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Measuring project performance by applying social network analyses

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A B S T R A C T

It is often argued that the core of organizational success is efficient collaboration. Some authors even posit that efficient collaboration is more important to organizational innovation and performance than individual skills or expertise. However, the lack of efficient models to manage collaboration properly is a major constraint for organizations to profit from internal and external collaborative initiatives. Currently, much of the collaboration in organizations occurs through virtual network channels, such as e-mail, Yammer, Jabber, Microsoft Teams, Skype, and Zoom. These are even more important in situations where different time zones and even threats of a pandemic constrain face-to-face human interactions. This work introduces a multidisciplinary heuristic model developed based on project risk management and social network analysis centrality metrics graph-theory to quantitatively measure dynamic organizational collaboration in the project environment. A case study illustrates the proposed model's implementation and application in a real virtual project organizational context. The major benefit of applying this proposed model is that it enables organizations to quantitatively measure different collaborative, organizational, and dynamic behavioral patterns, which can later correlate with organizational outcomes. The model analyzes three collaborative project dimensions: network collaboration cohesion evolution, network collaboration degree evolution, and network team set variability evolution. This provides organizations an innovative approach to understand and manage possible collaborative project risks that may emerge as projects are delivered. Organizations can use the proposed model to identify projects' critical success factors by comparing successful and unsuccessful delivered projects' dynamic behaviors if a substantial number of both project types are analyzed. The proposed model also enables organizations to make decisions with more information regarding the support for changes in observed collaborative patterns as demonstrated by statistical models in general, and linear regressions in particular. Further, the proposed model provides organizations with a completely bias-free data-collection process that eliminates organizational downtime. Finally, applying the proposed model in organizations will reduce or eliminate the risks associated with virtual collaborative dynamics, leading to the optimized use of resources; this will transform organizations to become more lean-oriented and significantly contribute to economic, social, and environmental global sustainability.

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1. Introduction

It is often argued that organizations wanting to achieve sustainable advantages—or simply survive—in today's unpredictable business landscape must excel in performance and innovation (Nuryakin, 2018; Ng and Law, 2015; Adro and Leitao, 2020; Vagnani and Volpe, 2017). While these two factors are critical for an organization's survival, they depend on several interrelated factors, such as the organization's structure, motivations, leadership style, technologies, resources, differences in geographic locations and time-zones, and cultural fit (Hansen, 2009; Lutfihak and Evrim, 2016; Lee et al., 2017).

There are several ways to measure organizational performance. For example, it can be measured by analyzing a set of organizational characteristics, such as marketing, operations, human resources, and strategy (Richard et al., 2009). More concretely, some authors argue that the measuring of organizational performance involves three specific areas: (1) financial performance, which is comprised of profits and returns on assets and investments; (2) product market performance, or the organization's sales and market share; and (3) shareholder returns, or the total shareholder returns and economic value added, among others.

According to several researchers, the measurement of performance is a dependent variable (Richard et al., 2009). In this line of thought, organizational performance can also be measured by analyzing how collaboration occurs internally—within and between different functional departments within an organization, and externally—between a given organization and its customers, suppliers, and the broader society; subsequently, these can be correlated with organizational outputs and outcomes (Nunes and Abreu, 2020a; Workday studios, 2018).

Collaboration is a broad term that can include several dimensions, such as communications, exchange of information, providing advice or support, teaching, elaborating upon written or graphical reports, or even conducting presentations (Abreu and Camarinha-Matos, 2010; Nunes and Abreu, 2020a). Often, effective collaboration is the greatest success factor in organizational performance (Workday studios, 2018). In fact, literature demonstrates that one of these key factors in the modern business landscape—if not the major factor—involves how well organizations can work internally and externally in collaborative networks (Pertusa-Ortega and Molina-Azorin, 2018; Arena, 2018; Krackhardt and Hanson, 1993; Nunes and Abreu, 2020c; Workday studios, 2018).

In this modern business landscape, organizations recognize that the ability to join forces—whether internally, or between different functional departments, and externally, or between such different organizations as research institutes, universities, and even competitors—is vital to achieving fruitful common outcomes and a sustainable competitive advantage (Chesbrough, 2020; Workday studios, 2018).

One popular approach organizations can adopt to facilitate these achievements involves engaging in collaborative projects, or “open innovation” projects (Brunswicker and Chesbrough, 2018; Chesbrough, 2003, 2020; KPMG, 2016). Recent research has noted that engagement in open innovation projects has reached up to 78 percent of companies in North America and Europe (Chesbrough, 2020).

Further, literature also indicates that working in collaborative networks supported with diversity and inclusion (Bouncken et al., 2015; Hewlett et al., 2013) and efficiently distributed across different organizational functions, geographies, and technical expertise domains (Cross, 2013) strongly contributes to the efficient achievement of competitive advantage (Pertusa-Ortega and Molina-Azorin, 2018; Arena, 2018).

Much of the current collaboration in organizations occurs through virtual networks, such as e-mail, Yammer, Jabber, Microsoft Teams, Skype, and Zoom. Such virtual communication channels gain even higher importance in times of constraints to face-to-face human interactions, including changes to flexibility needs, different time zones, or even the threat of pandemic (Wang et al., 2021).

Some authors argue that the network factor regarding innovation and organizational performance is a greater predictor of success than individual competencies and knowledge, and especially if such collaborative networks are built with positive energy, reach, and diverse problem-solving skills (Cowen et al., 2017; Krackhardt and Hanson, 1993; Workday studios, 2018). However, if such collaborative networks are not efficiently managed, they may become burdens to organizations and ultimately threaten their chances of success (Dutton, 2008).

Most organizations have a formal structural diagram or chart known as a “formal network” that represents a designated chain of authority; this is often ruled by a rational-legal authority system based on universalistic principles that are understood as fair that determine the line of command and official responsibilities. However, the informal network is another type of organizational network that typically exists hidden behind an organization's formal chart (Kadushin, 2012). These informal networks are initially difficult to observe, and are often responsible for how work really occurs in organizations (Cross et al., 2016; Kadushin, 2012).

Such informal networks are not ruled by the formal network's rational-legal authority system, but rather by unbalanced or particularistic aspects, such as friendship, propinquity, homophily, or trust; these are characteristic of individuals' personal and social needs (Kadushin, 2012). Some authors argue that informal networks are almost entirely responsible for how organizations solve problems, capitalize upon opportunities, and generate satisfaction and employee retention (Arena, 2018; Cross & Prusak, 2002; Kadushin, 2012).

Several researchers have indicated that it would be difficult—if not impossible—for organizations in today's business environment to be competitive and complete workplace projects if their employees rigidly adhere to their formal chart obligations regarding their work tasks and activities. In other words, this indicates a lack of agility, flexibility, empowerment, and nimble response, which are considered the “seeds of death” (Arena, 2018; Workday Studios, 2018; Abreu and Nunes, 2020).

In this line of thought, some authors argue that organizations must discover new ways of working (Workday studios, 2018). They also indicate that these new methods directly imply the development of new ways of thinking about work, and consequently, perceiving organizations less as monolithic pyramidal structures and more as emerging, self-organizing network structures in which people form and reform to get work done (Workday studios, 2018).

Research demonstrates that it is nearly impossible to distinguish whether the relationships between organizational entities (employees) are formal or informal (Björkman and Kock, 1995; Kontinen and Ojala, 2011). Further, work in these organizations occurs through a combination of formal and informal collaborative networks (Kadushin, 2012). These informal networks may become formal, and vice versa (Kontinen and Ojala, 2011), which indicates that a blurred line exists between informal and formal networks in an organization.

Several studies also reveal that if the combination of formal and informal collaborative networks are not effectively managed, this will harm an organization's performance and innovation capacity; this will eventually either evolve to a collaborative overload or a lack of collaboration (Arena, 2018; Cross and Prusak, 2002; Cross, Rebele, & Grant, 2016). Such a negative evolution can be characterized as involving collaborative risks, such as behavioral or task assignment risks, or risks in selecting critical partners (Abreu et al., 2018). Further, the negative evolution of organizational collaborative networks can also lead to the emergence of four high-level project risk types as proposed by Hillson (2014): (1) event-based, (2) variable, (3) ambiguous, and (4) emergent risks.

The lack of efficient models to support collaborative networks’ management creates even more entropy in the organizational structure; this increases the difficulty in managing collaborative network activities, and in most cases, such management is impossible for these organizations (Santos et al., 2019; Nunes et al., 2020).

Authors, researchers, and institutes have highlighted the efficient management of collaborative networks as a critical factor that both positively and negatively impacts project performance and outcomes (Cross and Prusak, 2002; Cross et al., 2016).

Several studies have also demonstrated that the only efficient approach to manage formal and informal organizational networks involves the application of graph-based social network analysis centrality metrics (Cross, 2013; Cross & Prusak, 2002; Cross et al., 2016; Nunes & Abreu, 2020a). The social network analysis is used to model pairwise relationships between dynamic entities, such as people or organizations, to assist in explaining how social structures not only evolve across time and space, but also impact the environment in which they emerge and exist (Nunes and Abreu, 2020a).

Although the potential benefits from applying a social network analysis (SNA) in organizations to manage their combinations of formal and informal networks are well-documented throughout literature, most organizations have still not integrated the SNA into their organizational strategic management processes due to a failure to understand how the SNA functions and should be applied (Arena, 2018; Nunes and Abreu, 2020a; Workday Studios, 2018).

Therefore, this work introduces a heuristic model: the dynamic collaboration in networks to measure project performance model (DCN-PP). This has been developed based on two scientific concepts—(1) the SNA and (2) project risk management.

In summary, the proposed model in this work aims to understand and provide meaningful input to answer the following research question:

> To what extent does dynamic collaboration in the organizational virtual networks that emerge and evolve across the different phases of a given project lifecycle impact project performance and outcomes (success or failure)?

To answer this question, the model proposed in this work will access and analyze two different collaborative dimensions. As the first dimension, e-mail characterizes the collaborations that occur through the traditional electronic information exchange across the different phases of a project's lifecycle, in which a more detailed, comprehensive information exchange type is traditionally expected. The second dimension is iTools, which characterizes the collaboration that occurs through virtual tools that enable a given type of instant communication. This can include either written correspondence or video calls, such as web meetings, which traditionally involve a less detailed and comprehensive type of information exchange.

The proposed model in this work analyses the dynamic collaboration among the combinations of formal and informal networks that emerge across the different phases of a project lifecycle in three different but interrelated dimensions: (1) network collaboration cohesion evolution (NCE), or how collaboration cohesion evolves over time, measured by the number of e-mail communication channels generated across the project lifecycle; (2) network collaboration degree evolution (NDE), which represents the evolution of the average insight and active participation among the elements comprising a project's social network across the project lifecycle, measured by the average number of direct and weighted e-mail communication channels; and the (3) network team set variability evolution (NTVE), which represents the evolution of a given team set's variability across a project lifecycle and is measured by the variability of participation in virtual project meetings.

As previously mentioned, the proposed model in this work was developed based on two principal scientific fields: project risk management and the SNA. The project risk management scientific field has two components. The first component is project management, which contributes to the proposed model with the typical project management definitions, such as the definition of a project, project lifecycle, or project phases. The second component is risk management, which contributes to the proposed model with the most common risk management approach and process that is utilized in the processes of identifying, analyzing, measuring, treating, and monitoring dynamic collaborative risks that may arise as projects are delivered.

The SNA scientific field contributes to the proposed model in this work with the tools and techniques to quantitatively measure the dynamic collaboration in the NCE, NDE, and NTVE as three different but interrelated dimensions.

The application of the SNA to quantitatively measure dynamic collaborations across the different phases of a project lifecycle is critical to the proposed model. This is because it enables the transformation of typically non-measurable or qualitatively measured organizational components—such as collaborations that may include communications, information exchanges, or problem-solving—into quantitatively organizational components. This transformation will enable organizations to observe collaborations from a more data-driven perspective, which will subsequently help organizations to make more data-informed decisions regarding components that are traditionally and almost exclusively managed in a qualitative manner (Impink et al., 2020; Nunes & Abreu, 2020a).

Thus, the proposed model aims to not only understand how performance is affected by the dynamic mix of formal and informal networks across a project lifecycle, but also provide meaningful, unique, and actionable insight to the decision-making process regarding how to best manage the collaborative dimensions of a virtual project team.

1.1. Relevance and novelty of the research in the present work

The proposed model addresses several relevant aspects of collaborative organizational initiatives. From a high-level perspective, this model aims to contribute with meaningful and valuable insights to answer.

By providing meaningful and unique insights that answer this question, the proposed DCN-PP model directly addresses the potential collaborative project risks that may emerge and evolve as projects are delivered across the different phases of a project's lifecycle. These risks include: (1) behavioral risks, (2) risks from assigning tasks to partners, and (3) risks from selecting critical partners (Abreu et al., 2018), and (4) the ambiguity risk type, which is one of four high-level typical collaborative project risks proposed by Hillson (2014).

The proposed model provides organizations a heuristic model to help them holistically manage networks of collaboration, or the combinations of formal and informal relationships that emerge and evolve between the different persons, groups, or organizations that engage in collaborative networks while delivering projects.

According to modern research (Arena, 2018; Narsalay, 2016; Nunes and Abreu, 2020c), the combination of formal and informal collaborative networks must be managed in a more hands-on approach to achieve successful outcomes, in contrast to a more distanced approach.

The former approach is characterized by a more proactive, continuous control over collaborative project networks to avoid leaving any incoming strategic, operational, and cultural issues or differences to chance, or handling management through a more reactive perspective.

The proposed model analyzes how virtual collaboration emerges and evolves in e-mails and iTools communication channels. Subsequently, this enables organizations to quantify the extent to which more- or less-centralized collaborative network structures can positively or negatively influence project outcomes.

The obtained results contribute to current literature in two ways. First, they can support theories that posit that the effective management of the combination of formal and informal collaborative networks is a critical factor to enhance organizational performance and innovation (Müller et al., 2020; Krackhardt and Hanson, 1993; Arena, 2018; Urze and Abreu, 2016; Nunes and Abreu 2020b). Second, they can reinforce theories that defend the notion that no direct or indirect relationship exists between such management and organizational performance and innovation (Ng and Law, 2015).

Nonetheless, the proposed model aligns with the organizational digital transformation strategy and Industry 4.0 concepts (Digital Transformation Monitor of the European Commission, 2017; Müller et al., 2020), as it standardizes the process to measure organizational performance in a more data-driven way by analyzing dynamic virtual collaborative networks. This enables the implementation of and transformation toward an autonomous, continuous improvement performance management cycle—or a supervised machine-learning model—that self-updates and optimizes.

Finally, this model quantitatively measures the potential influence from the combination of formal and informal collaborative networks on organizational performance to enable managers to make more data-informed decisions. Consequently, this enables a more effective planning process that reduces or eliminates the risks associated with virtual collaborative dynamics. The results from this process include the optimization of resource usage to compel organizations to become lean-oriented; in turn, this strongly contributes to economic, social, and environmental global sustainability.

1.2. Structure of the present work

This work is divided into five chapters to introduce a heuristic model to help organizations understand the extent to which organizational, virtual collaborative networks influence project performance and outcomes.

Chapter 1 (Introduction) introduces the proposed model, the motivation for its development, the principal scientific fields that support this development, and the individual contributions from each scientific field to such development.

Chapter 2 (Literature Review) provides an extensive overview of literature regarding the two scientific fields that support the proposed model's development: (1) project risk management and (2) the SNA. This also highlights the most relevant contributions from each of these scientific fields in developing the proposed model.

Chapter 3 (Model Development and Implementation) describes the functioning principles and steps in applying the proposed model. These include the research methodology; the model's key concepts, centrality metrics, and implementation process; the span of its application, and any legal and ethical considerations.

Chapter 4 (Application of the DCN-PP Model—A Case Study) illustrates the proposed model's application in an organization across several virtual projects conducted in 2020. This chapter details how the model is applied and how it helps organizations to measure project performance.

Chapter 5 (Discussion, Conclusions, Implications, and Further Developments) summarizes and discusses the major conclusions regarding the proposed model's development and application. It includes not only research implications, or specifically, how this research enhances the two scientific fields that support the proposed model's development, but also managerial implications, or how organizations can benefit from applying the proposed model. This chapter concludes by discussing the work's limitations and enumerating several suggestions for further research and development of the proposed model.

2. Literature review

2.1. Project risk management

According to several renowned project management institutes and organizations, a project can be defined as a transient endeavor with a well-defined start and end that aims to create a unique product, service, or value through a set of coordinated and controlled activities (PMI, 2017; APM, 2021; ISO, 2021).

It is through projects' implementation that organizations deliver value and execute their strategies (PMI, 2017; Nunes and Abreu, 2020b). However, efficient management must occur for organizations to achieve success through such implementation (PMI, 2017; Nunes and Abreu, 2020b; APM, 2021).

Organizations possess a set of tools and techniques developed by renowned international project management institutes and organizations to manage and deliver projects efficiently, such as the PMI (2017), APM (2021), and ISO (2021).

Such tools and techniques are essentially a set of best practices based on lessons learned that have been collected across many years of experience in delivering both physical and software projects; these are also supported by mathematical methods that include statistics and probability (PMI, 2017; APM, 2021; ISO, 2021; Nunes and Abreu, 2020a).

For example, the PMI (2017) defines project management as the application of knowledge, skills, tools, and techniques to project tasks and activities to meet project requirements across all the different phases of a project's lifecycle.

Regardless of how an organization is equipped with the latest project management tools and techniques, delivering projects always includes both positive risks, or opportunities; and negative risks, also known as threats (APM, 2021; ISO, 2021; Nunes and Abreu, 2020a; PMI, 2017).

Risk can be defined as an uncertain event or a set of circumstances that, should they occur, will (positively or negatively) affect the achievement of one or more objectives (PMI, 2017).

In projects, such uncertain events reference the potential impacts on project tasks and activities, such as a project's scope, quality, schedule, costs, and resources (PMI, 2017; APM, 2021; ISO, 2021).

Organizations efficiently manage the risks that may emerge as projects are delivered by conducting risk assessment activities. These essentially include risk identification, analysis, or mitigation; risk response planning; the implementation of procedures to respond to risk; and risk monitoring (PMI, 2017; APM, 2021; ISO, 2021). The ISO (2021), in particular, has suggested one global consensus and applied approach to managing risk in organizations—which includes a set of principles, one process, and one framework—in its 31000:2018 standard.

In this standard, a set of well-defined principles aim to create value by effectively identifying and treating risks in a timely manner, supported in six well-structured steps (ISO, 2021): (1) Establishing scope, or defining risk management scope activities, which include internal and external contexts. In these, organizations seek to define and achieve their objectives and focus on risk criteria, or the amount of risk that an organization is willing to accept. (2) Identifying risk, which consists of finding, recognizing, and describing the risks that might help or hinder an organization from achieving its objectives. (3) Performing a risk analysis to understand the nature of risk; uncertainties; risk sources; consequences; the likelihood of risk; risk events or scenarios; and risk controls and their effectiveness. (4) Evaluating risks, which involves an efficient, effective risk analysis to establish risk criteria and determine the areas requiring additional action. (5) The treatment of risk, which includes monitoring plans. Finally, (6) The previous steps must be recorded and reported, or the evolution of identified risks and the efficacy of applied controlled measures must be continuously monitored and reviewed.

These six steps are a standard risk-management process typically used by organizations to manage risk, whether threats or opportunities (PMI, 2017; APM, 2021; ISO, 2021).

In a project management context, risk can be simply defined as the uncertainty that matters (Hillson, 2014). According to Hillson (2014), an international project risk management expert and thought leader, four major types of project risks exist: (1)

event, (2) variability, (3) ambiguity, and (4) emergent risks. Table 1 briefly describes these four types of risks, their respective associated uncertainties, and the suggested management approach for each as suggested by Hillson (2014).

Project risk management from a holistic perspective—or in the merging of both project and risk management as much as possible—can be comprised of well-defined and structured steps. These can include a set of tools and techniques based on the best practices and supported by mathematical approaches to manage projects' risks, such as the event and its variability, ambiguity, and emergent risks that may emerge across the different phases of a given project lifecycle.

The proposed model in this work is a project risk management tool or technique that specifically addresses ambiguity risk as illustrated and described in Table 1. It provides organizations a unique, meaningful, and actionable collaborative historic evolution by examining the lessons learned when addressing risk. Namely, the work analyzes how virtual collaborations occurred in the different phases of a project's lifecycle, and to a certain extent, how such virtual collaborations may correlate with project outcomes. The proposed model will help organizations to better identify and manage collaborative virtual risks in a more efficient and timely manner.

2.2. Social network analysis in organizations

Psychiatrist, psycho-sociologist, and educator Jacob Levy Moreno (1889–1974) first used graph theory in the 1930s to analyze the relationships between dynamic entities, such as persons, groups, or organizations (Wasserman & Faust, 1994; Scott, 2017; Borgatti, 2016).

Today, better known as social network analysis (SNA), is defined as a process of studying and analyzing social structures data, with a variety of metrics developed based on graph theory that explains how social structures evolve across time and how they impact the environment where they do exist (Nunes and Abreu, 2020a; Durland and Fredericks, 2006).

The SNA can be defined as a specific set of connections among a defined set of persons, with the additional property that these connections' collective characteristics may be used to interpret the social behavior of the persons involved (Mitchell, 1979).

The application of SNA involves a variety of different fields, such as organizational science, management, and leadership (Kacanski and Lusher, 2017); political science (Ward et al., 2011); behavioral science (Clifton and Webster, 2017); communication, learning, and media (Jarman et al., 2014); and law, criminology, and terrorism (Maghraoui et al., 2019).

The SNA has also been applied to study social structures and has gained significant popularity owing to the desire to understand the extent to which people's dynamic relationships influence other people and outcomes, such as performance, innovation, social cohesion, or even information diffusion (Borgatti, 2016; Harary, 1969). In fact, it is difficult to find something that is not connected in some way (Nunes and Abreu, 2020a).

Such relationships are complex in nature, and cannot be entirely explained with traditional theory and data analysis methods, but rather by methods that are based in sociology, because they consider the individual's social context in the decision-making process (Borgatti et al., 2017).

The SNA offers unique insights regarding the study, understanding, and development of organizational theory, and especially regarding its dynamic component (Tichy et al., 1979). Applying SNA in organizations provides valuable insights regarding social capital challenges (Abreu and Camarinha-Matos, 2010). It is also used to study talent shortages and retention, competencies, network collaborations, innovation, collective and individual performance, cultural fit, values, unethical behavior, low morale, employee wellness, noncompliance with industry regulations, and fraud (Meyer et al., 2011).

Recently, the SNA has also been incorporated into organizational risk management approaches as a supportive tool for decision-making and risk analysis (Organizational Network Analysis Gain insight drive smart, 2016).

Although still in an initial phase, the application of SNA has expanded to diverse scientific areas, such as project management (Ruan et al., 2011).

Table 1
Types of risks and their respective uncertainties (Hillson, 2014; Nunes and Abreu, 2020b).

Risk types	Uncertainty types	Brief description	Management approach
Event Risk	Stochastic uncertainty	Also known as event risks, these relate to something that has not yet happened or may not happen at all; however, if it does happen, it will impact at least one project objective	A set of well-established techniques for identifying, assessing, and managing these risks based on risk management standards and best practices
Variability risk	Aleatoric uncertainty	Includes several possible known outcomes, but one does not know which will actually occur	The application of advanced analysis models, such as the Monte Carlo simulation
Ambiguity risk	Epistemic uncertainty	Also known as “know-how” and “know-what” risks, these include the use of new technology, market conditions, and competitor capabilities or intentions, among others	Learning from past experience and the lessons learned. Prototyping and simulations are the best methods to manage such risks
Emergent risk	Ontological uncertainty	Also known as “Black Swans,” emergent risks cannot be seen because they exist outside a person's experience or mindset. These typically arise from game-changing and paradigm-shifting events, such as the release of disruptive inventions or products	Contingency planning is key to managing such risk

In project management, the SNA is primarily applied to identify the critical success factors regarding the dynamic combinations of formal and informal project social networks that may positively and negatively may impact project outcomes, with several works published in recent years to substantiate this trend (Carlsson and Sandström, 2008; Newig et al., 2010).

For example, Krackhardt and Hanson (1993) applied the SNA to identify three critical collaborative organizational networks: (1) the advice network, which reveals the people to whom others turn to in successfully completing a project; (2) the trust network, which identifies who shares sensitive information with whom; and (3) the communication network, which demonstrates who talks to whom regarding work-related matters.

Mead (2001) applied the SNA to visualize project stakeholders' informal communication network; identifying central and isolated stakeholders helped him to create a corrective plan to improve poorly integrated (peripheral) stakeholder performance.

Cross and Parker (2004), in his work "The Hidden Power of Social Networks," identified a set of informal roles that exist in all organizations regardless of their size, culture, or structure that are typically responsible for how work gets done in organizations (Cross and Parker, 2004): (1) central connectors, or the people who many others rely on regarding advice or problem-solving; (2) boundary spanners, or the people who connect an organization to its external environment; (3) information brokers, or the people who connect two different organizational functions or departments; (4) peripheral experts, or those who are experts but isolated from most of their co-workers; (5) those with peripheral intentions, or the people isolated due to non-integration; and (6) energizers, or people who energize others in a positive way.

Similarly, Prell et al. (2009) applied the SNA to identify and analyze stakeholder networks in natural resource management projects to pinpoint critical stakeholders.

Toomey (2012) identified four aspects of SNA theory that are critical in projects' development and outcome (success or failure): (1) centrality, (2) structural holes, (3) boundary management, and (4) tie strength.

Subsequently, Mok et al. (2017) applied SNA centrality metrics to identify key challenges in major engineering projects based on interdependencies between critical stakeholder concerns. This resulted in not only the dentification of many critical challenges that had occurred, but also aiding in the development of a set of beneficial practices to be used in future major engineering projects.

Arena (2018) applied the SNA to identify the "adaptive space" as an organizational area, defined as a virtual place that enables an effective connection between the operational and entrepreneurship pockets in an organization; employees in these connections explore new ideas and empower the most creative ones to improve organizations' agility. Further, the centrality in social networks refers to the structural location of an entity's combination of formal and informal relationships, rather than to its own inherent attributes such as age, tender, gender, or official role (Nunes and Abreu, 2020a).

Research suggests that centrality is the measure of an entity's importance, influence, prestige, control, and prominence within a given network, or the function of an entity's specific structural location within the network; this can be quantitatively measured by the application of graph theory centrality metrics, such as the degree, betweenness, and closeness (Freeman, 1979; Ove, 2002).

For example, a person with a high degree of centrality within friendship, respect, or advice networks may have many advantages. For example, others may perceive him or her as powerful or prestigious, highly influential, and with the ability to obtain resources (Nunes and Abreu, 2020a).

Research also indicates that for each SNA centrality metric, the following respective social implications may exist (Freeman, 1979): (1) the organization's degree of activity, which can be identified and measured by applying the degree centrality metric; (2) control, which can be identified and measured by applying the betweenness centrality metric; and (3) independence, which can be identified and measured by applying the closeness centrality metric.

Finally, network centrality is essentially and directly associated with the power that exists in informal social networks (Cross et al., 2016; Monge and Eisenberg, 1987). More often than not, this will influence the coordination and decision-making processes in project management, which will consequently impact project performance and outcomes (Dogan et al., 2013; Wen et al., 2018).

3. Model Development and Implementation

3.1. Introduction to the DCN-PP model

The proposed DCN-PP model is primarily implemented to answer the following research question:

> To what extent does dynamic collaboration in the organizational virtual networks that emerge and evolve across the different phases of a given project lifecycle impact project performance and outcomes (success or failure)?

In summary, the proposed model will analyze how virtual collaborations occurred across a set of delivered projects by analyzing the following three different but interrelated dimensions:

(1) The network's collaboration cohesion evolution (NCE), which represents the evolution of the degree of collaborative cohesion across a particular period—typically the project lifecycle—as measured by the number of e-mail communication channels generated;

(2) The network's collaboration degree evolution (NDE), which represents the evolution of the average insight and active participation of the elements of a project's social network across the project's lifecycle, as measured by the average number of direct and weighted e-mail communication channels; and
(3) The network's team-set variability evolution (NTVE), which represents the evolution of the variability of a given project team set across a project lifecycle, as measured by the variability of the participation in virtual project meetings.

The proposed model in this work does not define the level of project performance (average, good, or bad) or outcome type (typically successful or unsuccessful); rather, this classification must involve the information provided before the model can identify the critical success factors from delivered projects.

Further, this model may cover other dimensions than merely identifying project performance, such as how efficiently information is exchanged or interpreted, or even the degree of satisfaction among project participants across a project's lifecycle.

Finally, the proposed model can be used to analyze the differences between successful and unsuccessful delivered projects. Specifically, the model can compare the network's dynamic evolutions of such projects as measured by applying the SNA's centrality metrics).

3.2. The DCN-PP model research methodology

The model proposed in this work results from the need to efficiently address the previously mentioned research question. It is supported by an extensive literature review as illustrated in the previous chapter regarding two scientific fields—risk in project management and the social network analysis—that support the development of the DCN-PP model.

The motivation for developing the proposed model is also connected to what has been previously, as indicated in the literature review. This essentially presented the benefits to organizations regarding innovation, performance, and competitive advantage from working in collaborative network models. Further, this demonstrates whether a correlation exists between the dynamic collaborative interactions between project team elements and a project's performance and outcomes.

The proposed model targets the collaborative networks that occur through virtual communication channels, such as e-mail, Yammer, Jabber, Microsoft Teams, Skype, and Zoom, which are essentially used to exchange project-related information.

The research methodology in this work follows a multidisciplinary and well-defined sequential approach essentially based on the literature review, which highlights the importance in applying SNA centrality metrics. These are the most appropriated and critical tool to identify the influence of collaborative networks—comprised of a combination of formal and informal relationships—in organizational outcomes. The proposed model's research methodology process involves the following steps:

First, the work defines the physical and spatial environment where the action occurs (a virtual project environment), as well as details regarding the subject (project collaborative networks). These include the project's typical structure (project lifecycle), work sequence (different project phases), and interdependencies (the dynamic connections between project participants).

Second, the work defines the different levels of collaboration in an organizational context (the communication and information exchanges) between the different entities designed to participate in the project.

Third, data collection methods are selected (virtual project meetings in general, or iTools in particular; and the exchange of project e-mails) that will support the DCN-PP model's structure.

Fourth, the most appropriated tools and techniques are selected to quantitatively analyze the collected data based on the SNA centrality measures, which are graph theory-based, such as the in-degree, out-degree, total degree, density, and average degree.

Fifth, the correlation is measured between the results obtained from applying the SNA centrality metrics and project performance. For example, this can be measured by the type of project outcome (successful or unsuccessful), team satisfaction level, or information exchange efficiency.

Finally, the work will identify projects' critical factors and the model results' suitability in supporting the organizational decision-making process.

3.3. The DCN-PP Model's key concepts

In introducing the DCN-PP model, some of its key concepts must first be illustrated and explained. As Table 2 illustrates, these include the project concept; the project phases, lifecycle, and outcome; the project's virtual channels (iTools) and project e-mail exchange; dynamic collaborative network dimensions; and project performance.

As Table 2 demonstrates, five key concepts in the proposed model must be clearly defined before the model's implementation and application.

Table 2
DCN-PP model's key concepts.

Key Concepts	Description
Project, project phases, & project lifecycle	The proposed model defines a project as a temporary endeavor to create a unique product, service, or result (according to the definitions proposed by the PMI, API, and ISO in the literature review chapter). Any given project has a set of well-defined project phases. However, the model does not examine a given or fixed number of project phases; in other words, the user can customize the number of project phases and the number of projects to be analyzed. Nevertheless, for analysis purposes all projects, whether successfully or unsuccessfully delivered, must have the same number of phases across the project lifecycle.
Project outcome	The proposed model includes only two types of project outcomes: the project was either successfully or unsuccessfully delivered. The proposed model does not define the criteria that determines both types of outcomes.
Project virtual channels (iTools) and project e-mail exchange	The proposed model defines a project's virtual channels as all the channels in which thought collaboration regarding a given project occurs (information exchanges, help or advice, or problem-solving, among others). Such channels are denoted as iTools in this work, and include such popular tools as Yammer, Jabber, Microsoft Teams, Zoom, and Skype. The project e-mail exchange is comprised of all the project-related e-mails that have been exchanged across a project's lifecycle, which illustrates the second type of dynamic collaboration between project collaborators.
Dynamic collaborative network dimensions	The proposed model defines dynamic collaborative networks as all the collaborations captured in three different interrelated dimensions: network collaboration cohesion evolution (NCE), network collaboration degree evolution (NDE), and network team set variability evolution (NTVE). Data from e-mail exchange communication channels will be used for the first two dimensions. Data from virtual project meetings will be used for the third dimension.
Project performance	A definition for project performance is outside of the proposed model's scope, as project performance is defined by previous information given before the proposed model's application. Typically, project performance is defined by a given project's outcome, often defined as successful or unsuccessful. This may be translated into having met (or not having met) all the project criteria as defined in the planning phase. Such criteria may include the project participants' degree of satisfaction, how efficiently the information was exchanged across the different project phases, or how efficiently the project's problem-solving network operated across the different phases of a given virtual project, among others.

3.4. The DCN-PP Model's dimensions, centrality metrics, and requirements

Table 3 illustrates the three different interrelated dimensions that the DCN-PP model will analyze: the NCE, NDE, and NTVE. This table also details the objectives of these dimensions, the metrics to be applied in each, and each metric's respective calculation process.

Table 3 illustrates the three different but interrelated dimensions to be addressed by the proposed model. This table also reveals that for each of the different dimensions (NCE, NDE, and NTVE), a specific SNA centrality metric will be applied to quantitatively measure the amount of dynamic virtual collaboration.

Table 4 displays the DCN-PP model's requirements, which refer to the necessary data to be used as input for the proposed model.

3.5. The DCN-PP Model's implementation steps

Implementing the proposed model requires a set of sequential steps for effective results.

First, a project team assigned to accomplish the project's objectives must be defined. This includes the number of people for specific contributions in a given project. The proposed model does not address the aim and scope of any given virtual project.

Second, the project team's information must be detailed and disclosed as indicated in Table 4, which essentially illustrates the data sources and required information.

Third, the different phases of a project must be well-defined across the project's lifecycle, as illustrated in Fig. 1.

Fourth, related project information should be divided into two categories. As Fig. 1 indicates, the first category ("E-mails") refers to the collaborations that occur through traditional e-mail information exchanges across the different phases of a project's lifecycle, which traditionally involves a more detailed and comprehensive information exchange. The second category ("iTools"; see Fig. 1) involves the collaboration that occurs through tools that enable a given type of instant communication, such as web meetings, in which a less detailed and comprehensive information exchange is anticipated.

Fifth, as illustrated in Table 4, data should be collected across all the phases of a virtual project's lifecycle.

Sixth, all collected data must be treated and quantitatively measured by applying the SNA centrality metrics as defined in Table 3.

Seventh, the DCN-PP model's output and results should be analyzed and correlated with a given customizable performance criteria as defined in Table 2. In this step, one common approach could include a comparison between successfully and unsuccessfully delivered projects to identify the critical success factors that drive successful project outcomes.

Finally, the results should be used as to quantitatively support virtual dynamic collaborations across project lifecycles in the organizational decision-making process.

Table 3
DCN-PP model's three interrelated dimensions.

Dimension	Description
(1) Network collaboration cohesion evolution (NCE)	**Brief description**: This dimension represents the evolution of collaboration cohesion across a period (typically the project lifecycle) as measured by the number of e-mail communication channels generated during that period. **Data source**: E-mails regarding project information **Calculation/output:** SNA Centrality Metric: In this case, *density* ($\boldsymbol{Ds}$) (Nunes & Abreu, 2020a, 2020b) will be used to characterize the number of e-mail communication channels that exist across the different phases of a project lifecycle. This is defined as $\boldsymbol{Ds} = \frac{N_{L\ REAL}}{N_{LMAX}}$ (1) where $N_{L\ REAL}$ is the existing number of ties (links) within a given graph (network). The maximum number of ties (links) is calculated as $N_{LMAX} = \frac{\boldsymbol{n}(\boldsymbol{n}-1)}{2}$ (2) where n denotes the number of entities (persons) within a graph (network).The output for this metric is: a) A numerical value ranging from 0 (no cohesion), to 100 or 1 (full cohesion regarding e-mail communication channels). b) An evolution across time throughout the different phases of a project's lifecycle, with output generated by applying the simple linear regression across the numerical results for the density in each project phase. c) The evolution across time as output from the linear regression may have three forms: 1. **Positive slope**: this indicates growth over time, or cohesion increases as the different project phases sequentially occur. 2. **Constant slope**: this indicates consistency over time, or an unchangeable degree of cohesion as the different project phases sequentially occur. 3. **Negative slope**: this decreases over time, or cohesion decreases as the different project phases sequentially occur.
(2) Network collaboration degree evolution (NDE)	**Brief description**: This dimension represents presents the evolution of the average insight and active participation of the elements that comprise a project's social network across its lifecycle, as measured by the average and weighted number of direct and e-mail communication channels, respectively. **Data source**: E-mails regarding project information **Calculation/output:** SNA Centrality Metric: For this case, the *Average degree* ($\boldsymbol{A_D}$) centrality metric will be applied (Nunes & Abreu, 2020a, 2020b), which characterizes the average insight and active participation of the elements that comprise a project's social network across its lifecycle: $\boldsymbol{A_D}(n_i) = \frac{\sum_j x_{ji}}{n} = \frac{\sum_{i=1}^{n} \boldsymbol{C_{DT}}(n_i)}{n}$ (3) where $\boldsymbol{A_D}$ = average degree (weighted variation) n = total number of entities within a graph $\boldsymbol{C_{DT}}$ = total degree of an entity within a graph, or $\boldsymbol{C_{DT}}(n_i) = \sum_j x_{ji}$ (4) where: n = total number of entities within a network (graph) for $i = 1 \ldots, n$ x_{ji} = number of links from entity j to entity i, where $i \neq j$, and vice versa. The output for this metric is: a) A numerical value ranging from 0 (no average insight) to a maximum, given by the average weighted total degree of a given entity. The latter is calculated by the ratio between the sum of all total degrees and the number of entities in a given network (full insight). b) An evolution across time throughout the different phases of a project's lifecycle, calculated by applying the simple linear regression across the numerical results for the average weighted degree in each project phase. c) The evolution across time as output from the linear regression may have three forms: 1. **Positive slope**: this indicates growth over time, or that the average weighted degree increases as the different project phases sequentially occur. 2. **Constant slope**: this indicates consistency over time, or an unchangeable weighted degree as the different project phases sequentially occur. 3. **Negative slope**: this decreases over time, or the weighted degree decreases as the different project phases sequentially occur.

Table 3 (*continued*)

Dimension	Description
(3) Network team set variability evolution (NTVE)	**Brief description**: This dimension represents the network team set variability evolution, or the evolution of a given team-set's variability across a project lifecycle. This is measured by the variable participation in virtual project meetings. **Data source**: iTools project-related information **Calculation/output:** SNA Centrality Metric: In this case, the *meetings cohesion degree* centrality metric will be applied; also known as *variability* (***V***; Nunes and Abreu, 2020a; 2020b), this will be applied to characterize a given project team-set's evolving variability across a project lifecycle. This metric was developed based on the weighted average degree. $\mathbf{V}_{(Et)} = \frac{WL_{(Et)}}{TPP_{(Et)} \times Et}$ (5) where: **V** = the project social network's variability Et = event number (virtual project meeting), where Et = 1,2,3, …,TE TE = total number of events (project meetings) that occurred within a project phase TPP = total number of event Et participants WL = total cumulative value of weighed links given each project participant's total degree in each event Et. For example, if participants 1 and 2 participated in event X, the connection between them is valued at 1. If participants 1 and 2 participated in event X + 1, the link between them is valued at 2. The output for this metric is: a) A numerical value ranging from greater than zero to a maximum given by the average variability calculated by $\mathbf{V}_{(Et)}$. b) An evolution across the time throughout the different phases of a project's lifecycle, calculated by applying the simple linear regression across the numerical results for the degree of variability in each project phase. c) The evolution across time as output from the linear regression may have three forms: 1. **Constant linear slope**: no change in the project team-set across a project's lifecycle. All the participants who initiated the project tend to remain unchanged until the project is complete. 2. **Positive linear slope**: this indicates that new (additional) project participants may join the project across its lifecycle, while those who initiated the project tend to remain unchanged until the project is complete. 3. **Negative linear slope**: this indicates that the number of those who initiated the project significantly fluctuate during the project's lifecycle until the project is complete.

Fig. 1 illustrates a typical project lifecycle with several different project phases; this example includes Phases I, II, III, and *ph* as adapted from the PMI (2017) and API (2021).

The black hatched circles in this figure represent project entities—typically a project's people, groups, or organizations—and the lines between them represent the different interactions or relationships. Such relationships may include the communication channels through which project-related information flows among the different project entities. In the case of the model proposed in this work, such relationships represent the e-mail exchange communication channels (or "e-mails," represented by plain, weighted blue lines in Fig. 1), and the participation in virtual collaborative meetings (or "iTools," represented by non-weighted, zigzag blue lines in Fig. 1).

The connections in the "E-Mails" dimension in Fig. 1 have different weights and have been customized, ranging from levels 1 to L, which represent the amount of project-related information e-mails exchanged between any two given entities.

The grey line that continuously moves across all the different phases in Fig. 1 represents the anticipated, different levels of effort according to a given virtual project phase.

The proposed model provides no fixed amount for either *ph* (which represents the number of phases in a given project lifecycle) or *pp* (which represents the number of participants in each phase of a given project lifecycle). Further, the degree of participation (*pp_p*) evolves as the project phases *(ph)* evolve. For example, in project phase I in the iTools dimension (Fig. 1), participants 2 and 3 have collaborated in at least one iTools virtual project meeting. Therefore, a zigzag line is drawn between participants 2 and 3, and the *pp_p(ph)* of that line has a value of 1.

In the same dimension, participants 1 and 4 have not collaborated in at least one iTools virtual project meeting across phase I; therefore, no zigzag line has been drawn between them. In project phase II, participants 2 and 3 again collaborated in at least one iTools virtual meeting, and thus, a zigzag line has been drawn between them, and the *pp_p(ph)* has a value of 2.

In another example, participant 6 participates for the first time in an iTools virtual meeting in project phase III. Hence, the value of the *pp_p(ph)* zigzag lines between 6 and all the other participants is 1.

Each virtual project phase in the proposed model, which includes virtual project-related e-mail data exchanges, must be collected and treated separately from data collected from iTools data sources.

3.6. The DCN-PP Model's application span and legal and ethical considerations

The proposed DCN-PP model is not limited to any given or determined number of projects or project phases across a given project lifecycle. However, if the proposed model is applied with the aim to compare successful and unsuccessful delivered

Table 4
Required information for input in the DCN-PP model.

Data Source	Required Information
Virtual project iTools	- Total number of virtual project meetings that occurred in each project phase across a project's lifecycle. - Total number of participants assigned to each project and the total number of participants in each project meeting, in each project phase, across a project's lifecycle.
Virtual project e-mails	- Total number of e-mails sent/received in each phase of a project lifecycle that relates to project information. - E-mail senders and receivers must be identified in any form.

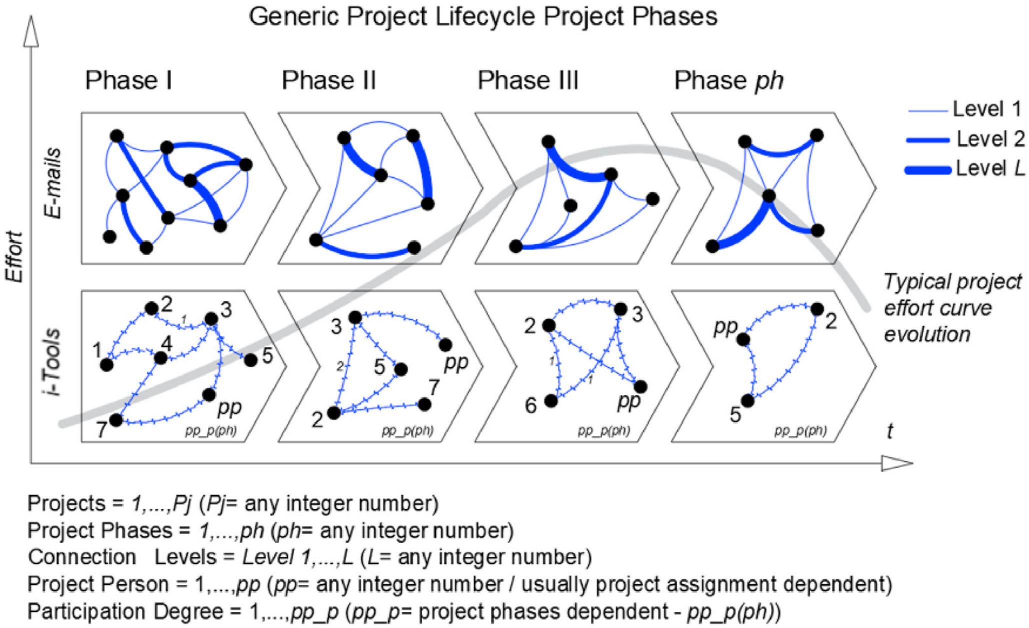

Fig. 1. Typical project lifecycle and the proposed model (adapted from PMI, 2017; API, 2021).

projects, the number of project phases must be the same for both types. The proposed model can also be applied regardless of project size and complexity. Finally, this model is not limited to a given determined number of project participants, a determined number of iTools, or a determined number of exchanged project-related e-mails.

The DCN-PP model accesses and analyzes sensitive project-related information that flows across the different phases of a given virtual project lifecycle. Such project information is often considered confidential, and should not be accessed and exposed within an organization. As this may constrain the proposed model's implementation and application, an effective implementation and application in organizations to measure project performance strongly depends on its acceptance from the respective authorities that are responsible for legal and ethical data protection issues at the organizational and national levels.

4. Application of the DCN-PP Model—A case study

4.1. Introduction to the case study

The following case study to be presented in this chapter was conducted in a leading food and beverage organization in central Europe during 2020. Organization A applied the proposed model to monitor and measure project performance within its internal research and development (R&D) processing department. This work only illustrates an excerpt of the proposed model's large-scale application. In applying in the proposed model to a large-scale case study, Organization A could examine and identify potential critical project success factors by accessing and analyzing a significant number of successful and un-successful delivered projects that essentially run in a virtual environment.

Organization A has provided the data resulting from applying the DCN-PP model in two internal and successful delivered projects. These projects as illustrated in the following case study are highly similar in dimension, staff, and duration. On average, both projects had a budget of approximately 500,000 euros and a seven-month duration, and were delivered by six employees of Organization A. Both projects concerned the development of two new production lines for a well-known cream cheese brand, or specifically, regarding the final product's transformation and transportation processes in delivering the cream cheese brand to customers. These processes ranged from completely manual to partially and fully automated procedures. For legal and protective reasons and to ensure competitiveness, Organization A has not disclosed further information regarding the two successful delivered projects.

4.2. Application of the DCN-PP model in the project management environment

As previously mentioned, Organization A has applied the proposed model to monitor and measure the performance of several successful and unsuccessful virtual projects delivered in 2020. The case study presented in this work will analyze two successful delivered projects, and will serve as a basis to explain the proposed model's implementation and application. Fig. 2 illustrates the collected and processed data regarding Organization A's two successful delivered projects. Fig. 2a displays the results for each of the successful delivered projects (P1 and P2), and Fig. 2b presents the two respective projects' averaged results.

For both successful delivered projects (P1 and P2), related e-mails and iTools project information were collected according to Table 4, across a seven-month period. In P1 and P2, three different levels were defined (level 1: from 0 to 10, level 2: from 11 to 50, and level 3: from 51 to 100) to characterize the amount of e-mail exchanges for a given person within the project network, as illustrated in Fig. 2. For example, in phase I of P1 regarding the e-mail dimension, two connections correspond to an amount between 51 and 100 exchanged emails. This is represented by the thicker blue line (level 3) as illustrated in the

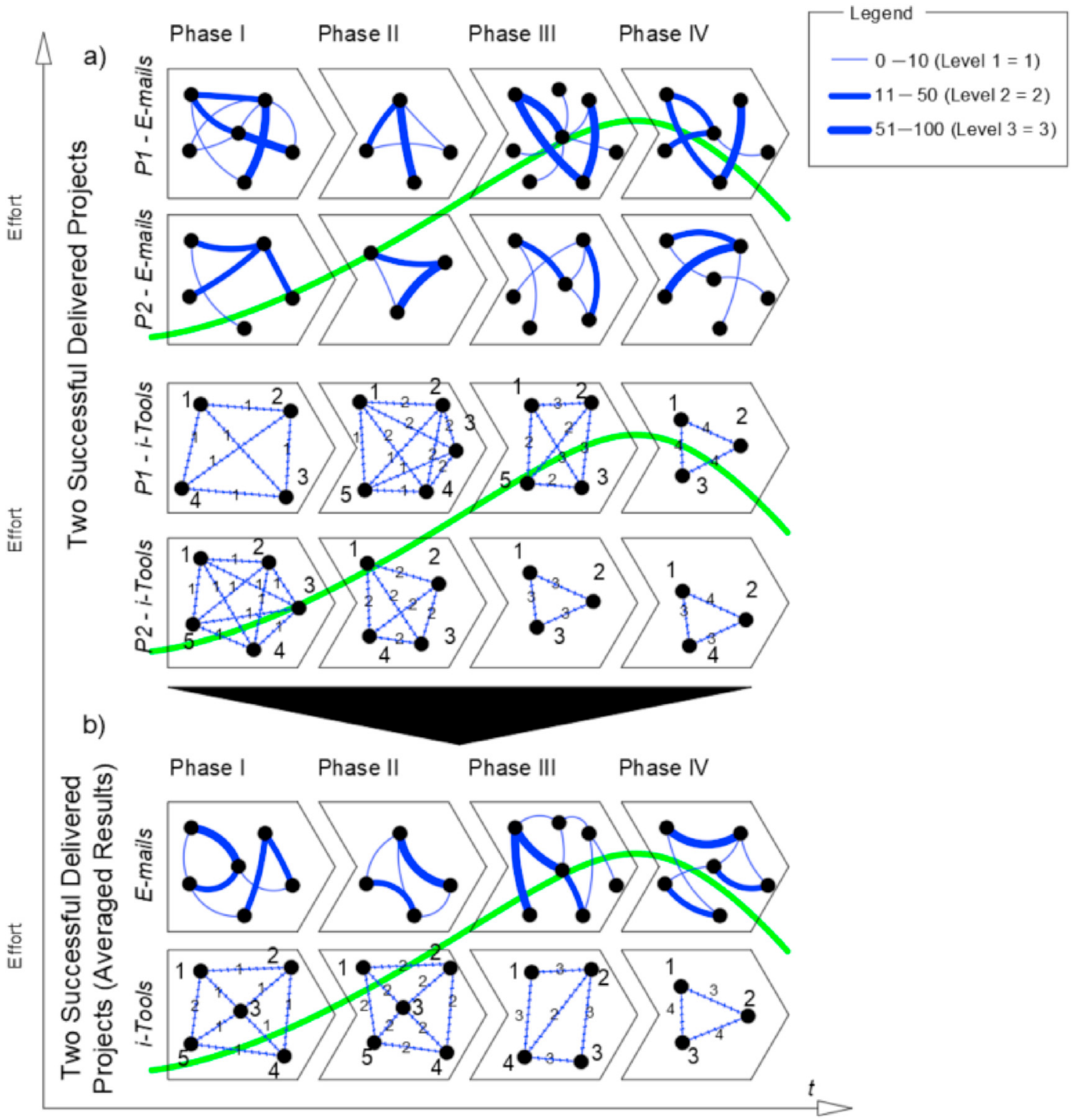

Fig. 2. Application of the DCN-PP model in the case study organization.

legend on the right side in Fig. 2. For example, in the iTools dimension and for the same phase and project, participants 1, 2, 3, and 4 participated in all project meetings conducted across phase I of P1 (Fig. 2a).

Fig. 2b illustrates the averaged results given the individual results from applying the proposed model to projects P1 and P2, which are illustrated in Fig. 2a. Both projects had four different phases (I, II, III, and IV), as illustrated in Fig. 2. For example, in phase I of P1, two lines of thickness level 3 are noted according to the legend on the right side of Fig. 2a. In the same point in time but for P2, it can be observed that no line of thickness level 3 exists. A simple average of P1 and P2 ($1 + 1/2 = 1$) reveals one single connection of level 3 for phase I of successful delivered projects. This single connection is represented in Fig. 2b, or specifically, in phase I; this represents the average of all Organization A's analyzed successful delivered projects. The results for the e-mail dimension as illustrated in Fig. 2b are only valid for a visual inspection. A quantitative analysis must always be conducted by applying the SNA centrality metrics as illustrated in Table 3.

In the present case study, Organization A disclosed only two projects: P1 and P2. The procedure conducted for connection level 3 is adopted for the other two connection levels (levels 1 and 2) for the visual inspection.

Regarding the iTools dimension, in which the NTVE metric is to be applied according to Table 3, the process is not as straightforward. Therefore, the detailed process is illustrated as follows. Applying Equation (5) according to Table 3 to each phase of each project provides the following results; for example, V (I, P1) represents the variability results of project 1 in phase I in the iTools dimension:

Results for successful delivered Project P1 in phases I, II, III, and IV:

$$\mathbf{V}_{(\text{I, P1})} = \frac{6}{4 \times 1} = 1.5$$

$$\mathbf{V}_{(\text{II, P1})} = \frac{16}{5 \times 2} = 1.6$$

$$\mathbf{V}_{(\text{III, P1})} = \frac{15}{4 \times 3} = 1.25$$

$$\mathbf{V}_{(\text{IV, P1})} = \frac{12}{3 \times 4} = 1$$

Results for successful delivered Project P2 in phases I, II, III, and IV:

$$\mathbf{V}_{(\text{I, P2})} = \frac{10}{5 \times 1} = 2$$

$$\mathbf{V}_{(\text{II, P2})} = \frac{12}{4 \times 2} = 1.5$$

$$\mathbf{V}_{(\text{III, P2})} = \frac{9}{3 \times 3} = 1$$

$$\mathbf{V}_{(\text{IV, P2})} = \frac{10}{3 \times 4} = 0.83$$

A negative trend can be clearly observed in these results from applying Equation (5) to both P1 and P2 and simply analyzing the individual results of the variability (V) in the four different phases of P1. This suggests a negative linear slope according to Table 3. Once the individual results for the variability in each phase of each project are obtained, the average results can be calculated for the variation in successful delivered projects 1 and 2:

Averaged results for successful delivered Projects P1 and P2 in phases I, II, III, and IV:

$$\mathbf{V}_{(\text{Av, I, P1;P2})} = \frac{1.5 + 2}{2} = 1.75$$

$$\mathbf{V}_{(\text{Av, II, P1;P2})} = \frac{1.6 + 1.5}{2} = 1.55$$

$$\mathbf{V}_{(\text{Av, III, P1;P2})} = \frac{1.25 + 1}{2} = 1.13$$

$$\mathbf{V}_{(\text{Av, IV, P1;P2})} = \frac{1 + 0.83}{3 \times 4} = 0.92$$

These results involve the averaged individual results for projects P1 and P2 as illustrated in Fig. 2a. This clearly confirms what had already been observed in the individual results for projects P1 and P2 regarding the NTVE metric's tendency toward evolution.

Finally, the results as illustrated in Fig. 2b for the iTools dimension can be fully understood. For example, phase I of the iTools dimension includes five project participants (1, 2, 3, 4, and 5). This total results from the average of projects P1 (4 elements) and P2 (5 elements) in phase I in the iTools dimension, as illustrated in Fig. 2a. The zigzag lines between each

Table 5
NCE for successful delivered projects P1 and P2 relative to Fig. 2.

	NCE—Successful Project Outcome P1			
	Phase I	Phase II	Phase III	Phase IV
Density—E-mails	0.9	0.7	0.14	0.33
	NCE—Successful Project Outcome P2			
	Phase I	Phase II	Phase III	Phase IV
Density—E-mails	0.4	1	0.4	0.33

element in Fig. 2b represent the average of P1 and P2 for the same period, respectively, and directly result from the application of Equation (5) according to Table 3.

The blue zigzag lines between any two given persons in the iTools category, as illustrated in Fig. 2, demonstrate that they have participated in at least one of a given number of virtual project meetings that were conducted in each project phase. The numbers associated with each zigzag line between any two given persons in the iTools category represent the cumulative degrees of participation among any two persons. For example, in phase II of P1 in the iTools category, the zigzag line between persons 1 and 2 has a value of 2. Therefore, these two participants have collaborated in at least one virtual project meeting in phase II.

The first analysis of the proposed model in this work involves the NCE; density (*Ds*) will be used to identify and characterize the number of existing e-mail communication channels across the different phases of a project lifecycle according to Table 3. Table 5 displays the results from applying Equation (1) for P1 and P2 in Fig. 2a.

A longitudinal analysis is recommended as illustrated in Table 3 to better understand the results obtained in Table 5. The longitudinal analysis will enable a classification of how the degree of network collaborative cohesions has evolved according to Table 3, as denoted by a positive, constant, or negative slope.

The longitudinal analysis involves applying a simple linear regression across all collected and measured data regarding the three previously mentioned dimensions (NCE, NDE, and NTVE) in each project phase, as illustrated in Table 3. Applying a linear model to the model proposed in this work can quantitatively verify what type of trend evolution is observed—positive, negative, or constant—in the data collected and analyzed for each of these three dimensions.

The linear model is chosen to analyze the trends and evolution of collected and measured project data across the different phases of a given project lifecycle. Further, this will ultimately provide organizations with a simple, practical, and actionable measurement approach that enables them to more easily and clearly draw conclusions about given observed trends. In this way, organizations can better understand observed trends across the analyzed time period and more accurately correlate them with organizational outcomes. Consequently, this will enable organizations to more accurately adjust their measures to change or support overserved trends.

However, applying the linear model to identify trends across a period has its limitations, which can lead to dubious or even misinterpreted observed results to a certain extent. In this line of thought, it is recommended that organizations tighten the analysis mesh, which essentially involves defining smaller periods of time to be accessed and analyzed. For example, instead of analyzing an entire complete project phase with one unique result, organizations can define several analysis points within a given project phase. In other words, the more thorough the analysis period mesh, the more reliable the resulting trends, and the more effective the measures to support or change these observed trends.

Further, it is more meaningful to apply the linear model (simple linear regression) to analyze trends over time when analyzing many points within a given period, as a visual analysis typically cannot properly or accurately provide conclusions regarding observed and measured data. In such cases, the linear model should be characterized by such coefficients of significance as the R-squared statistical indicator, which provides information about a model's goodness of fit.

Nevertheless, this process to refine the analysis mesh must always be individually defined by the organizations that apply this proposed model by considering a proper cost-benefit analysis.

The present case study's analysis mesh as decided by Organization A has one unique measure that immediately characterizes the entire project phase. In this case, it is optional to apply the linear model to characterize a given trend; one simple visual analysis can clearly identify which trends regarding the three previously mentioned dimensions have occurred in the observed and measured project data.

However, as an example this work includes the linear model's application to quantitatively characterize observed trends over time.

As projects P1 and P2 refer to projects that Organization A has successfully delivered, it makes sense to analyze the averaged results rather than each project's individual results. Therefore, a longitudinal analysis will be performed using the average results from the individual data obtained in Table 5.

Fig. 3 displays the NCE longitudinal analysis that includes the four phases of both projects P1 and P2. The longitudinal results concern the average results of those illustrated in Table 5.

A negative trend can be observed in Fig. 3 across the different phases in both of Organization A's successful delivered projects P1 and P2. This trend is also clearly observed in the linear trend (regression) displayed in Fig. 3.

According to Table 3, the observed trend in Fig. 3 is characterized as a negative slope, and thus, the degree of cohesion decreases across the different phases of projects P1 and P2 as they evolve. In other words, the observed trend in Fig. 3 indicates a decrease in the e-mail communication channels as both projects progress over time.

The next dimension to be analyzed by the proposed model in this work is the NDE, which involves using the average degree of simple variation (Table 3). In applying Equation (3) to the data in Fig. 2, the following Table 6 displays the results.

A longitudinal analysis is recommended as illustrated in Table 3 to better understand the results obtained in Table 6.

Fig. 4 displays the NDE longitudinal analysis that spans the four phases of both projects P1 and P2. The longitudinal results concern the average results of those obtained in Table 6.

Fig. 4 reveals a clear negative trend regarding the NDE's growth across all phases of Organization A's successful delivered projects P1 and P2.

According to Table 3, the observed trend in Fig. 4 is characterized as a negative slope, and thus, a decrease occurs in the average in-degree across the different phases of projects P1 and P2 as they evolve. In other words, the observed trend in Fig. 4 indicates a decrease in the average number of communication channels for each participant as both projects move to completion. Therefore, a decrease occurs regarding the insight and active participation of the elements that comprise both project social networks (from P1 and P2) across the different phases of P1 and P2. The observed negative trend in Fig. 4 is highly significant in terms of the NDE's average evolution across the different phases of projects P1 and P2, given by the R-squared value. This demonstrates that a strong correlation exists between the observed individual values illustrated in Table 6 and the averaged values illustrated in Fig. 4.

The next dimension to be analyzed by the proposed model is the NTVE, with the variability metric applied as described in Table 3. Applying Equation (5) to the data displayed in Fig. 2 provides the following results, as noted in the following Table 7.

A longitudinal analysis is recommended as illustrated in Table 3 to better understand the results obtained in Table 7. Fig. 5 displays the NTVE longitudinal analysis that spans the four phases of both projects P1 and P2. The longitudinal results concern the average results of those as illustrated in Table 7.

As can be observed in Fig. 5, a clear negative trend also exists regarding the NTVE across all phases of Organization A's successful delivered projects P1 and P2. The variability metric characterizes the variability evolution of a given project team-set across a project lifecycle. In Fig. 5, the averaged variability results characterize the evolution of both project team-sets in projects P1 and P2. According to Table 3, the trend observed in Fig. 5 is characterized as a negative linear slope; on average, the people or team-set that initiated projects 1 and 2 strongly change across a project's lifecycle until the project's closure for both projects P1 and P2. In other words, a change occurs in the project team-set since the beginning of a project (measured in phase I) until its end (measured in phase IV).

The negative trend observed in Fig. 5 is even more significant in terms of the NTVE's average evolution across the different phases of projects P1 and P2 when compared with the two other previously analyzed dimensions (NCE and NDE) given by the R-squared value. Therefore, a strong correlation exists between the observed individual values illustrated in Table 7 and the averaged values illustrated in Fig. 5.

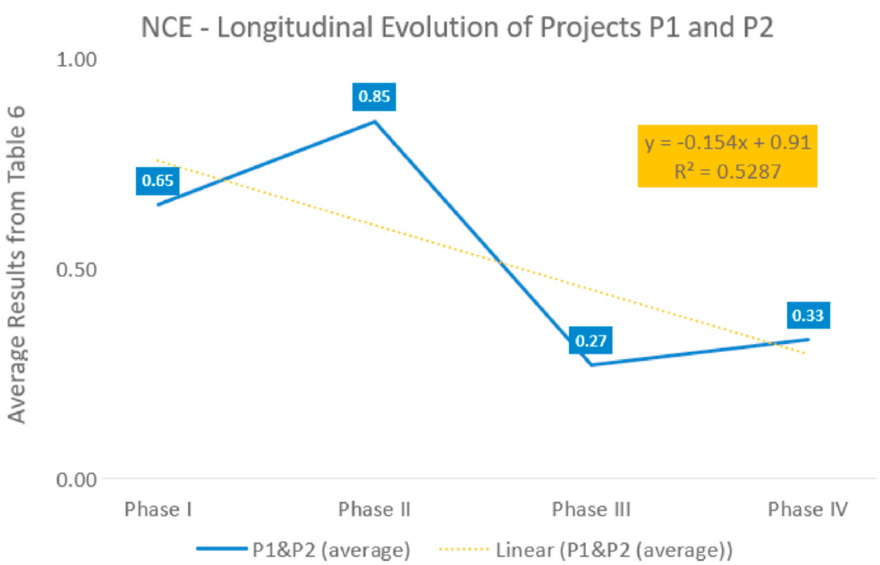

Fig. 3. NCE—longitudinal evolution for projects P1 and P2.

Table 6
NDE for successful delivered projects P1 and P2 relative to Fig. 2.

	NDE—Successful Project Outcome P1			
	Phase I	Phase II	Phase III	Phase IV
Average in-degree—E-mails	3	2	2	1.67
	NDE—Successful Project Outcome P2			
	Phase I	Phase II	Phase III	Phase IV
Average in-degree—E-mails	1.6	2	2	1.67

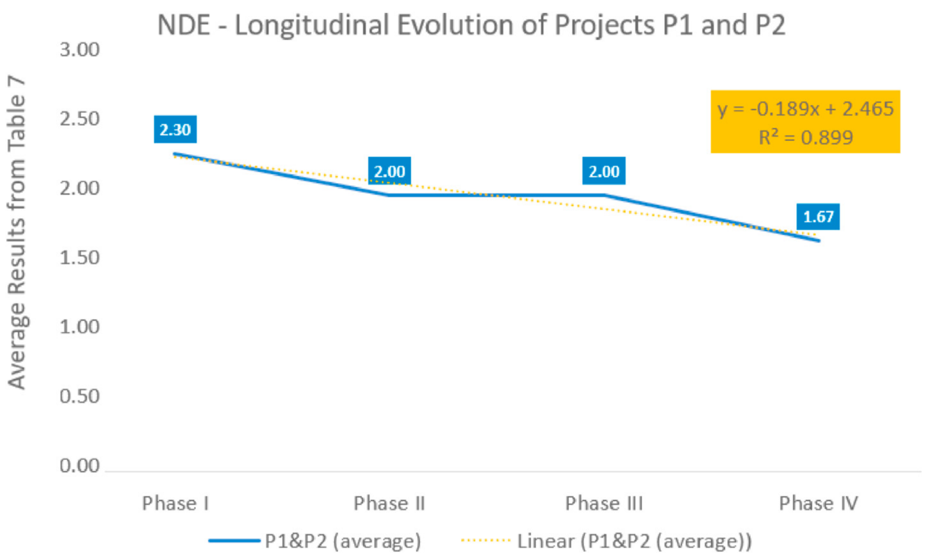

Fig. 4. Longitudinal evolution of NDE for projects P1 and P2.

At this point, the proposed model has been fully applied. In this case study, the proposed model was applied to analyze two successful virtual projects delivered by Organization A.

After a detailed analysis of the three dimensions (Table 3) and their relationship with projects P1 and P2, it can be concluded that a negative trend exists in all three analyzed dimensions in both successful delivered projects P1 and P2.

5. Discussion, conclusions, implications, and Further Developments

This work proposes a DCN-PP model to help organizations measure their project performance. The model was developed based on two scientific topics: (1) project risk management and (2) the social network analysis. It quantitatively measures how virtual collaborations occur by analyzing the NCE, NDE, and NTVE as different yet interrelated dimensions.

The proposed model in this work operates under a heuristic-holistic approach, and particularly regarding the quantitative analysis and identification of behavioral patterns across a determined period (typically a project's lifecycle).

As can be observed in the previous case study chapter, applying the model proposed in this work enables organizations to quantitatively access how collaborations emerge and evolve in the different phases of a given project lifecycle. Subsequently, this will help organizations to identify behavioral patterns that may be associated with a certain work culture, which may contribute to project performance. Further, the results from applying the proposed model can be used as input for several dimensions of organizations' decision-making activities.

First, organizations can use the results to identify problems, such as unbalanced informal networks or the emergence of organizational silos (Nunes and Abreu, 2020).

Second, organizations can use the output from applying the DCN-PP model to identify critical, informal employees that may disproportionately influence the combination of formal and informal organizational networks, as well as poorly integrated employees in the organizational project-based social network.

Third, organizations can use the results from applying the proposed model to more advanced activities and predict the best team-set that optimally fits a certain project type to maximize the chances of success.

Table 7
NTVE for successful delivered projects P1 and P2 relative to Fig. 2.

	NTVE—Successful Project Outcome P1			
	Phase I	Phase II	Phase III	Phase IV
Variability (***V***) iTools	1.5	1.6	1.25	1
	NTVE—Successful Project Outcome P2			
	Phase I	Phase II	Phase III	Phase IV
Variability (***V***) iTools	2	1.5	1	0.83

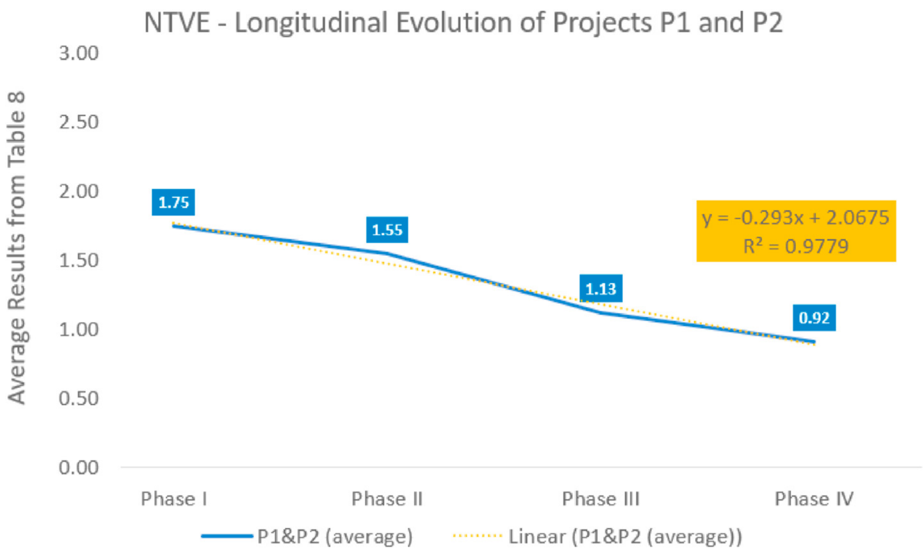

Fig. 5. Longitudinal evolution of NTVE for projects P1 and P2.

The research presented in this work highlights the importance in applying an SNA in managing collaborative networks. This point is expected to serve as a road map for organizations that still are reluctant to incorporate an SNA in managing their internal and external collaborative initiatives (Arena, 2018; Workday Studios, 2018; Nunes and Abreu, 2021).

Finally, the proposed model's implementation and application should be extended to other organizations to evaluate its implementation and applicability in several dimensions, such as cost-benefit analyses, organizational employees' adherence to norms or resistance to change to new, implicit ways of working, or even attractiveness to different industries. Any optimization or improvement of the model proposed in this work would also benefit from a broader implementation and application from internal, external, or mixed perspectives; these will directly benefit analyses of organizations' customers and suppliers, for example.

5.1. Proposed model and researched literature

The proposed model provides valuable, essential contributions to the two scientific pillars used as a foundation for its development.

The research conducted in this work addresses two of the most relevant risks in collaborative network projects as proposed by Abreu et al. (2018) and Hillson (2014). This provides a means to gain further insights regarding the importance of the dynamic behavioral relationships between entities (persons) in a project management context. These relationships occur because the proposed model enables the generation of a dynamic knowledge-base, which literature has noted is a highly effective management approach to address relevant risks (Abreu et al., 2018; Hillson, 2014). This aspect first contributes to a better understanding of how the behavioral dimension of collaborative network projects emerges and evolves across the different phases of a given project lifecycle. Second, this may contribute to the development of new theories and approaches to better manage collaborative behavioral risks.

The research conducted in this work also addresses one of the most important organizational trends: digital transformations through digitalization, which is also known as Industry 4.0 (Digital Transformation Monitor of the European Commission, 2017; Müller et al., 2020).

Digital transformation essentially involves changing ways of thinking and executing work by addressing, changing, and constantly optimizing organizational processes and procedures. Simultaneously, the organizational culture transforms to include flexible, adaptable machine-learning systems that efficiently use a combination of formal and informal collaborative networks (Arena, 2018; Workday Studios, 2018; Chesbrough, 2020; Müller et al., 2020). In this line of thought, if the proposed model is implemented in an organizational business intelligence architecture, this can enable organizations to boost their digitalization and transformation strategies in several organizational dimensions, such as human resources and project management. This may contribute to developing new theories and approaches to manage risk in projects.

5.2. Proposed model and managerial implications

From a managerial perspective, the DCN-PP model offers organizations an effective data-driven model to support the management of virtual collaborative networks and the decision-making process. The proposed model delivers a meaningful history to organizations regarding the occurrence of virtual collaborations across the different phases in a project lifecycle. Also known as the dynamic lessons learned, this enables organizations to learn from past experiences—whether failures or successes—regarding the dynamic behavioral interactions that are associated with success or failure.

The DCN-PP model can provide organizations support in managing collaborative network projects, such as open innovation, in which the lack of such models is noted in literature as a major obstacle (Santos et al., 2019).

Concerning the measurement of organizational performance, the proposed model offers organizations a different approach characterized by a completely bias-free data-collection process. This eliminates organizational down-time, as employees do not need to answer organizational pulse surveys.

Organizations can also apply the proposed model to identify project critical success factors by comparing successful and unsuccessful delivered projects and their associated dynamic behaviors, if a substantial number of both project types are analyzed. This can enable organizational decision-makers to engage in more data-driven decision processes and approaches, rather than relying on instinct or key influencers' often biased opinions.

By quantitatively measuring the combination of formal and informal collaborative networks' influence on organizational performance, the proposed model enables managers' most accurate and appropriate actions in a more data-informed manner. Ultimately, their organizations can support or even enhance the collaborative network dynamics associated with successful outcomes, and eliminate those that push in the other direction (failure outcomes).

Finally, the DCN-PP model provides organizations a more efficient planning process that reduces or eliminates the risks associated with virtual collaborative dynamics. This can lead to the optimization of resources and compel organizations to become more lean-oriented, which will strongly contribute to economic, social, and environmental sustainability worldwide.

5.3. Suggestions for future research

The DCN-PP model's implementation requires organizations to have access to the necessary technology to collect the data that fuels the model proposed in this work. However, not every organization will have such resources at their disposal. Given this perspective, further research should occur to develop affordable systems and approaches that enable every interested organization to implement the model proposed in this work.

Moreover, the present version of the DCN-PP model only requires data from project e-mails and project iTools. However, other sources of data related to virtual projects should also be accessed—such as phone calls and SMS—to build a more robust analysis that better mirrors the reality regarding projects and virtual collaborations. These two data sources still cannot be accessed and collected owing to data protection laws implemented by such official regulatory bodies as the GDPR (General Data Protection Regulation) in Europe (https://gdpr-info.eu/). Regarding this topic, further research should develop new data-collection methods that could distinguish personal from professional interactions without interfering in individual and collective legal and ethical aspects.

Finally, the model proposed in this work only uses three social network centrality metrics. Thus, further research is suggested to develop other SNA centrality metrics that could be adjusted and applied to measure organizational performance.

Author contributions

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

Declaration of competing interest

The authors declare no conflict of interest.

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