Metric/Organization | MNE3 | SME1 | MNE4 | SME6 | SME2 | SME3 | SME4 | SME5 |
|---|---|---|---|---|---|---|---|---|
| In-degree (1) | 8 | 2 | 10 | 8 | 8 | 2 | 1 | 9 |
| Out-degree (2) | 6 | 0 | 5 | 0 | 6 | 0 | 0 | 0 |

According to Table 6, the best classified organizations are: in C3: SME5, SME2, and SME6; in C4: MNE3; and in C5: MNE4. MNE1 and MNE2 hold C1 and C2, respectively. MNE3, SME2, and MNE4 accepted the invitation to partner in an open innovation initiative to develop a solution for MNE1's challenge, proposed by MNE1 and MNE2.

### *4.3. P2, Blending, P2_a—IP and Legal Aspects*

Part 2 step _a initiates the open innovation legal aspects, as included in Table 4. Tasks such as defining IP (intellectual property); RFIs (request for information); RfP (request for proposal); IP contamination of IP background, IP foreground, IP side-ground, and IP post-ground; NDAs (non-disclosure agreements); OIAs (open innovation accelerators); JDA (joint development agreement); and the planning of innovation jams are executed and programmed.

### *4.4. P2, Blending, P2_b—Task Assignment*

In part 2 step _b, the objective is to identify possible hidden talents regarding innovation competencies, so that innovation tasks can effectively assigned. Each of the selected partners will search inside their department's "informal" key actors, which may have valuable and unique know-how to the open innovation initiative regarding all the necessary innovation competencies. Each open innovation partner will conduct an internal SNA assessment, searching for "informal" key actors by launching two questions, as follows: question 1: "Please name two colleagues within your team, department or organization that have idea generation mind-set potential and easily engages in cross functional collaboration with other colleagues across the organization"; question 2: "Please name two colleagues within your department or organization, that you would like to have, if you were to set a team regarding the following competences: C1, C2, C3, C4, and C5". Figure 11 illustrates a network which results from the combined mapping answers to questions 1 and 2 from the MNE2 internal SNA assessment.

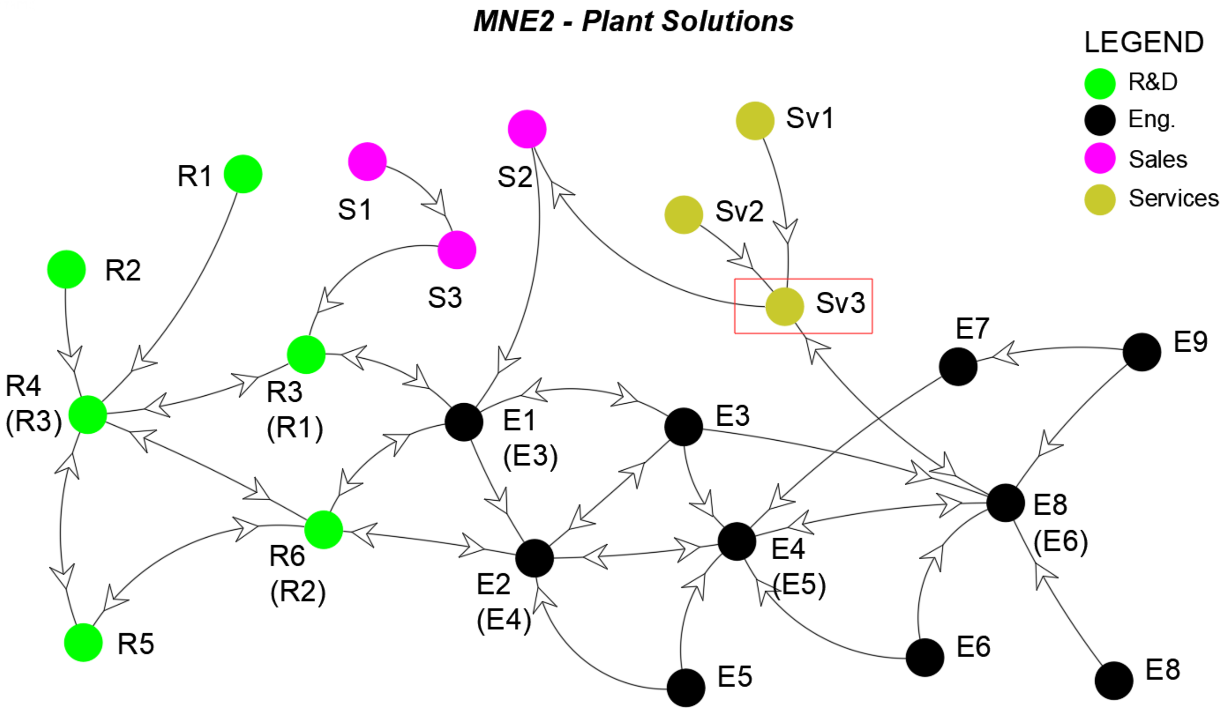



**Figure 11.** Case study: P2_b, organization MNE2.

In Figure 11, MNE2's employees are coded by colors regarding their functional department according to the legend. Initially, MNE2 counted only with the R&D and engineering departments. However, the results of the SNA assessment show that some sales and services employees could potentially have valuable know-how for the innovation initiative. Applying (1) and (3) according to Table 4, the results are presented in Table 7 (only for higher ranked actors). Actor Sv3 (marked with a red rectangle in Figure 11) declined the invitation to take part in the innovation initiative.

**Table 7.** Case study: P2_b, organization MNE2.

| Actor | Dept. | In-Degree (1) | Competencies | Betweenness (Alternative: between Departments) (3) |
|---|---|---|---|---|
| R4(R3) | R&D | 5 | C2 | Low or zero |
| R6(R2) | R&D | 4 | C2 | Very high |
| R3(R1) | R&D | 3 | C1, C2 | Very high |
| E1(E3) | Eng. | 4 | C2 | Very high |
| E2(E4) | Eng. | 5 | C2 | Very high |
| E4(E5) | Eng. | 6 | C1, C2, C3 | Low or zero |
| E8(E6) | Eng. | 6 | C2 | Low or zero |

According to Table 7, E1(E3) has a high betweenness degree because it connects three different organizational departments: R&D, sales, and engineering. This is particularly important for the innovation ecosystem, first because contributes to the diversity and inclusion factor (claimed a key factor for successful innovation), and second, it makes cross-functional connections, contributing to break organizational silos. For example, E4(E5) has an in-degree of 6 (the highest rank) regarding competencies C1, C2, and C3, which makes this actor a very valuable asset for the innovation initiative. Figure 12 illustrates the final innovation partners, their actors, and their respective competencies.

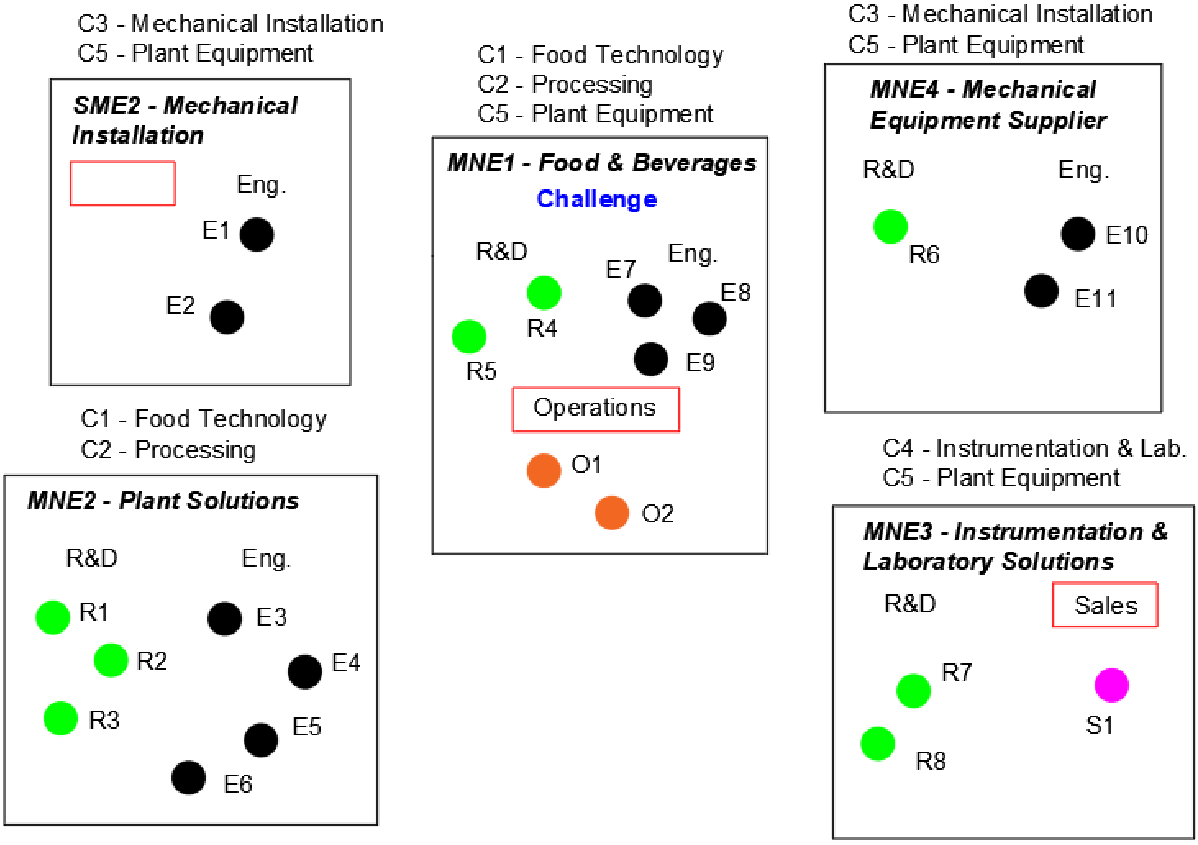



**Figure 12.** Case study: P_2b.1, final open innovation partners.

There are a few surprises (red rectangles) illustrated in Figure 12 regarding the final selection of organizational departments and respective actors. For example, MNE3 in Figure 12 was only counting that the "smartest" people would be in the R&D department. It turned out that after conducting the SNA assessment, actor S1 was indicated as having valuable input regarding plant equipment. After a follow-up assessment, S1 was invited and brought to the innovation ecosystem. According to Figure 12, SME2 was counting on having valuable input from the engineering and sales departments. However, the SNA assessment concluded that no actor from the sales department had valuable input for the innovation initiative (therefore, an empty red rectangle). Still, the SNA assessment in MNE1 identified two actors from the services department with valuable input regarding competencies C1, C2, and C5, who were brought into the open innovation ecosystem. This concludes part 2 of the proposed model.

*4.5. P3, Developing, P3_a—Monitoring Dynamic Development (Behaviors)*

In part 3 _a, the core innovation development process takes place, coordinated and controlled by the hybrid stage-gate system, as illustrated in Figure 13.

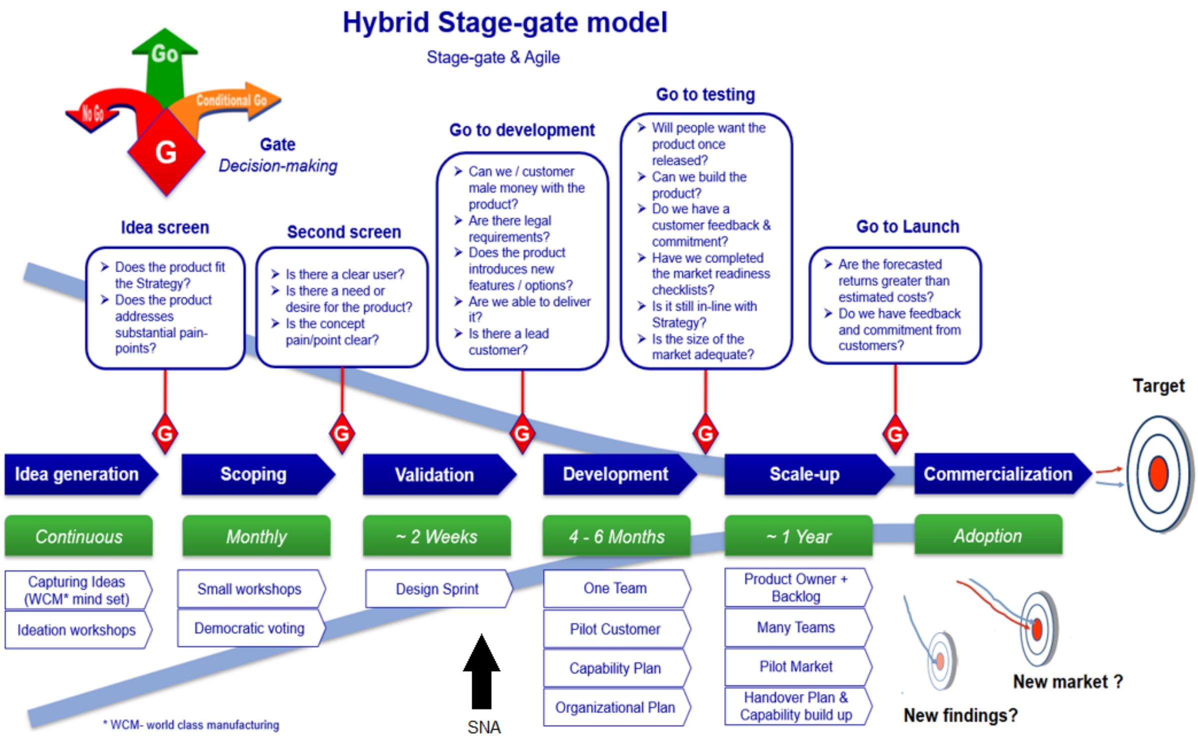



**Figure 13.** Case study: hybrid stage-gate system for the innovation development process.

In the adopted stage-gate system illustrated in Figure 13, there are six stages (from idea generation to commercialization) and five gates (from idea screen to go to launch). Each stage has a timeslot (from continuous to adoption), where the respective activities (from capturing ideas to handover plan and capability build up) are defined. After approximately 7 weeks of collaborative work, an SNA assessment was conducted before the go-to-development gate (marked with a black arrow in Figure 13) to monitor the ongoing dynamic behavior (behavioral risks) of the open innovation development process. Data were collected through the application of an SNA survey, with all innovation ecosystem actors and those consulting the email communication network recorded in the collaborative virtual platform. The SNA survey had the following questions:

Question 1: *"With whom do you communicate in a daily basis regarding the development of the innovation process?"*

Question 2: *"With whom you share most information regarding the findings and progress, concerning to the development of the innovation process?"*

Question 3: *"Whom do you go, to get approval or opinion regarding the importance of the intermediate findings, and if they should or not be discarded?"*

Figure 14 illustrates the resulting combined network for the answers provided to the three mentioned SNA questions.

Applying (1) and (2), according to Table 4, the results regarding the network illustrated in Figure 14 are illustrated in Table 8 (only the highest ranked actors).

As can be seen in the network of Figure 14 and as is quantified in Table 8, actor E9 has a disproportional central role within the open innovation ecosystem. E9's extreme central position regarding informal power, measured by the above-mentioned three questions, represents a given dependency degree of the innovation ecosystem. E9 has three times more in-connections than those of the second most connected person (R2) in the network. About 60% of actors within network of Figure 14 pointed E9 as being the person with whom to communicate on a daily basis to share information and to get approval or opinions regarding the future direction of the innovation initiative. E9's location suggests he is almost in absolute control of the information flow, control, and decision making concerning the evolution of the open innovation initiative. Such a central position may be a risk (threat) for the innovation initiative if, for example, E9 turns into a bottleneck, which may delay the entire innovation team. Still, it may influence the innovation team towards a particular direction (which may be biased), hindering the active and free participation of the innovation team. Other aspects such as a certain engineering and operations actors' internal connectedness are visible in the network, reflecting the poor collaboration among them.

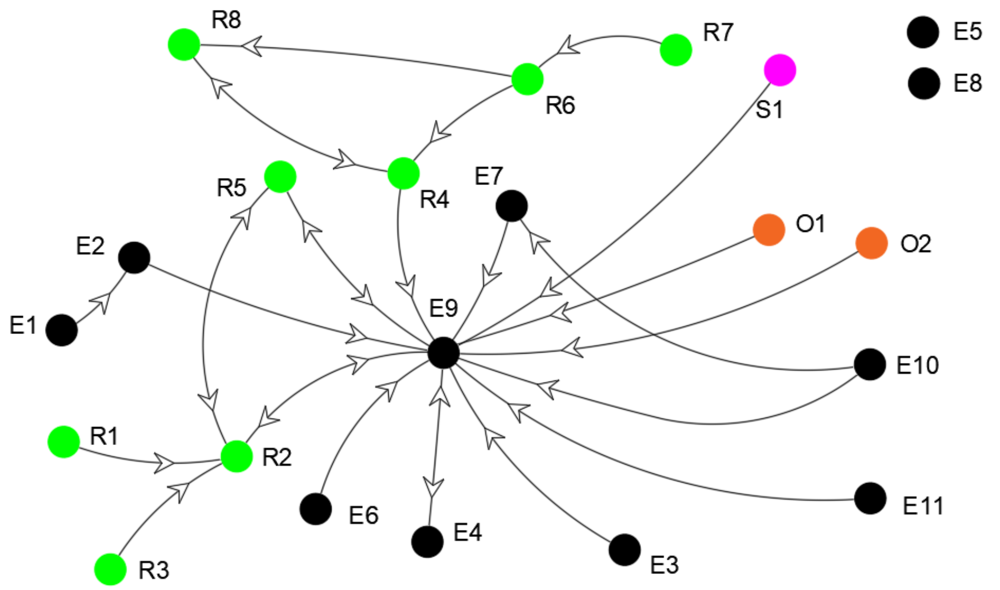



**Figure 14.** Case study: P_3a.1_a.

**Table 8.** Case study: P_3a.1_a.

| | E9-Eng. | R2-R&D | R4-R&D | R5-R&D | R8-R&D | R6-R&D | E7-Eng. |
|---|---|---|---|---|---|---|---|
| In-degree | 13 | 4 | 2 | 2 | 2 | 1 | 0 |
| Out-degree | 3 | 2 | 2 | 1 | 1 | 2 | 2 |

Figure 15 illustrates the network of Figure 14, but without element E9. If E9 is removed, the innovation team becomes strongly fragmented, leaving most of the engineers disconnected between them and completely disconnected from the R&D, sales, and operations actors. Still, isolated clusters arise, composed essentially of elements of the same nature. This means that the diversity and inclusion are in danger.

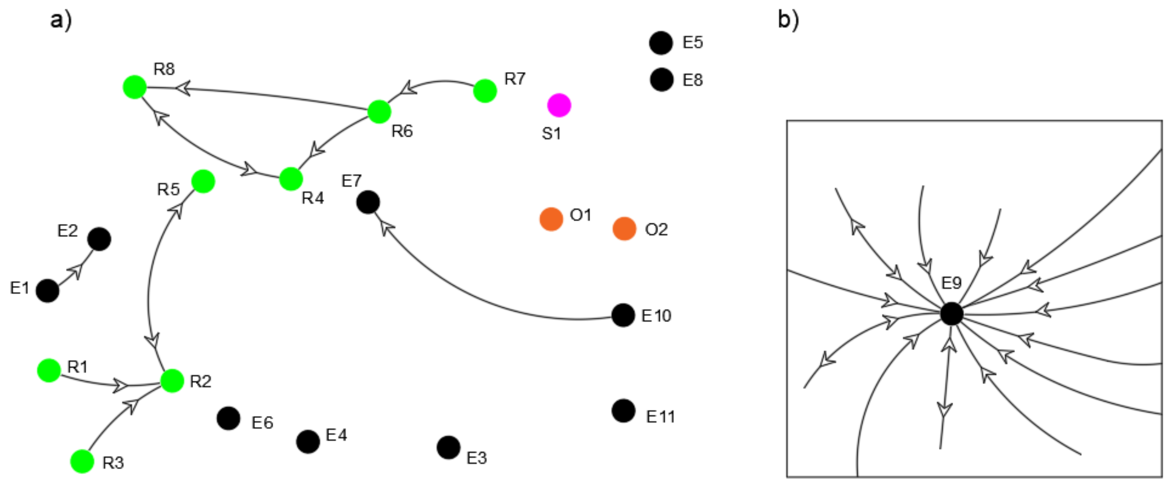
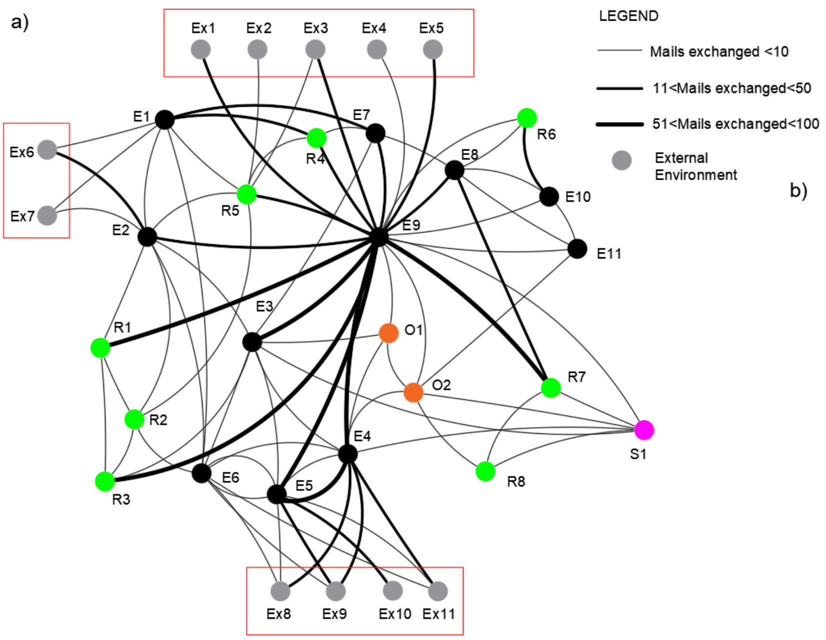



**Figure 15.** Case study: P_3a.1_b. (**a**—network without element E9) (**b**—only element E9 connections).

By analyzing the network illustrated in Figure 15a,b, it can be concluded that E9 is the glue that holds the innovation ecosystem together. In fact, E9 has an amount of 12 in-links, whereas all the other remaining elements do not have even half as many in-links as E9 has.

Figure 16a illustrates the email communication network of the innovation ecosystem across the first 7 weeks of collaborative work. To map this network, all the emails exchanged have been collected in the virtual platform. For example, in the network of Figure 16, R7 and R8 have an email exchange channel (represented by a line between any two given actors), through which less than 10 emails were exchanged according to the legend in Figure 16. In Figure 16, the red boxes represent the external environment of the innovation ecosystem and the grey dots represent the respective external actors. The content of the mapped emails in Figure 16 has not been disclosed, rather the sent/received quantity. Figure 16b illustrates the results ordered according the in-degree, from highest to lowest degree, of the application of (1) and (2) according to Table 4, and the difference between (1) and (2). Again, E9 holds a privileged position within the email communication network, holding, by far, the highest number of email communication channels (21 channels), corresponding to a total of 400 emails (sent and received) when compared with E4, which has the second highest number of email communication channels (11 channels), corresponding to a total of 181 emails (sent and received).




b) Total Number of emails received (IN-DEGREE) and sent (OUT-DEGREE) and the difference (IN-OUT)

| Element | IN-DEGREE | OUT-DEGREE | IN - OUT |
|---|---|---|---|
| E9 | 185 | 215 | -30 |
| E4 | 98 | 83 | 15 |
| E5 | 85 | 77 | 8 |
| E8 | 75 | 29 | 46 |
| R7 | 75 | 24 | 51 |
| E3 | 63 | 25 | 38 |
| R1 | 62 | 43 | 19 |
| E7 | 52 | 35 | 17 |
| R3 | 52 | 23 | 29 |
| R4 | 44 | 36 | 8 |
| E1 | 43 | 62 | -19 |
| E2 | 39 | 51 | -12 |
| R5 | 35 | 39 | -4 |
| R6 | 21 | 14 | 7 |
| E10 | 16 | 45 | -29 |
| E6 | 15 | 22 | -7 |
| E11 | 15 | 21 | -6 |
| S1 | 15 | 8 | 7 |
| O2 | 12 | 5 | 7 |
| O1 | 9 | 3 | 6 |
| R2 | 8 | 18 | -10 |
| R8 | 5 | 3 | 2 |

**Figure 16.** Case study: P_3a.2_a. (**a**- complete network, **b**- results in numerical format regarding in and out-degree of (**a**)).

In Figure 16a, a very small number of actors (including E9) have a disproportional number of communication channels compared with the rest of the innovation team. This represents an unbalanced communication and information-sharing network, which again may evolve to collaborative risks.

First, much of the information that flows through the email communication network does not reach all participants. In fact, only 32% of elements (E9, R7, R1, E3, R3, E5, and E4) are within the 51–100 mails-exchanged level, which is distributed between the engineering and R&D groups.

Second, E9 also has the highest difference (−30) between in- and out-degrees (Figure 16b, which means that he sends more mails than he receives, only comparable with actor E10 (−29); however, E10's span of action is, by far, smaller than the one from E9. This suggests that E9 has even more control or influence over the collaboration within the open innovation ecosystem. The email communication channels between the innovation ecosystem and the exterior environment represent simultaneously a threat (possible information leakage path) and opportunity (new insights or perspectives regarding a particular important subject for the innovation initiative). Actors E1 and E2 have exclusive access to Ex6 and Ex7, where a considerable number of emails have been exchanged, particularly between Ex6 and E2. Additionally, E9 has exclusive access to Ex1, Ex4, and Ex5, which reaffirms the informal power and influence of E9 within the innovation network. E4, E5, and E5 have a much more balanced communication between Ex8, Ex9, Ex10, and Ex11. As with before, if E9 is removed from the innovation ecosystem, the email network may be temporally or definitely defragmented, as suggested by Figure 17a. E9's removable impact is best measured applying (5) according to Table 4. Removing E9 makes the density fall from 27% (Figure 16a) to 20% (Figure 17a). This means that E9 alone is responsible for about 26% of all the existing email communication channels (considering 27% of the 100%). If E9 is removed, only 18% of actors (E1, E6, R2, and R8) do not strongly suffer from his departure (considering only actors from the innovation ecosystem), and the average degree (6) falls from 5,7 links (channels) to 5,2 links (channels). If the actors with the highest in- and out-degrees (E9, E4, and E5) left the network, the density would fall from 27% to 14%, making them responsible for about 42% of all the existing email communication channels. Furthermore, the average degree would fall from 5.7 to 5 links. These numbers only reaffirm how unbalanced the global collaboration network is and the disproportional informal power that element E9 has within this innovation ecosystem. Removing E9 (Figure 17a), the network becomes fragmented to a certain extent, appearing, for example, as "isolated" clusters formed by actors E8, R6, and E10.

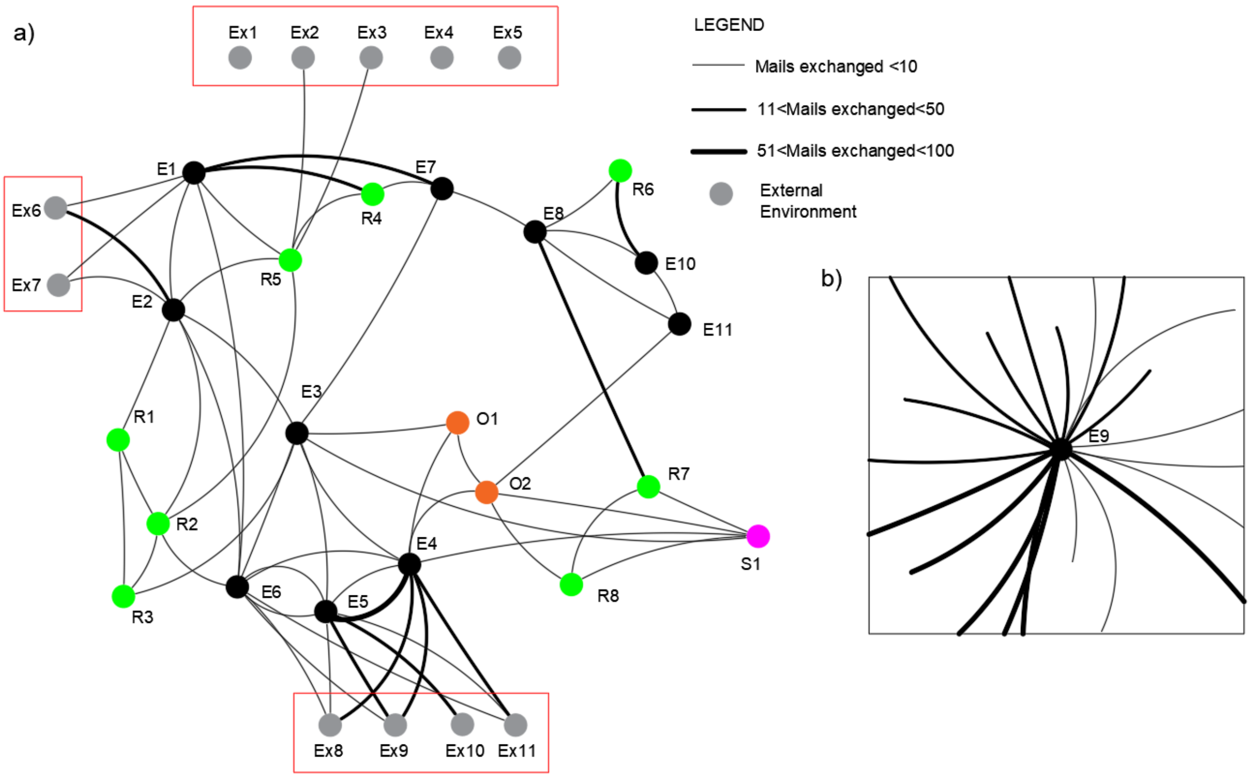



**Figure 17.** Case study: P_3a.2_b. (**a-** network without element E9, **b-** connections of element E9 only).

The actual dynamic structure of the innovation ecosystem may lead to the emergence of open innovation silos, strongly threatening cross-functional collaboration, which may evolve into an uncoordinated development process, which, in turn, may drive the innovation ecosystem to pursue different development directions, eventually threatening all the innovation efforts. Another interesting aspect that mirrors how the dynamic collaboration is evolving within the innovation ecosystem can be seen by measuring the feedback speed regarding the information requests or answering questions, which can be calculated by analyzing the time difference between incoming and replied-to emails, of a given subject. Applying (4), according to Table 4, the results (in average hours) are illustrated in Table 9.

**Table 9.** Case study: P_3a.2_b_Reciprocity.

| **Actors** | **E9** | **E4** | **E5** | **E8** | **R7** | **E3** | **R1** | **E7** | **R3** | **R4** | **E1** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***R*(*h.*)** | 32 | 15 | 3 | 6 | 21 | 17 | 9 | 16 | 24 | 8 | 7 |
| **Actors** | **E2** | **R5** | **R6** | **E10** | **E6** | **E11** | **S1** | **O2** | **O1** | **R2** | **R8** |
| ***R*(*h.*)** | 11 | 8 | 7 | 6 | 9 | 15 | 13 | 10 | 16 | 0 | 0 |

Not surprisingly, actor E9 has the highest "delay" (about 32 h, ~1.2 days) when it comes to answering emails providing project information or feedback. This reflects a certain dependency degree from other actors related to E9. Interestingly, the average feedback speed of the different functions (engineering ~13 h, R&D ~10 h, sales ~13 h, and operations ~13 h) is quite the same, which suggests that the innovation ecosystem, on average, is not strongly dependent on actor E9, although he has an extreme central position, as can be seen in the networks of Figures 14 and 16. This contradictory fact could mean that E9 may reply to information requests through other communication channels (phone, personal chats, or other). If such communication channels have not been officially designated to support collaboration, they may represent a behavioral risk in terms of coordination and information exchange, which, in turn, may end up threatening the innovation efforts.

### *4.6. P4, Diffusing, P4_a—Forecast Adoption (Behaviors)*

In part 4 _a, approval and adoption likelihood will be looked at regarding the results of the open innovation R& D process. Figure 18 illustrates the network that results from the answers to two questions addressed to all the actors of the open innovation team. They are: question 1: "Do you know somebody from your personal or professional network, that could possibly adopt the new process under development across the actual open innovation initiative?"; question 2: "Whom do you think that the person or persons you indicated in question 1 would suggest the adoption of the new process developed throughout the open innovation initiative?"

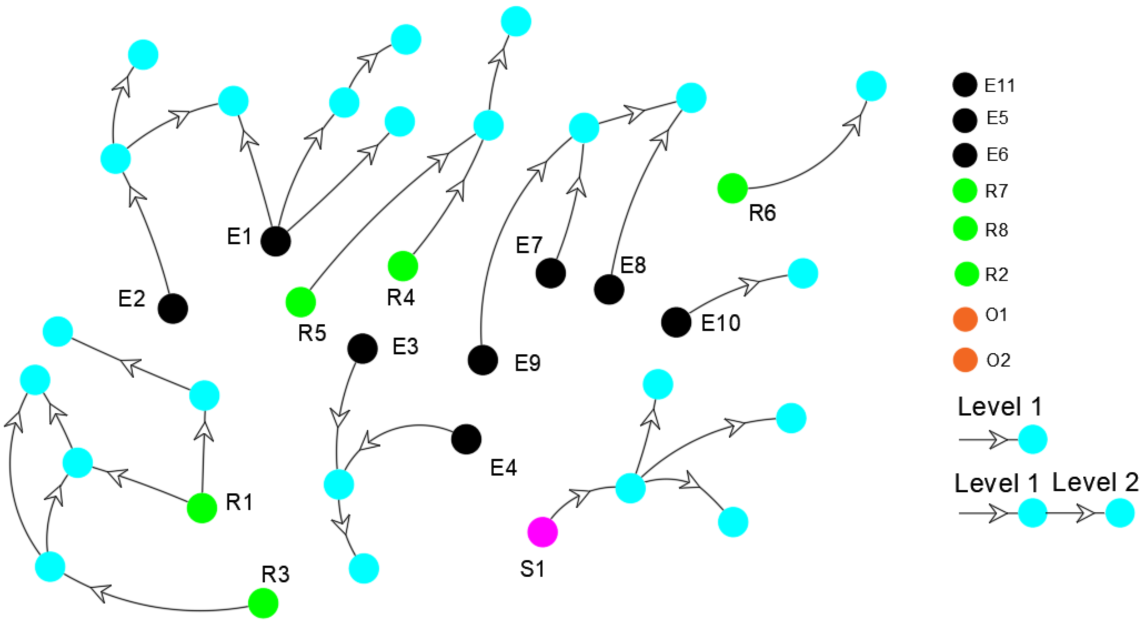



**Figure 18.** Case study: P_4a.

In Figure 18, the blue dots represent the people that were nominated by the open innovation team as they answered questions 1 and 2. For example, actor E10 answered question 1, saying that he knows only one person (level 1) who could potentially be an early adopter of a new process under development. For question 2, actor E10 mentioned nobody, which means that he is not aware if the person he nominated for question 1 is a potential early adopter or knows somebody that also could be a potential early adopter of the new process that is under development. On the other side, E3 and E4 nominated the same person (Level 2) as an answer for question 2. Applying (2) to the network in Figure 18 according to Table 4, the results are displayed in Table 10.

**Table 10.** Case study: S4a.

| Department/Actor | E1 | E2 | E3 | E4 | E7 | E8 | E9 | E10 | R1 | R3 | R4 | R5 | R6 | S1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Out-degree | 4 | 3 | 2 | 2 | 2 | 1 | 2 | 1 | 4 | 4 | 2 | 2 | 1 | 4 |

It can be concluded that about 64% (14 persons) of all the open innovation actors named, on average, another 2.42 persons (the rate between the sum of all out-degrees in Table 10 and the number of participants in the open innovation initiative that named somebody) as potential adopters (early adopters) of the innovation process outcome. The 23 nominated persons (blue dots in Figure 18) represent both the innovator and the early adopter groups. These should be properly addressed in order to help get through the chasm and efficiently help to diffuse the innovation outcome as the theory of innovation diffusing stipulates [86].

## 5. Conclusions, Implications, and Further Developments

This work proposed a model to manage three major collaborative risks ((1) partner choice risks, (2) task assignment risks, and (3) behavioral risks) that may emerge as organizations engage in collaborative initiatives under the open innovation umbrella, where the innovation development process is guided and controlled by the hybrid stage-gate framework. The proposed model divides a typical innovation process into four distinct parts ((1) setting up, (2) blending, (3) developing, and (4) diffusing), providing a structured management framework for each one of the parts. In part 1, the model addresses the partner choice risks. In this part, the model sets the type of innovation to be conducted under the open innovation and hybrid stage-gate frameworks and analyzes the capabilities of each potential partner to take part in the collaborative initiative. As can be seen in the case study, this part of the model contributes to identify the "best possible" arrangement of partners based on data analysis in order to minimize the emergence of potential task assignment and behavioral risks. In part 2, the model addresses the task assignment risks. In this part, the model manages the intellectual property rights and legal aspects of the collaborative process. It also addresses the task assignment risks in order to minimize or eliminate any mismatch regarding the attribution of specific collaborative tasks and activities, assuring the correlation between necessary skills and tasks and activities—in other words, assuring that there is an optimal correspondence between a given skill and a given task or activity. The novelty in this part is that the model enables screening out, in a measurable way, which stakeholder is best positioned to execute given tasks, and activates not solely relying on a stakeholder's official position within an organization and influence, rather by combining information collected by the administration of a strategic SNA survey. For example, this is observable in the case study, as the proposed model discovered that some sales and services employees could potentially have valuable know-how for the innovation initiative, and otherwise would easily be neglected. Another example of the importance of the proposed model is also illustrated in the case study part 3, as a few surprises came to the management team—MNE3 in Figure 12 was only counting that the "smartest" people would be in the R&D department; however, it turned out that after the SNA assessment was conducted, actor S1 was indicated as having valuable input regarding plant equipment. Finally, this part of the model also addresses the diversity and inclusion aspects in the process of selecting partners and promotes cross-functional connections contributing to minimize the potential emergence of organizational silos right from the beginning of the collaborative process. In part 3, the model addresses the behavioral risks. In this part, the model guides the collaborative process by continuously monitoring the interactions among the different stakeholders looking for trends that indicate the emergence of collaborative risks. As illustrated in the case study, this part of the model is critical because it is the part where it controls the evolution of a collaborative initiative regarding the interactions of the different stakeholders. For example, as illustrated in the case study, the proposed model discovered that actor E9 had a disproportional central role within the open innovation ecosystem by measuring (applying network graph theory) the data collected from three strategic survey questions addressed to the collaborative ecosystem. The model identified that as a consequence of E9's almost absolute information flow, control, and decision-making-controlling position, it had turned out that there was an information bottleneck, with the highest delay of about 32 h, ~1.2 days regarding answering emails providing project information or feedback. This discovery of the proposed model is particularly critical because it clearly indicates the existence of a huge dependency degree from other actors of the collaborative ecosystem regarding E9. This is a behavioral risk that may put at risk all the collaborative efforts of the innovation process presented in the case study. In part 4, the model addresses the partner choice risks. In this part, the model quantitatively measures the potential adoptability rate of a developed or developing product or solution by applying network graph theory. As illustrated in the case study, the proposed model identified that 64% (14 persons) of all the open innovation actors named, on average, another 2.42 persons as potential adopters (early adopters) of the innovation process outcome. This enabled the sponsoring organization to clearly target that group of potential early adopters in order to increase the success of the innovation.

### *5.1. Academic Implications*

From an academic perspective, the 4-OI model acts as an integrator between two existing models, which is in line with [23], which argues that instead of building models from scratch, liable to unknown threats, one should adapt and integrate existing ones. The proposed model in this work also gives an answer to the following research question: *to which extent does the application of graph-based centrality metrics contribute to a better identification and understanding of how mentioned collaborative risks may impact open innovation initiative development and outcomes?*

It has been demonstrated throughout the application of the case study presented above that the application of graph-based centrality metrics clearly contributes to a better identification and understanding of how the mentioned collaborative risks may impact open innovation initiative development and outcomes. The 4-OI model is also in line with the latest research regarding the management of open innovation initiatives that argues that collaborative initiatives (innovation initiatives) that have more control have better outcomes than those that are less controlled [22]. By applying graph-based centrality metrics to quantitatively measure three different collaborative risks [26], the proposed model enables a better understanding of how dynamic interactive behaviors really influence outcomes in organizations, and, thus, provides valuable insight to the social capital organizational and human risk management fields. In other words, the proposed model eliminates, to a great extent, the "use" of *gut feelings* in decision making, contributing to bias reduction in decision making. This is also in line with the latest research that argues that gut feelings are mostly harmful in decision making [87,88]. The proposed model also enables the quantification of how much the dynamic interaction of formal and informal collaborative networks influences innovation development and outcomes, which provides complementary perspectives to the existing literature that argues the importance of networks of collaboration and their effective management as being critical for the success of organizations [12,14,22,89], and research that points in other directions, arguing that other factors are of most importance for innovation and performance [27]. Finally, the presented work holistically contributes to the development of the application of the hybrid stage-gate model under the open innovation umbrella, contributing to a better understanding of how this approach benefits organizations in their collaborative initiatives as a subject that needs to be further researched, as suggested by the literature [60].

### *5.2. Managerial Implications*

From a managerial perspective, the proposed model in this work provides organizations with a set of benefits in different dimensions, as illustrated across the different phases of the presented case study. First, acting as an integrator between existing models, the proposed model minimizes the usage risks and necessary resources associated with the implementation of new models. Second, dividing the innovation process into four distinct parts provides organizations with a clearer structure of the innovation process where bureaucratic work can be clearly divided from core innovation work. This facilitates the management of resource allocation and the monitoring and controlling of collaboration between the different entities of the innovation ecosystem. Third, defining different innovation dimensions in part 1 (Figure 2, and Table 5) enables organizations to better visualize the articulation between them, which, in turn, provides organizations with a structured framework in the decision making process regarding organizational strategies to apply in the innovation process, tackling subjects such as which management and leadership style should be adopted, how to prepare the management of diversity and inclusion, what resources are needed and how to best allocate them, and so on. This also enables aligning the necessary efforts with the different organizational high-level strategies. Fourth, the proposed model in this work identifies and quantitatively measures the emergence of collaborative risks (partner choice, task assignment, and behavioral risks) as organizations engage in open innovation initiatives by the application of network graph-based metrics that will analyze data collected in strategic SNA surveys, online information, and project email exchange. Applying network graph-based centrality metrics to quantify dynamic behaviors of collaborative networks enables organizations to incorporate such behaviors in the organizational decision making process, contributing to a more data-driven approach, minimizing or eliminating the very popular and dangerous *gut feelings* and the "very likely" biased recommendations of influent (formal or/and informal) actors as they make use of heuristics such as representativeness, availability, and anchoring and adjustment to draw non-programmed decisions. In other words, the proposed model can be used to identify unbalanced collaboration between the different partners of open innovation initiatives such as disproportionate control or influence from some actors over others; identify collaborative overload or lack of collaboration, bottlenecking, delays, functional silos, potential burn-outs, lack of diversity and inclusion, intense or poor connection to the external environment; and forecast the adoption likelihood of open innovation outcomes. This, in turn, acts as a holistic continuous risk management process regarding the interactions of the different stakeholders in collaborative initiatives that contribute to the development of organizational strategic, tactical, and operational strategies.

### *5.3. Suggestions for Future Research*

Regarding suggestions for future research, there are three key aspects to consider. First, the quality of necessary data to map critical networks is participant-dependent regarding how information really mirrors the reality regarding the dynamic collaboration. This occurs as strategic SNA surveys are conducted and where the answers obtained may be, to a certain extent, biased. Second, although the proposed model collects data from project emails, from SNA surveys, and from online research, it is common that project-related matters are discussed through other communication channels such as phone or personal conversations. However, due to ethical and legal aspects (GDPR issues), these are not allowed to be captured by the proposed model. In this line of thought, new non-intrusive and unbiased data collection methods should be developed to address this issue. Finally, the continuous research and development of new graph-based centrality metrics to analyze interactive dynamic collaboration from as many angles as possible is recommended to get a realer picture of how formal and informal networks of relationships evolve and influence the environment where they exist.

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