Achieving Organizational Ambidexterity:

An Exploratory Model, Using Fuzzy Cognitive Maps

by

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Abstract

Over the course of three to four decades, most well-established companies lose their dominating position in the market or fail entirely. Their failure occurs even though they have resources for sensing shifting market trends, skills and assets to develop next-generation technologies, and the financial means to fill skill gaps and afford risky investments. Nevertheless, incumbents obviously find it very difficult to invest in innovation that takes attention and resources away from a highly successful core business. A solution to this “innovator’s dilemma” is the concept of “organizational ambidexterity”, which has garnered considerable attention among researchers in organization and innovation. According to empirical findings and emergent theory, companies can improve their financial performance and ensure their long-term survival by balancing their innovation activities, so that they are equally focused on exploratory (discontinuous) and exploitative (incremental, continuous) innovations. But how can such a balance be achieved? The literature on the organizational theory and related fields (product innovation, knowledge management, creativity, etc.) identifies more than 300 contributing factors to innovation and ambidexterity: many are interdependent so that their impacts compound or cancel each other. Moreover, for many factors, there is limited empirical data and the size of impacts is unknown. To understand which managerial actions lead to ambidexterity, this dissertation develops a novel approach to the

study and analysis of complex casual systems with high uncertainty: exploratory fuzzy cognitive mapping.

Fuzzy Cognitive Mapping (FCM) is a semi-quantitative system modeling and simulation technique. It is used to represent qualitative information about complex systems as networks of casual relationships that can be studied computationally. Exploratory modeling and analysis (EMA) is a new approach to modeling and simulation of complex systems when there is high uncertainty about the structural properties of the system. This work is the first to combine both approaches.

The work makes several contributions: First, it shows that only a small fraction of management interventions will actually lead to ambidexterity while most will, at best, improve one type of innovation at the expense of the other. Second, it provides a simulation tool to management researchers and practitioners that allows them to test ideas for improving ambidexterity against a model that reflects our current collective knowledge about innovation. And third, it develops a range of techniques (and software code) for exploratory FCM modeling, such as methods for transforming qualitative data to FCM, for exploratory simulation of large and complex FCM models, and for data visualization. They can be utilized to study other similarly complex and uncertain systems.

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First and foremost, I would like to express my sincere gratitude to my advisor Dr. Antonie Jetter. It was an honor to get to know her at personal level and work with her on this research. The results of this research would have not been the same, if it was not for her extensive knowledge of the field combined with personal high-quality standards. I learned a lot from, and truly enjoyed our discussions all these years. I am so grateful for her contributions of time, and ideas, as well as providing excellent directions for this research from the beginning.

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1. Introduction

Many well-established, once innovative firms, such as Nokia, Barnes & Nobel, AOL, Polaroid, Kodak, and Blockbuster have suffered substantial decline or even collapse. This occurred despite their initially high market shares, strong brands, efficient internal processes, and a strong resource base. In his influential book *The Innovator's Dilemma*, Christensen (C. M. Christensen 2003) explains that such failures occur when two factors come to play: First, in all of the cases he describes, the existing technologies or business models of these firms were disrupted by a new technology or business innovation, e.g., digital photography for Kodak (Lucas and Goh 2009; C. A. O'Reilly and Tushman 2004), Smartphone technologies for Nokia (Surowiecki 2013; Huy and Vuori 2014) and digital books and E-commerce for Barnes and Noble (Nolan 2010). Second, these firms were so efficient and successful in their businesses that they either did not pay adequate attention to the changes in their business environment, or presumed that investing resources for exploratory, uncertain activities to counter emerging threats posed too great a distraction from their core business and would be hurtful to their high performance at the time (C. M. Christensen 2003).

Christensen (C. M. Christensen 2003) suggested that this pattern, the so-called *innovator's dilemma*, is difficult to escape and decline may be the likely fate of many organizations. Organizational ambidexterity (OA) provides a response. It suggests that firms can ensure long-term financial success and survival by embracing two fundamentally conflicting sets of strategies: excelling at exploiting the existing competencies – in knowledge, technologies and markets – and concurrently exploring new opportunities and technologies with equal dexterity (Lubatkin et al. 2006).

A fast growing body of empirical research provides evidence that ambidexterity increases firm survival and significantly improves performance: Pursuing both exploitation and exploration is associated with a higher likelihood of survival in different industries, including medical diagnostic imaging (W. Mitchell and Singh 1993), computer software (Cottrell and Nault 2004), hard disk drives (Piao 2010), and optical library storage (Yu and Khessina 2012). Ambidexterity also increases the survival of corporate ventures, created to develop new business opportunities and are therefore exploration focused. Such venture however, would be more successful if they also keep a strong focus on exploitation as well (Hill and Birkinshaw 2014). Others have shown a significant positive relationship between ambidexterity and sales growth in manufacturing industries (He and Wong 2004b; Auh and Menguc 2005; Geerts, Blindenbach-Driessen, and Gemmel 2010; Han and Celly 2008) and in the semi-conductor industry (Lee, Lee, and Lee 2003). Also, market valuation, measured by Tobin's Q, is positively associated with ambidexterity (H. Wang and Li 2008; Uotila et al. 2009). In addition, and not surprisingly, it has been argued that ambidextrous firms are also more innovative (Adler, Goldoftas, and Levine 1999; Govindarajan and Trimble 2010a; Andriopoulos and Lewis 2009).

Despite evidence that ambidexterity has a significant positive impact on firm performance, the literature on how to build ambidextrous capability is scarce. Also, controversial and sometimes conflicting recommendations are given (Raisch et al. 2009): Proponents of *structural ambidexterity* practices aim to achieve ambidexterity through the design of organizational structures, such as the separation of units that focus on invention from units that are focused on commercialization of the existing knowledge base (Adler, Goldoftas, and Levine 1999; C. O'Reilly and Tushman 2008; C. A. O'Reilly and Tushman 2004; He and Wong 2004b; Chang and Hughes 2012; Li and Huang 2013). Proponents of *contextual ambidexterity* practices, on the other hand, focus on aspects that do not address structure directly, such as organizational culture and practices (Gibson and Birkinshaw 2004; Jansen, Van Den Bosch, and Volberda 2006; Chang and Hughes 2012; Gupta, Smith, and Shalley 2006; Raisch and Birkinshaw 2008). Researchers in both camps tend to downplay the importance and effectiveness of their counterparts' approaches. Even less attention has been given to factors beyond these two dominant approaches. Moreover, the interdependencies between different practices are poorly understood.

In contrast, the present study employs a holistic view and considers the factors and practices suggested in both structural and contextual ambidexterity as interdependent and possibly complementary pieces of a puzzle. Moreover, it draws insights from related research branches that investigate approaches to achieving innovation and operational efficiency, namely open innovation, knowledge management, product development, and project management. By focusing on ambidexterity as a complex and multi-perspective problem that requires a systems approach and proper modeling techniques, this research brings these different research streams together to investigate how ambidexterity can be achieved in practice.

The research uses fuzzy cognitive map (FCM) modeling in an exploratory modeling approach to identify those factors and factor combinations that causally impact ambidexterity. FCM is a modeling technique that helps represent complex systems as networks of casual relationships that are visually easy to understand and can studied in a quantifiable manner (Kosko 1986, 1988a, 1988b) Exploratory modeling and analysis (EMA) is a new approach to modeling and simulation of complex systems when there is high uncertainty about the structural properties of the system (Bankes 1993; Agusdinata 2008; J. H. Kwakkel, Walker, and Marchau 2010). In EMA, computer simulations are used to experiment with sets of models with different structures, as well as with different input combinations, all of which are plausible but uncertain representations of reality in order to find a spectrum of results that provides insights into how the system under study could potentially behaves (Bankes 1993; Agusdinata 2008; Stormer et al. 2009; J. H. Kwakkel, Walker, and Marchau 2010; Bankes, Walker, and Kwakkel 2013). As discussed in detail later in Chapter 3, the capacity of exploratory modeling to employ computational analysis to determine how complex systems behave under different assumptions (Bankes 1993; Agusdinata 2008) is paramount for improving understanding of ambidexterity in the real world.

Chapter 2 of this dissertation, Approaches to Organizational Ambidexterity, includes an extensive discussion about the state of the art of organizational ambidexterity and explores practices to transform a firm into an ambidextrous state. The chapter ends with a discussion on current gaps in the research. Chapter 3, Research Foundations: Exploratory Modeling and Analysis and Fuzzy Cognitive Mapping, focuses on the proposed method, fuzzy cognitive map (FCM) with exploratory modeling and analysis approach (EMA), to bridge the identified gaps. This chapter provides an extensive review of the literature on FCM, EMA and their applications. Chapter 4, Research Design, describes how these methodologies were used step-by-step process to fill the gaps identified in Chapter 2 and expand the theory of organizational ambidexterity. Chapter 5, describes the simulation results and findings while Chapter 6 provides a discussion of results. Chapter 7, explain the limitations of research. Chapter 8 suggests some potential future research and finally Chapter 9 provides a summary of the research contributions.

2. Approaches to Organizational Ambidexterity

This chapter begins with definitions of the key concepts within the literature of organizational ambidexterity and then describes the available practices for achieving it. Based on the insights taken from the literature, a framework was then constructed to highlight the areas where the theory needed to be further developed. Sections 2.5 through 2.9 provide an introduction to each of the relevant theories that were used to fill these gaps. The chapter ends with a summary of the gaps and overarching approach that is required in order to address those gaps.

2.1. Key concepts

The concept of organizational ambidexterity stems from the field of organizational theory (Duncan 1976; March 1991) and characterizes a company's ability to satisfy current business demands and to also be adaptive to environmental changes. The term "ambidexterity" was first used in this context by Duncan (1976). March (1991) suggested that ambidexterity is a primary factor for survival and prosperity for any system and is only achievable through maintaining a balance between two mutually exclusive (learning) activities, namely exploitation and exploration. According to March, "Exploitation includes such things as refinement, choice, production, efficiency, selection, implementation and execution, whereas exploration includes things captured by terms such as search, variation, risk taking, experimentation, play, flexibility, discovery and innovation" (March 1991, p. 71). Similarly, Adler et al. (1999) define ambidexterity as an organization's ability to pursue two disparate things at the same time: efficiency and flexibility.

Exploitation and exploration require different structures, processes, management styles, cultures, values and even expectations to succeed. Therefore, organizations have to decide which one to emphasize in their resource allocation (C. M. Christensen and Overdorf 2000; Gupta, Smith, and Shalley 2006; Govindarajan and Trimble 2010a).

Exploitation initiatives look for solutions inside the existing technologies and for the existing market, and thus are more likely to have a predictable return on investment. In contrast, exploration initiatives seek solutions beyond existing technologies or beyond markets served by the organization. They are more vague, less certain, and slower to produce results (March 1991). While a highly disciplined, market-driven, objectives-oriented organization leads to an increase in the performance of exploitation initiatives, exploration activities may be hindered by limiting or completely disabling an organization’s ability to reach out-of-the-box solutions (Gibson and Birkinshaw 2004).

It may seem counterintuitive that organizations can increase their chances of prosperity and survival by investing in higher-risk, uncertain explorative activities along with exploitative activities. As proponents of the ambidexterity concept point out, businesses encounter two types of changes: evolutionary and revolutionary. Both of these types of changes are driven by technology, competitors, regulatory events and similar parameters, but while evolutionary changes are incremental and slow, revolutionary changes have a relatively larger impact in a shorter time (Tushman and O’Reilly III 1996). Often, emerging technologies are the primary reasons for the significant and fast shift in the business environment leading to revolutionary changes. While exploitative activities and innovations constantly keep or increase the fitness and alignment of the organization with evolutionary changes in the market and demand, explorative innovations give new competencies to the organization in order to confront the revolutionary changes. This includes potential disruptions or shifts in the existing market and the emergence of disruptive technologies (March 1991; C. A. O'Reilly and Tushman 2004; Govindarajan and Trimble 2010a).

There is a tendency in established firms to invest more in the exploitation of their existing capabilities and to overlook the riskier explorations of new opportunities. This is known as a success trap (Levinthal and March 1993). Ambidexterity suggests a balanced approach and blames the lack of ambidexterity for hindering firms from adapting to environmental changes.

There are many cases where successful firms in their core business failed to adapt to big changes in the market. For instance, Kodak excelled at analog photography but failed to make the leap to digital cameras. Boeing, a longtime leader in commercial aircraft, stumbled in the face of competition with Airbus in the late 1990s (C. A. O'Reilly and Tushman 2004). While exploitation activities mainly lead to lower cost and an increase in quality or performance, exploration innovations either embody new technologies or target new markets (Tushman and O'Reilly III 1996; He and Wong 2004b; Lubatkin et al. 2006).

2.2. An overview of organizational practices for achieving ambidexterity

A vast body of literature on organizational theory, which is characterized in a taxonomy in Table 1, discusses practices for achieving ambidexterity. In organizational theory, these studies generally fall into two major categories: structural or contextual approaches (Gibson and Birkinshaw 2004). Structural approaches (discussed in the first main column of Table 1) aim to achieve ambidexterity by separating exploitation and exploration activities through changes in the organizational structures, namely through separate temporal settings, separate spatial settings, or separate teams and organizations (March 1991). In contrast, contextual approaches (second main column in Table 1) pursue ambidexterity through "organizational context," which is a big umbrella for generally culture- and process-oriented factors such as level of discipline, quality of management support, and performance management system (Gibson and Birkinshaw 2004; Gupta, Smith, and Shalley 2006).

Ambidexterity, however, is not exclusively impacted by decisions on organizational design, but also by factors that are external to the organization. These "other factors" (third main column in Table 1) are mentioned in the literature on organizational theory but are frequently covered in more depth in related fields such as literature on open and distributed innovation and knowledge management. The following sections discuss Table 1 in more detail. In the table, while filled cells generally show what practices have been suggested by any given study, two symbols of ● and ○ are used respectively to distinguish between empirical studies and theory development studies.

Table 1 - A taxonomy of current ambidexterity research and suggested factors impacting on ambidexterity

	Structural Ambidexterity Structure				Contextual Ambidexterity																Other factors											
					Processes				Culture																							
	1-Differentiation	2-Simultaneity	3-Sequential	4-Formalization/ hierarchies	5-Integration	6-Cross-functional communication	7-Manufacturing flexibility/Product & Production	8-Performance management system	9-Shared vision	10-Level of discipline/formalization	11-Level of support	12-Level of trust	13-Stretch/ Overachieving/ Incentive system	14-Ambidextrous Individuals	15-Horizontal and Bottom-up communication	16-Information exchange/knowledge transfer	17-Level of Risk Tolerance	18-Internal Rivalry	19-Collaborative decision making	20-Organizational Diversity	21-Spin out	22-External Sources (Suppliers/Strategic	23-Top Management Team	24-Strategic intent (ROI, Efficiency) …)	25-Job Rotation	26-Knowledge specializations in teams	27-External Rivalry	28-Regional factors	29-Firm Resources/Firm Size	30-Coordination	31-Individual/team Creativity level	32-Organic/Mechanistic controlling
(J. F. Christensen 1994)																					○											
(Tushman and O'Reilly III 1996)	○				○																											
(Hansen 1999)															○																	
(Adler, Goldoftas, and Levine 1999)																																
(C. M. Christensen and Overdorf 2000)																					○											
(Lee, Lee, and Lee 2003)							●																									
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(Gibson and Birkinshaw 2004)	o	o	o		o	o		o		o	o			o																		
(Isobe, Makino, and Montgomery 2004)	o	o																														
(Holmqvist 2004)																						o										
(C. A. O'Reilly and Tushman 2004)	●																●		●				●	●								●
(Cottrell and Nault 2004)																																
(W. K. Smith and Tushman 2005)	o	o																					o									
(Auh and Menguc 2005)																											●					
(Jansen, Van Den Bosch, and Volberda 2006)				●		●													●						●		●		●			

	Structural Ambidexterity Structure				Contextual Ambidexterity																Other factors											
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(Lubatkin et al. 2006)	●	●																					●									
(Gupta, Smith, and Shalley 2006)			○											○																		
(Mom, Van Den Bosch, and Volberda 2007)															●																	
(H. Wang and Li 2008)																																
(C. O'Reilly and Tushman 2008)	○	○			○																											
(Han and Celly 2008)																																
(Menguc and Auh 2008)			○																													
(Raisch and Birkinshaw 2008)	○	○	○		○																	○	○				○		○			

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(Uotila et al. 2009)	●	●																														
(Jansen et al. 2009)					●	●										●																
(Andriopoulos and Lewis 2009)																○																
(Raisch et al. 2009)	○	○	○		○									○	○							○										
(Piao 2010)							●																									
(Govindarajan and Trimble 2010a)	○																						○									
(Geerts, Blindenbach-Driessen, and Gemmel																																
(Yamakawa, Yang, and Lin 2011)																						●										

	Structural Ambidexterity Structure				Contextual Ambidexterity																Other factors											
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	1-Differentiation	2-Simultaneity	3-Sequential	4-Formalization/ hierarchies	5-Integration	6-Cross-functional communication	7-Manufacturing flexibility/Product & Production	8-Performance management system	9-Shared vision	10-Level of discipline/formalization	11-Level of support	12-Level of trust	13-Stretch/ Overachieving/ Incentive system	14-Ambidextrous Individuals	15-Horizontal and Bottom-up communication	16-Information exchange/knowledge transfer	17-Level of Risk Tolerance	18-Internal Rivalry	19-Collaborative decision making	20-Organizational Diversity	21-Spin out	22-External Sources (Suppliers/Strategic	23-Top Management Team	24-Strategic intent (ROI, Efficiency) …)	25-Job Rotation	26-Knowledge specializations in teams	27-External Rivalry	28-Regional factors	29-Firm Resources/Firm Size	30-Coordination	31-Individual/team Creativity level	32-Organic/Mechanistic controlling
(Yu and Khessina 2012)	●																															
(Chang and Hughes 2012)	●	●		●				●		●	●						●						●				●		●			
(Fatehi and Englis 2012)		○	○																													
(Kim, Song, and Nerkar 2012)																						●					●	●				
(Schultz, Schreyoegg, and von Reitzenstein 2013)														●																		
(Eriksson 2013)																						○										
(Li and Huang 2013)	●	●										●														●				●		
(Patel, Messersmith, and Lepak 2013)										●	●		●																			

	Structural Ambidexterity Structure				Contextual Ambidexterity																Other factors											
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(Hill and Birkinshaw 2014)																					●											
(Tamayo-Torres, Gutierrez-Gutierrez, and Ruiz-Moreno							●																									
(De Clercq, Thongpapanl, and Dimov 2014)																		●									●					
(Yang, Zheng, and Zhao 2014)																						●										
(C. L. Wang and Rafiq 2014)									●											●												
(C.-H. Wang and Hsu 2014)																						●										
(Abebe and Angriawan 2014)																							●				●					
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	Structural Ambidexterity Structure				Contextual Ambidexterity																Other factors											
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	1-Differentiation	2-Simultaneity	3-Sequential	4-Formalization/ hierarchies	5-Integration	6-Cross-functional communication	7-Manufacturing flexibility/Product & Production	8-Performance management system	9-Shared vision	10-Level of discipline/formalization	11-Level of support	12-Level of trust	13-Stretch/ Overachieving/ Incentive system	14-Ambidextrous Individuals	15-Horizontal and Bottom-up communication	16-Information exchange/knowledge transfer	17-Level of Risk Tolerance	18-Internal Rivalry	19-Collaborative decision making	20-Organizational Diversity	21-Spin-out	22-External Sources (Suppliers/Strategic	23-Top Management Team	24-Strategic intent (ROI, Efficiency) …)	25-Job Rotation	26-Knowledge specializations in teams	27-External Rivalry	28-Regional factors	29-Firm Resources/Firm Size	30-Coordination	31-Individual/team Creativity level	32-Organic/Mechanistic controlling
(Choi and Lee 2015)																															○	

● Empirical study ○ Theory development study

Structural approaches to ambidexterity, which is presented in the first group of columns in Table 1, can be characterized by how structural separation is achieved. *Differentiation* is the most-discussed practice within the structural approaches (column 1). It refers to two or more organizationally separated units pursuing either exploitation or exploration (W. K. Smith and Tushman 2005; C. O'Reilly and Tushman 2008; Raisch et al. 2009).

Differentiation practice enables an organization to plan, lead, and evaluate exploration and exploitation teams with different methods and use appropriate individuals and managers for each activity. Top management would be responsible for balancing the objectives of both units and assigning resources.

Simultaneous ambidexterity (column 2) refers to a practice wherein an organization concurrently pursues exploration and exploitation. This could be done by a single team or multiple teams, inside or outside of the firm. It often has been suggested as a complementary practice to differentiation. It stresses the importance of parallel investment in both exploration and exploitation activities. Almost all the empirical studies on ambidexterity have investigated the simultaneous form of ambidexterity (He and Wong 2004b; Isobe, Makino, and Montgomery 2004; Lubatkin et al. 2006; Uotila et al. 2009).

The counterpart of simultaneous ambidexterity is *sequential ambidexterity* (column 3). This refers to an organization performing either exploitation or exploration at any point in time (C. O'Reilly and Tushman 2008; He and Wong 2004b; Gibson and Birkinshaw 2004; Raisch et al. 2009; Uotila et al. 2009).

In sequential practice, a firm is encouraged to switch between time periods with more concentration on either exploratory activities or exploitative activities. Some researchers have argued that sequential practice is easier to manage, fits better with firms with access to fewer resources, and yields better knowledge transfer, since the exploratory and exploitative teams are the same (Gupta, Smith, and Shalley 2006; Beckman 2006; C. O'Reilly and Tushman 2008; Menguc and Auh 2008). While differentiation is concerned with spatial separation of units pursuing exploration and exploitation activities, simultaneous and sequential practices are concerned with temporal separation or overlap of such activities.

Different levels of *formalization and hierarchy* within organizations (column 4) have been recognized as factors with opposite effects on the explorations and exploitations. Higher levels of formalization and more divisions by function tend to increase the efficiency in organizations and facilitate exploitative activities. In the opposite situation, a flat hierarchy and more informal communication levels the ground for exploratory activities. Since ambidexterity is a balance between these two, it is very important to consider the effect of such structural designs (Jansen, Van Den Bosch, and Volberda 2006; Chang and Hughes 2012).

Contextual approaches to ambidexterity, which are presented in the second group of columns in Table 1, consider factors other than organizational structure. Gibson and Birkishaw (Gibson and Birkinshaw 2004) coined the term contextual ambidexterity to distinguish it from structural approaches that had dominated the literature (Birkinshaw and Gupta 2013).

Gibson and Birkinshaw (2004) introduced integration (column 5) as the first approach to ambidexterity that is explicitly characterized as "contextual ambidexterity." It provides an alternative to differentiation and refers to the degree to which individuals are involved in both exploration and exploitation. In an extremely integrated design, a unique team is in charge of both explorations and exploitations (Gibson and Birkinshaw 2004; Tushman and O'Reilly III 1996; C. O'Reilly and Tushman 2008; Raisch et al. 2009). This is an ideal practice for knowledge transfer and aligning the exploration and exploitation activities. Individuals on the team could be in charge of either explorative or exploitative activity, or both, yet communication within the exploratory and exploitative projects would be at a maximum. In a minimal integration setting, differentiated exploration and exploitation departments would frequently meet to communicate about goals, achievements and potential collaborations.

If individuals are involved in both types of exploratory and exploitative activities, they need to be *ambidextrous at an individual level* to be able to effectively and efficiently balance their two types of activities (column 14). Although some studies have emphasized the role of ambidextrous individuals in an integrated practice, they also admit that it is challenging for an individual to excel at both exploration and exploitation (Birkinshaw and Gibson 2004; Gupta, Smith, and Shalley 2006; Raisch et al. 2009; Schultz, Schreyoegg, and von Reitzenstein 2013). Moreover, there has been an argument that is simply having ambidextrous individuals does not make an organization either adaptive or ambidextrous (C. O'Reilly and Tushman 2008).

Other contextual factors that have been cited in the contextual ambidexterity literature include (columns 5 to 20): *cross-functional communication* (Birkinshaw and Gibson 2004; Jansen, Van Den Bosch, and Volberda 2006; Jansen et al. 2009), *manufacturing flexibility*, *product and production path dependency* (Tamayo-Torres, Gutierrez-Gutierrez, and Ruiz-Moreno 2014), *performance management system* (Gibson and Birkinshaw 2004; Chang and Hughes 2012), *shared vision* (C. L. Wang and Rafiq 2014), *level of discipline and formalization*, and *level of support* (Gibson and Birkinshaw 2004; Chang and Hughes 2012; Patel, Messersmith, and Lepak 2013), *level of trust* (Li and Huang 2013), *stretch, overachieving and incentive system, ambidextrous individuals, horizontal and bottom-up communication* (Hansen 1999; Mom, Van Den Bosch, and Volberda 2007; Raisch et al. 2009), *information exchange and knowledge transfer* (Jansen et al. 2009; Andriopoulos and Lewis 2009), *level of risk tolerance, internal rivalry* (De Clercq, Thongpapanl, and Dimov 2014), *collaborative decision making* (C. A. O'Reilly and Tushman 2004; Jansen, Van Den Bosch, and Volberda 2006), and *organizational diversity* (C. L. Wang and Rafiq 2014).

A common thread that is observed among all these contextual factors is the focus on organizational process or culture as the means to achieve ambidexterity. They can be grouped as process and culture-driven approaches. Process-driven approaches look for formal processes to bolster the exploration or exploitation activities, whereas culture-driven approaches look for shared values, norms and assumptions (which together form the organizational culture) (Schein 1984a, 1996) as the main contributors for achieving any organizational goal, including ambidexterity. While shared vision, level of risk tolerance, trust, and leadership support are among culture-driven approaches, performance management system, cross-functional communication, and integration are examples of process-driven approaches within the contextual ambidexterity literature.

In addition to the factors above, the literature suggests *other factors* (third main column in Table 1) that cannot be easily categorized such as process, culture or structure. For instance, Lubtakin et al. (Lubatkin et al. 2006) show the critical and unique role of the *top management team* (column 23) in achieving ambidexterity. Executives and top managers need to have the capability to balance exploration and exploitation activities within the organization and with external allies.

Other researchers have argued that even differentiated units still inherit the overarching values and culture of the parent organization, which limits exploration of technologies or markets that are outside of the existing competencies of the organization (Abebe and Angriawan 2014; Chang and Hughes 2012; C. M. Christensen and Overdorf 2000; J. F. Christensen 1994; Geerts, Blindenbach-Driessen, and Gemmel 2010). Therefore, they have suggested *spin-outs* (column 21) – the formation of separate firms for exploratory endeavors – as an effective solution to overcoming the inertia of the large companies.

Other studies have suggested that *external sources* (column 22) could be used for one set of activities – often exploration – through alliances to let the organization focus on the other set of activities (Holmqvist 2004; Raisch et al. 2009; C.-H. Wang and Hsu 2014; Yang, Zheng, and Zhao 2014; Kim, Song, and Nerkar 2012; Yu and Khessina 2012; Eriksson 2013; Yamakawa, Yang, and Lin 2011). This would decrease the complexity of internal ambidexterity, lower uncertainties, and decrease the risk of failure and knowledge obsolescence. Still, there would be challenges in the management and individual level for the integration of the external and internal knowledge (Raisch et al. 2009) as well as aligning the activities.

2.3. Conclusion: Insights from the literature about ambidexterity

A. The discussion above shows that ambidexterity research is mainly focused on creating structures that are conducive to ambidexterity and is only recently investigating so-called contextual factors. These factors can be further understood as either process-oriented or culture-oriented. This distinction is especially useful when putting into perspective that organizational theory is concentrated on structure, processes, and culture (Schein 1984b, 1996). Meanwhile, there are other management theories that also recognize other means for achieving desirable outcomes than organizing through structure, process or culture. Traditional frameworks for management activities, such as Henry Fayol's (1949) theory of management is useful for identifying managerial means beyond what has been explored by organizational theory and expanding the ambidexterity solutions beyond process, culture or structure-driven practices.

B. The literature has not identified a single independent factor that leads to ambidexterity by itself. On the contrary, all identified factors are intertwined with each other in such a complex form that it appears necessary to study them holistically. The lack of such a holistic view has led to some contradictory practices being suggested in the literature as well as contradictory findings across empirical studies. Taking into account all the direct and indirect impacts of the contributing factors at the same time could help to overcome such interdependency issues.

C. Ambidexterity research has begun to identify contextual factors related to individual creativity, suppliers, budgeting, and scheduling that are new to organizational ambidexterity theory. These factors, however, are investigated and discussed in some detail in other fields of research such as research on creativity, project management, knowledge management, and open and distributed innovation. Therefore, the present research will gain insights from other established branches of research to develop a comprehensive framework for achieving ambidexterity.

2.4. Research framework: A system perspective on achieving ambidexterity

The discussion above shows that factors impacting the ability to become ambidextrous are not limited to organizational theory, but can be found in a multitude of related fields, namely creativity, project management, knowledge management, and open and distributed innovation. Moreover, the review above has demonstrated that practices for achieving ambidexterity ought to be seen and assessed through a systems lens. To reach to this holistic multi-perspective, a new framework is presented in Figure 1.

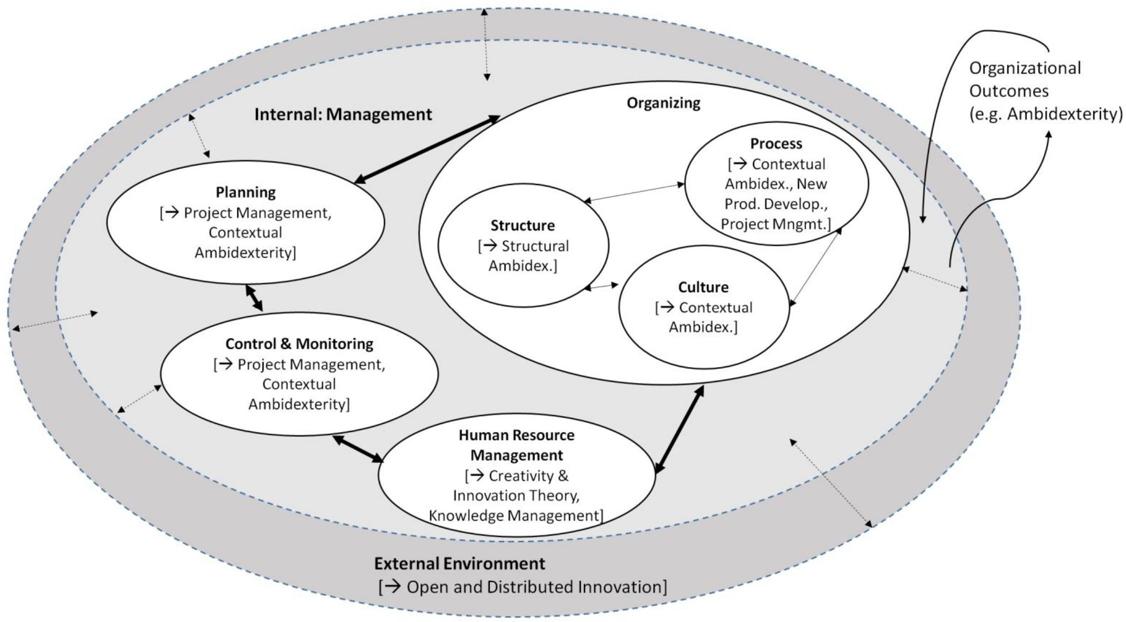

Figure 1- A framework based on Henry Fayol's (1916) functions of management theory

It is inspired by Henry Fayol's theory of *functions of management:* In an article published in the early twentieth century, Fayol (1949) argues that management consists of five different functions: planning, organizing, staffing (human resource management in more modern terms), controlling and coordination (Shafritz and Whitbeck 1978). Each function can be seen as a system element that can further be broken into sub-systems and elements and is embedded in a super system. Coordination connects these functions so that they influence each other (see solid arrows in Figure 1). Coordination refers to all the things managers should do to assure that all of the activities and procedures performed by the organization are in harmony, and complement and enrich the work of other activities (Okhuysen and Bechky 2009). "Coordination is about the integration of organizational work under conditions of task interdependence and uncertainty" (Faraj and Xiao 2006, p.

1156). In terms of the framework of the present research, coordination provides the linkage between framework elements and indirectly impacts ambidexterity.

The other four management functions – organization, control & monitoring, planning, and human resources – are internal to the organization (see large inner oval in Figure 1). The framework embeds them in the context of the business environment that provides external resources (e.g., through supply chain partners, distributors) and competition. The interplay of the internal management functions and the business environment results in organizational ambidexterity and multiple other outcomes, such as financial performance, firm survival, and societal impacts. Outcomes will feed back to the system, which may reinforce the application of some practices while discouraging some others. The focus of this study is the outcome of organizational ambidexterity, which has been frequently shown to have a positive impact on other outcome measures, such as innovation, survival, sales growth, and market valuation (W. Mitchell and Singh 1993; Cottrell and Nault 2004; Piao 2010; Yu and Khessina 2012; He and Wong 2004b; Auh and Menguc 2005; Geerts, Blindenbach-Driessen, and Gemmel 2010; Lee, Lee, and Lee 2003; H. Wang and Li 2008; Adler, Goldoftas, and Levine 1999; Govindarajan and Trimble 2010a; Andriopoulos and Lewis 2009).

The framework in Figure 1 does not only show the elements and interdependencies of a system model of ambidexterity but also demonstrates how different streams of research and theories can inform a multi-perspective view. To this end, each relevant stream of literature is mapped to the management function it informs.

The management functions of *Planning* and *Control & Monitoring* encompass practices concerning time, cost, price, quality, efficiency, and risk. These practices have an impact, either positive or negative, on the firms' exploration and exploitation capabilities. Critical path method (CPM), rolling wave planning, return on investment (ROI) method, present value analysis (PVA), earned value method (EVM), failure mode & effect analysis (FMEA), and quality function deployment (QFD) are examples of these planning and controlling practices advocated by project management literature with potential impact on the ambidexterity measures (Rose 2013). Conventional project management practices often put the primary emphasis on efficiency through time, cost and quality management practices (Rose 2013), which is argued to potentially harm exploration efforts within the firm (March 1991; Erno-kjolhede 2000). By contrast, exploration efforts are more successful when learning and even playing are considered as part of the culture and objectives of the organization (March 1991). Another example of the impact of planning and controlling methods on ambidexterity is the way that team leaders need to be evaluated in the different contexts (exploration vs. exploitation). Govindarajan and Trimble (Govindarajan and Trimble 2010a, 2010b) advocate for the idea that innovative leaders need to be assessed more subjectively in exploration projects and more quantitatively and against planned milestones in exploitation projects.

Another system element in the framework consists of *organizing practices* for achieving ambidexterity, which can be further broken into practices that interact within structure, processes, or culture. As mentioned earlier, differentiation and simultaneity are two structure-oriented practices that share this layer with culture-oriented practices such as discipline, bottom-up communication, cross-functional teams, and integration. Stage-gate processes for new product development, agile and similar innovation processes also fall under this layer (A. Jetter and Albar 2015; Cooper 2008; Beck et al. 2001).

Yet another system element in the framework is *human resources*. Traits of individuals and team diversity are human-resource related factors that indirectly impact exploitation and exploration measures. That is why some researchers have suggested bringing team members and team leaders from outside the current organization for the exploration projects (Govindarajan and Trimble 2010a, 2010b). This is yet another area where current ambidexterity theory could borrow from other research streams such as creativity theory and knowledge management. As will be further elaborated, creativity theory is concerned with how to find and reinforce the creativity at the individual level by the means of looking at individual traits, devising processes, and creating a supportive culture (Kanematsu and Barry 2016; Fleming, Mingo, and Chen 2007; Pope 2005; Zhang and Sternberg 2011). The knowledge-based theory is focused on how to build organizational knowledge by externalizing individual knowledge, transferring and spreading knowledge across the firm, and knowledge being internalized by individuals (Ikujiro Nonaka 1991). Therefore, not only are processes which facilitate knowledge transformation cycles suggested but also, more horizontal and team-based structures are encouraged (Hansen 1999; Mom, Van Den Bosch, and Volberda 2007; Raisch et al. 2009). Both of these theories were explored in order to identify additional human-resource and organizing practices that could be utilized to increase ambidexterity.

Naturally, human resources are not the only resource of relevance to organizational outcomes: capital and assets must also be accessible to management. However, these resources do not impact ambidexterity directly but require that managers engage in the activities of planning, control, organizing, and human resource management in order to put them to work. In focusing on management practices for ambidexterity, this research thus implicitly covers non-human resources.

The internal management functions are impacted by external factors that are outside the borders of the firm. However, management has interactions and potentially some level of control over these external factors and may, for example, obtain inputs in the form of information, knowledge, technology, parts, and raw materials. Consequently, these external factors are great candidates for harnessing additional resources for augmenting internal capabilities. These external resources consist of users, suppliers, joint ventures and spin-offs, research intuitions and the competition. This is the area that has received the least attention within the ambidexterity literature, whereas open and distributed innovation theories have been articulating for years how organizations can reconfigure their innovation processes to more effectively benefit from these sometimes virtually free resources (H. Chesbrough and Crowther 2006; K. Lakhani and Panetta 2007; West and Bogers 2011).

In the following pages, the research areas and theories identified in Figure 1, open and distributed innovation theory, knowledge-based theories, creativity and innovation theories, project management, and new product development research are discussed in detail, and their potential contribution to the framework are further explained.

2.5. Open and distributed innovation theories

Open innovation has been defined as the antithesis of traditional vertical integration model where R&D activities lead to internally developed products that are then distributed by the firm (H. Chesbrough 2006). Coined by Chesbrough (2003), open innovation instead suggests the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and to expand the markets for external use of innovation (H. Chesbrough and Crowther 2006). When using external knowledge for internal use, inbound open innovation happens, whereas external exploitation of internal knowledge is what is referred to as outbound open innovation (Huizingh 2011). Not only does inbound open innovation give firms access to a larger external source of innovation, often with a lower cost of investment, it also helps them have a better understanding of demands and changes in the market. Outbound open innovation, on the other hand, is concerned with the portion of accumulated knowledge in the firm that, due to limited abilities, never gets commercialized and turned into innovations that benefit the firm.

Practices for inbound open innovation include, but are not limited to, networking and collaboration with external sources such as suppliers, competitors, users, and universities; while practices for outbound open innovation primarily include spin-offs and licensing (Busarovs 2013; Huizingh 2011; H. Chesbrough 2006).

A similar concept forms the foundation of research on *distributed innovation*, which is focused on the user – which might be a firm or an individual – as the source of information for both needs and solutions (K. Lakhani and Panetta 2007). Von Hippel (Von Hippel 1986) was the first to suggest that in many industries users, rather than manufactures, were the originators of the most novel innovations. Since then the theory has grown and encompassed new notions such as "informal know-how transfer" between rivals (Von Hippel 1986) and product platforms that democratize the innovation processes such as software development kits and open source software, e.g., Linux (K. R. Lakhani and Von Hippel 2003; Von Hippel 2005).

Open innovation and distributed innovation theories are expected to inform the framework of the present study primarily in the external resource tier: customer, competition, suppliers, academia, and spin-offs.

2.6. Knowledge-based theories

A common denominator of knowledge-based theories is the perception of knowledge as the firm's most important resource, and knowledge creation as the key success factor of organizations (Ikujiro Nonaka 1991; Ikujirō Nonaka and Takeuchi 1995; Conner and Prahalad 1996; Ikujiro Nonaka and Toyama 2003; Macgregor and McCulloch 2006; Collins and Smith 2006). According to these theories, the primary role of the firm is to integrate the specialized knowledge that resides within individuals into goods and services (Grant 1996). Management's main task is to provide the coordination necessary for this integration to happen. The knowledge-based view, therefore, is mostly concerned with the transfer and aggregation of knowledge within the firm (Grant 1996) and how different types of knowledge, explicit or tacit, will impact these processes (Ikujiro Nonaka 1991). Tacit knowledge is highly personal and hard to formalize, making it difficult to communicate or share with others, whereas explicit knowledge is the codified knowledge that can be transmitted in formal, systematic language (Polanyi 1967). The continuous transformation of tacit to explicit knowledge and vice verca is suggested to be essential in creating and elevating both individual and organizational knowledge (I. Nonaka 1994).

The knowledge-based view has many implications, including those related to organizational structures and decision-making authorities. Only structures that facilitate the transfer of knowledge among individuals such as horizontal and team-based structures are encouraged since yielding successful products or services demands a broad range of knowledge within the firm. For the same reason, if cross-functional teams consisted only of managers, only a fraction of the firm's knowledge would be used when making decisions, whereas by including other employees, more effective decision making is expected to happen (I. Nonaka 1994).

Another example of the implications of knowledge-based theories on ambidexterity would be to consider new personnel as a knowledge flow channel that adds to the knowledge stock of the firm (Madsen, Mosakowski, and Zaheer 2003; Erden et al. 2014). A positive relationship between hiring new people and firm performance has been observed in knowledge-intensive industries such as biotechnology (Von Krogh, Nonaka, and Rechsteiner 2012). At the same time, it has been noticed that a rapid inflow of new personnel could reduce the labor productivity and make it difficult for an organization to institutionalize individual knowledge within the firm (Koch and McGrath 1996; Raisch and Von Krogh 2007).

Organizational ambidexterity could benefit from these and similar findings within the knowledge-based theories field in order to broaden its sets of practices and solutions.

Knowledge-based theories are expected to primarily inform the framework in the human resource management and organizing tiers.

2.7. Creativity and innovation theories

Theories on creativity and innovation see innovation as a product of creative people that enable organizations to survive environmental changes (Amabile 1988). Creativity is about coming up with a novel idea, whereas innovation does not exist until the execution of the idea occurs (Govindarajan 2010). Research in this context predominantly focuses on individuals and the internal processes that allow them to "go beyond the current boundaries, whether those are boundaries of technology, knowledge, current practices, social norms, or beliefs" (Anderson 1992, p. 41). Creativity is not understood as a personal trait available only to a few; rather, many can be creative if they possess the intrinsic motivation to do the task, the necessary task domain skills, and creative thinking skills (Amabile 1988, 1997). This is where organization climate could provide or hinder a creative culture. For instance, freedom, positive challenge, supervisory encouragement, work support groups, sufficient resources, and tolerance of failure consequences have all been cited as cultivating creativity in organizations as well as flexible structures, decentralized decision making, low hierarchical levels, diversely skilled members, and openness to new ideas (Parjanen 2012). Many techniques have been suggested to strengthen creativity skills such as idea marathon training or idea logging (Higuchi, Miyata, and Yuizono 2012; Hiam and Chalkley 1998), divergent-convergent thinking (Baer 2014; Runco 1993), brainstorming (Karakas and Kavas 2008), and TRIZ (Savransky 2000; Altshuler 1999).

From personal traits to cultural necessities for provoking and supporting creativity, within the creativity field, many aspects have been mentioned as having an indirect impact on the organizational ambidexterity. The framework of this research can be a guideline for finding the relevant observation and practices across the creativity field and integrating them into a holistic ambidexterity framework.

2.8. Product innovation

Product innovation literature is concentrated on implementing process management thinking in the innovation domain (Cooper 1990). The main objectives tend to be formulated as choosing the right innovation project and doing it correctly and quickly (Cooper 2000). The perhaps surprising results of a private study published by Booz, Allen and Hamilton in 1968 seem to have contributed greatly to the growth of the product innovation field (Griffin 1997). The 1968 study showed a third of the commercialization of new products failed due to "wrong" or un-vetted product ideas or bad timing, independent of the nature of the industry (Booz and Hamilton 1968). Therefore, new product development (NPD) within the product innovation stream focuses on recognizing the factors contributing to success or failure of both evolutionary and incremental innovations (Veryzer 1998).

Establishing formal processes for innovation is more challenging nearer to the birth of an idea and becomes more applicable when ambiguity around technical feasibility and business suitability diminish with further research and development. The literature often tags the very first steps in the innovation process, including idea generation and idea screening as the fuzzy front end. Fuzziness implies the experimental and often chaotic nature of these steps with the minimal predictability of outcomes (Koen et al. 2002; A. Jetter and Albar 2015). The fuzzy front end often proceeds with a more structured new product development (NPD) methodology such as stage-gate (Cooper 2008) or agile (Beck et al. 2001).

Water-fall methodologies, including stage-gate® (Cooper 2008) – a wide spread method in a variety of industries – recommend following clearly defined stages such as idea selection, technical development, business plan development, test and verification, and eventually production with a decision making gate between each stage. Each stage requires parallel activities in various disciplines to be completed followed by a cross-functional team of executives voting on whether the organization needs to move forward to the next stage or not (Cooper and Kleinschmidt 2001).

Since the introduction of water-fall methodologies in the 1960s, upfront planning, multi-disciplinary decision-making and implementation, and formal standardized processes were among the advantages that improved the success rate of many new product development projects while reducing their cycle time (Barczak, Griffin, and Kahn 2009). On the flip side, even with new modifications of water-fall methods, their linear nature makes it difficult to backtrack into earlier stages, to alter a decision after formal review or to facilitate early termination of the whole process (A. Jetter and Albar 2015; Conboy and Fitzgerald 2004) if required in response to unpredicted changes or new learning. Also, specification-driven review processes, although they might increase the efficiency of the new product development projects with an explorative nature, could be quite ineffective –

perhaps even detrimental − for exploratory projects with ambiguity around final product specification (A. Jetter and Albar 2015).

The product innovation stream of research is expected to chiefly inform the current study through organizational processes, culture and structures – the organizing layer of the framework. Although as is briefly discussed, it has the potential to contribute further to planning and controlling as well as in the human resource management tiers of the framework.

2.9. Project management theory

The roots of project management as a modern discipline have been traced back to the early 20th century when Henry Fayol (1949) published his book on "general and industrial management" and Henry Gantt introduced his modified version of "Gantt Charts" – originally introduced by Karol Adamiecki around 1896 – for planning and controlling tasks and schedule (Kwak 2005; I Cleland and Gareis 2006). But it was not until the 1950s and 1960s that these project management techniques, namely GANTT, PERT and CPM, were adopted in civil engineering and defense projects in the US. This was the birth of the project management era (Shenhar and Dvir 1996).

Despite the growing use of project management practices, the most research literature on the management of projects is young and suffers from a lack of sufficient theoretical basis (Shenhar and Dvir 1996; Koskela and Howell 2002). As a relevant example, methodologies suggested by accredited project management bodies of knowledge such as PMBOK and PRINCE2 assume that all projects are fundamentally similar regardless of the level of ambiguity or complexity involved (Shenhar and Dvir 1996). This is partially why conventional project management practices, although relevant to exploitation types of projects, are often challenging to apply in product innovation and explorative types of projects. Recently, there has been an effort to bridge this gap and make project management practices more adaptive to complexity, novelty, technology, and pace (A. Jetter and Albar 2015; Shenhar and Dvir 2007; R. Sperry and Jetter 2009).

On the positive side, project management as a practice-oriented discipline has the most to offer for the framework of the present research when it comes to planning and controlling practices. These practices often have been suggested in the context of different but interrelated domains –as PMBOK calls them– such as time, cost, scope, risk, quality, communication, human resource, procurement, stakeholders, etc. (Rose 2013). Different execution processes and even the degree of emphasis on planning and controlling methods, as endorsed by project management, could directly or indirectly impact or be affected by structural, cultural and other contextual factors and therefore help to lead an organization to ambidexterity. For example, while project management advocates for the use of cost-benefit analysis (CBA), more emphasis on rate of return or return on investment –especially in the short term– could be fundamentally detrimental to the exploration efforts in the organization, even though it helps to increase the productivity and efficiency of exploitation efforts (March 1991). Similar impact is expected when using the critical path method (CPM) to plan and control the scheduling of the activities. While this method increases efficiency, it might prevent an organization from taking on projects with high uncertainty, including exploratory projects.

Almost all of the other project management practices for planning and control have similar impacts on exploratory and exploitative projects in an organization and need to be taken into account while marching toward becoming an ambidextrous organization.

2.10. Summary of the state-of-the-art and research gaps

Organizational ambidexterity literature has been successful in finding enough evidence that ambidexterity yields higher than average financial performance in reality. Yet theory has not fully developed regarding practices that make a firm ambidextrous. Since the field originated from organizational theory, solutions are mostly confined within the borders of structural, procedural and cultural change. As explained previously, in addition to organizational theories, project management theories, knowledge-based theories, and human resource management, open and distributed innovation theories are shown to inform the understanding of the organizational ambidexterity beyond the structure, process, and culture-oriented factors.

Also, the theory has not been successful in describing the interactions in between different factors that impact the firms' ability to reach ambidexterity. In summary, the following gaps exist in the field of organizational ambidexterity:

a) **Multiple ways vs. single solution:** The literature falls short in capturing the wide range of contributing factors to ambidexterity beyond the boundaries of organizational theory. Many studies up to this point imply that there is only one – or very few – practices that foster ambidexterity. In addition, the literature primarily focuses on structural, procedural and cultural practices. A suggested framework, illustrated in Figure 1, is insightful for recognizing additional domains as potential sources for other parameters and practices that potentially impact on the firms' ambidexterity capability. Based on this framework, the present research draws from other established branches of research including creativity theory, knowledge-based theories, open and distributed innovation theories, project management, and product innovation theory to develop a more comprehensive framework for achieving ambidexterity.

b) System view vs. linear causality: Practices and parameters suggested in the literature for achieving ambidexterity cannot be seen as single independent factors that could gain the ambidexterity by themselves. On the contrary, all of these factors are intertwined with each other in a complex fashion, making it necessary to study them as a whole. Contradictory practices suggested for achieving ambidexterity, are the evidence that following a particular practice in the real world may or may not lead to the expected results due to the complexity of the system. For example, while a high level of discipline potentially has a positive effect on the productivity of exploitative activities, it could negatively impact exploration activities. It is still largely ambiguous how effectively a certain practice can be performed in the presence of other organizational aspects that could work in favor of or against it. Although the qualities of the ambidexterity issue make it a perfect fit for a system modeling study, prior research has not taken this approach. Therefore, our understanding of the phenomenon is limited to some simple and direct relationships in a much broader system of causally linked components. To fill this gap, the present research employs fuzzy cognitive mapping in an exploratory fashion to fill this gap to advance our understanding of how an ambidextrous system works in reality. This research methods is extensively discussed in chapter 3.

c) **Practicality:** Currently, the literature has not progressed sufficiently to bridge the gap between ambidexterity as a theory and managerial needs for a practical, yet versatile, a framework for achieving ambidexterity – a framework that helps different organizations to replicate the similar outcomes of the ambidexterity, but through tailored solutions. Such a framework will support executives and managers in understanding the far-reaching and indirect effects of their decisions toward increasing innovation – exploratory and exploitative – within the organization. Studies on the organizational ambidexterity stream are focused on very limited prescriptions with no clear instructions, and on when and in what context any of these prescriptions could be used. Managers could gain more benefit from the theory if the requirements and side effects of implementing any sets of these practices were to be defined.

Table 2 summarizes the research gap, research objectives and research questions of this study.

Table 2- Summary of gaps, research objectives, and research questions

Gaps	Research Objectives	Research Questions
Multiple ways vs. single solution: The literature falls short in capturing the wide range of contributing factors to ambidexterity outside the boundaries of organizational theory.	A. Identify practices and other factors that lead to organizational ambidexterity.	1. What sets of practices lead to relatively higher exploration, exploitation, or balanced organizational ambidexterity?
		2. Are the practices for achieving exploration different from the practices for achieving exploitation?
		3. How might theory outside the literature on organizational theory* inform the challenge of reaching organizational ambidexterity? (*: product innovation theory, creativity theory, knowledge management theory, open innovation theory, human resource management theory, and project management theory)
System view vs. linear causality: Practices and parameters suggested in the literature for achieving ambidexterity cannot be seen as single independent factors that could achieve ambidexterity by themselves. To the contrary, all of these factors are intertwined in a complex form such that only studying them as a whole can emulate reality.	B. Investigate ambidexterity with a system perspective.	4. What are the factors that may directly or indirectly impact organizational ambidexterity?
		5. How can the systems approach of exploratory FCM modeling be used to effectively represent the complexity and subtleties of the non-linear problem of ambidexterity?
		6. How can a simulation model be used to create solutions for achieving ambidexterity that are customized to address different limitations and different firms?
Practicality: Currently, the literature has not progressed sufficiently to bridge the gap between ambidexterity as a theory and managerial needs for a practical, yet versatile framework for achieving ambidexterity –a framework that helps different organizations to replicate the similar outcomes of ambidexterity, but through tailored solutions. Such a framework would support executives and managers in understanding the far-reaching and indirect effects of their decisions toward increasing innovation, both exploratory and exploitative, within the organization.	C. Provide managerial guidance for achieving ambidexterity.	7. What is the theoretical framework for a potential decision support system for organizational ambidexterity (and innovation in general)?

3. Research Foundations: Exploratory Modeling and Analysis and Fuzzy Cognitive Mapping

The prior section explains that the factors that impact ambidexterity are highly interdependent and need to be researched from a system perspective.

To address the gaps identified above, this research combines two techniques: exploratory modeling and analysis (EMA) and fuzzy cognitive mapping (FCM). Chapter 3 introduces both techniques and discusses how they can be used in combination. The research design of this dissertation, which applies these two methodologies, is explained in Chapter 4.

Exploratory modeling is an approach to modeling that is independent of specific modeling tools and techniques. FCM is a specific modeling technique that has been shown to have a wide range of applications in different contexts. Both methodologies are discussed separately and in detail. At the end of the chapter there is a discussion of how these two pieces complement each other for the purpose of the current research.

3.1. Exploratory modeling and analysis (EMA)

In an influential article, Bankes (Bankes 1993) suggests a new approach for using simulation modeling, namely *exploratory modeling*, in order to gain insight into phenomena with high levels of uncertainty. To distinguish exploratory modeling from the previous modeling approach, Bankes (Bankes 1993) tags them as *consolidative* modeling. In consolidative modeling – later also referred to as predictive modeling (J. H. Kwakkel, Walker, and Marchau 2010) – the intention is to build a model with as much detail as possible to resemble reality, and then validate the inputs, parameters and, eventually, the outputs based on empirical data. The resulting consolidative model is generally intended to predict the future behavior of the system (Laskey 1996; J. H. Kwakkel, Walker, and Marchau 2010; Bankes, Walker, and Kwakkel 2013).

This approach has been criticized in the context of complex social and economic systems. In research funded by the RAND Corporation, Bankes (Bankes 1993) has investigated multiple million-dollar simulation projects that employed consolidative modeling on highly uncertain phenomena such as battle strategies. In practice, these models turned out to be unreliable in predicting the exact future state of the system. More recent cases, which have used the growing computational capacities of state-of-the art computers, continue to show the same difficulty in making reliable simulations (Fowler and Rose 2004; Brailsford 2007; Pennington 2007; Crooks, Castle, and Batty 2008).

Three different reasons have been suggested as the root causes for this phenomenon: (1) lack of sufficient rigor from the researcher or model designers; (2) incompetency of the existing hardware or software packages to do the simulation; and (3) a fundamental inability of the many methods of forecasting to ever predict the behavior of highly complex and uncertain systems (Bankes 1993). Supporters of consolidative modeling, who see the problem as a lack of rigor or inadequate simulation ability, advocate for limiting simulation modeling to cases for which all input data for designing the model can be experimentally validated in a way similar to the case for natural science research (Hales, Rouchier, and Edmonds 2003).

Exploratory Modeling and Analysis has a different approach to the issue. An increasing number of researchers (Bankes 1993; Agusdinata 2008; Stormer et al. 2009; J. H. Kwakkel, Walker, and Marchau 2010; Bankes, Walker, and Kwakkel 2013; Jan H. Kwakkel and Pruyt 2013) suggest that abandoning today's incomparable available computational capacity is not the solution. Instead, research objectives need to be adjusted in such a way that uncertainty is embraced: by experimenting with sets of models with different structures and parameters that are plausible and may resemble reality, it is possible to find a spectrum of results that provide insights into how the system under study might behave. In this approach, computer modeling is used to run a vast number of different scenarios that potentially cover the most likely possibilities of the inputs into the system in order to find distinctive patterns among the outcomes.

In general, three steps have been suggested within the modeling phase of the EMA:

i) "Conceptualize the decision problem and the associated uncertainties.
ii) Develop an ensemble of fast and simple models of the system of interest.
iii) Specify the uncertainties that are to be explored" (Kwakkel et al. 2013, p. 791).

When the simulations are performed and outputs are collected, different methods of analysis could be adopted to learn from the results. While analyzing the behavioral pattern is naturally the first step, *scenario discovery* also provides a novel tool that can be used to make sense from the resulting outcomes when the simulation model involves a large number of actors with diverging world views and conflicting interests (Lempert et al. 2006; Groves and Lempert 2007; Bryant and Lempert 2010; Jan H. Kwakkel, Auping, and Pruyt 2013). Scenario discovery assesses the reduced version of the models in which combinations of uncertainties result in an interesting behavioral landscape (Jan H. Kwakkel, Auping, and Pruyt 2013; Jan H. Kwakkel and Jaxa-Rozen 2015). Therefore, using scenario discovery may be formulated in the following steps in the context of EMA:

iv) "Analyze the behavioral landscape resulting from (iii).

v) Identify the combinations of uncertainties from which regions of interest in the behavioral landscape originate.

vi) Assess these combinations of uncertainties using various model quality metrics and related machine learning for assessing model quality.

vii) Qualitative or quantitative communicate the typical futures in these regions of interest, i.e., exemplary scenarios" (Kwakkel et al. 2013, p. 791).

As should be clear at this point, exploratory modeling is not a class of modeling techniques but an approach to modeling. For the purpose of this research, fuzzy cognitive mapping (FCM), explained next, is the specific type of simulation modeling that was used within the framework of exploratory modeling.

3.2. Fuzzy cognitive map (FCM)

The formation and development of fuzzy cognitive mapping as a modeling method has been the result of the integration of multiple techniques, namely cognitive mapping, fuzzy logic and artificial neural networks. The contributing techniques are rooted in different disciplines such as policy making and computer science. In the following sections, all of these preceding techniques and how they have been integrated into FCM are explained. The reasoning on why FCM is used within an exploratory modeling approach to conduct this research is discussed at the end of this chapter.

3.2.1. Introduction to FCM

Fuzzy cognitive mapping (FCM) is a method to model complex causal-effect systems utilizing cognitive maps and fuzzy logic (Kosko 1986). It provides a means to represent complex human cognition in a computable format. It can deal with linguistic ambiguities, complex causalities – including loops and feedbacks – and dynamic changes in the system. It also has been praised for its ease of use, understandable end-results – even for a non-technical audience – and relatively low computational time (Papageorgiou, Salmeron, and others 2013; van Vliet, Kok, and Veldkamp 2010; Antonie J. Jetter 2006).

In the past decade, FCM has been widely used as a tool for collective decision making (Khan and Quaddus 2004), exploring complex behavioral systems and scenario building (Muhammad Amer, Antonie Jetter, and Tugrul Daim 2011; A. Jetter and Schweinfort 2011; Salmeron, Vidal, and Mena 2012), and studying the stakeholders' conflicts of interest (R. C. Sperry 2014; A. J. Jetter and Sperry 2013; Kafetzis, McRoberts, and Mouratiadou 2010) in different fields, including medical (Papageorgiou et al. 2003; Georgopoulos, Malandraki, and Stylios 2003; Papageorgiou, Stylios, and Groumpos 2006; Stylios et al. 2008; Iakovidis and Papageorgiou 2011), robotics (Motlagh 2011; Motlagh et al. 2012), and social and environmental research (Madlener, Kowalski, and Stagl 2007; Ozesmi and Ozesmi 2003; Kontogianni, Papageorgiou, and Tourkolias 2012).

In this section, an overview of the principles of fuzzy cognitive mapping and state-of-the-art FCM extensions is provided. It is organized as follows: In 3.2.2, cognitive maps are introduced as the foundation of FCMs. In 3.2.3, *fuzzy sets theory* and its implication in FCM are briefly discussed.

3.2.2.Cognitive maps

The political scientist Robert Axelrod (Axelrod 1976) first introduced cognitive mapping in order to represent political elites' social knowledge. Cognitive maps are directed graph structures, like Figure 2, that represent experts' knowledge or perception of a complex causal system. Systems are modeled via variables (concepts) and causal connections (edges) in between them. Concepts can have positive or negative impacts on each other.

A positive causality between concept C_1 and concept C_2 means that by increasing or decreasing concept C_1, concept C_2 would be increased or decreased respectively if no other concepts or edges exist in the system. For example, Figure 2 depicts a casual cognitive map in which concept C_1 impacts positively on both concept C_2 and C_3, while concept C_3 itself has a negative impact on concept C_2. Therefore, by increasing concept C_1, concept C_2 may increase or decrease based on the strength of the impacts.

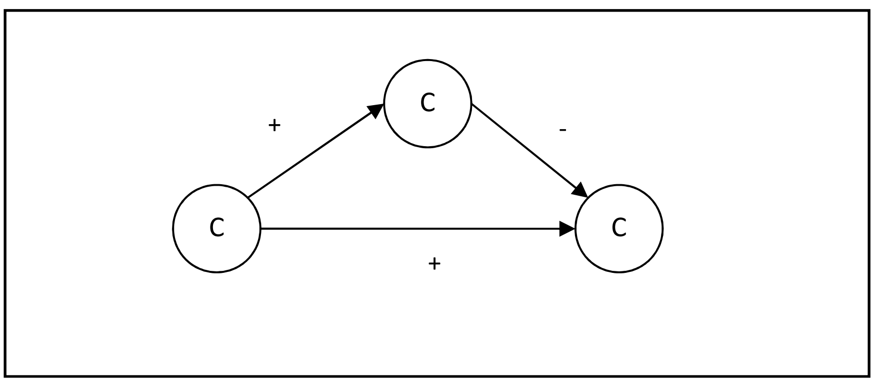

Figure 2- A simple casual cognitive map

In the early introduction of the cognitive maps by Axelrod (Axelrod 1976), the strength of the connections was not taken into account. In another word, all edges were considered to carry equal impact, but in negative or positive directions. An adjacency matrix is used to show these associations in between concepts where -1, 0 and 1 represent negative impact, no impact, and positive impact, respectively. Therefore, an adjacency matrix (M) would be a square n by n matrix where n is the number of concepts. An element of the matrix (m_{ij}) is a value function of the corresponding concepts: $m_{ij}= f(C_i, C_j)$. If C_i causally increases C_j, $m_{ij}= +1$, if C_i decreases C_j, $m_{ij}=-1$ and if there is no causality, then $m_{ij}=0$. The adjacency matrix of Figure 2 would be as follows:

$$\begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

Adjacency matrices are not necessarily symmetric and would have values other than zero on the main diagonal only if a concept directly impacts itself, also known as a self-loop.

3.2.3.Fuzzy set theory

In contrast to the classic theory of sets, where an object is either a member of a class or not, within fuzzy sets, a theory introduced by Zadeh (1965), the object can be a member of the class with different grades or degrees ranging between zero and one. Fuzzy theory is a response to the fact that in many cases in the real world there are no clear criteria that include or exclude objects from a class. "Class of tall men," "class of beautiful women" and "class of numbers much greater than 10" are a few examples to show the degree of ambiguity involved in human reasoning and linguistics in everyday life that are very difficult or impossible to express with the classic theory of sets (Zadeh 1965).

Zadeh later defines "linguistic variable" as an alternative to numerical variables such as age with linguistic values of *young*, *not young*, *very young*, *old*, *not very old* and so forth. In this case, while an age of 27 might be 0.7 compatible with young, an age of 35 might be 0.2, and the number shows to what degree each variable belongs to the class of "young."

Fuzzy sets and their application to the concept of linguistic variables have "provided a means of approximate characterization of phenomena which are too complex or too ill-defined to the description in conventional quantitative terms" (Zadeh 1975, p. 199).

Kosko (1986) added fuzzy logic to cognitive maps and introduced fuzzy cognitive maps (FCM). In an FCM, nodes not only accept values of 0, 1 and -1 but also all other real numbers in between them. Also, edges accept a weight that determines what fraction of the activation from the proceeding node will be transferred to the succeeding node. Figure 3 illustrates the FCM model of the cognitive map shown earlier.

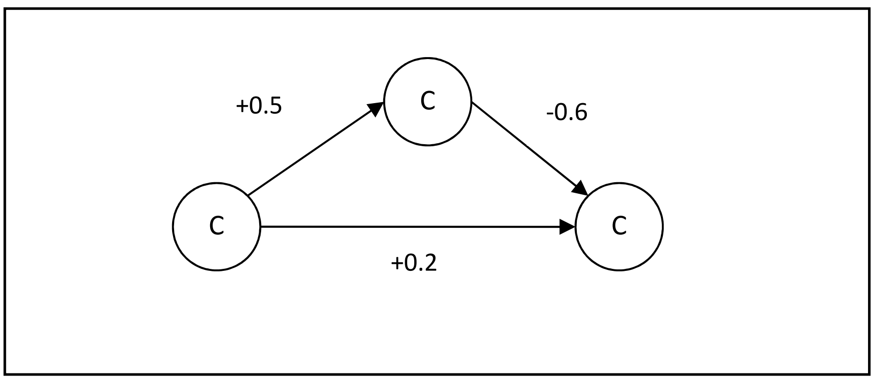

Figure 3 - A simple casual cognitive map with fuzzy connections

Respectively, the adjacency matrix of the map would be as follows:

$$\begin{bmatrix} 0 & .2 & .5 \\ 0 & 0 & 0 \\ 0 & -.6 & 0 \end{bmatrix}$$

In this example, if concept C_1 increases from 0 to 1 (iteration 1), then concept C_2 would increase by 0.2 immediately (iteration 2). But it also increases concept C_3 by 0.5. Since concept C_3 has a negative impact on concept C_2 (-0.6), in the next iteration concept C_3 would be dropped to -0.3.

Different values of the concepts in each iteration could be shown as a vector matrix as follows:

Iteration 1, $[1 \quad 0 \quad 0]$

Iteration 2, $[0 \quad 0.2 \quad 0.5]$

Iteration 3, $[0 \quad -0.3 \quad 0]$

Iteration 4, $[0 \quad 0 \quad 0]$

In general, the value of each concept is calculated based on the value of influencing concepts and the strength of the influence as follows:

$$C_i^{(k)} = C_i^{(k-1)} + \sum_{All\, j \neq i} C_j^{(k-1)} \; W_{ji}$$

where W_{ji} is the value of an edge from concept C_j to concept C_i at iteration k.

3.2.4. ***Artificial neural networks theory and its implication in FCM***

McCulloch and Pitts introduced a simplified model of biological neurons in 1945. They summarized the model as parallel neurological cells that are connected via long branches called axons. Each neuron – or node – also has multiple sensing arms called dendrites that collect inputs from all around. When a dendrite senses environmental stimuli, it sends a signal to the neuron. The neuron may receive multiple signals through its dendrites at different times with different levels of significance. When the right thresholds are met – depending on the neuron's type – the neuron gets activated and fires a new signal that is sent to other neighboring neurons (Izhikevich 2003).

The elaboration of a neurological system and how its interconnected cells perform complicated processes triggered an interest in applying similar concepts to new sets of modeling techniques such as *connectionist models*, *parallel processing* and *artificial neural networks (ANN)* (Ajith 2005).

In the context of ANN, after input stimulus has been received, a *transfer function* (f) decides whether an output signal (O) is required to be sent to neighbor nodes as follows:

$$O = f\left(\sum_{i=1}^{n} \mathrm{w_i x_i}\right) = \mathrm{f}(\mathrm{w^T x})$$

Where w_i is the member of a weight vector associated with the members of the neuron vector, c_i and w^T is the transposed matrix of w. In the simplest form, transfer function could be computed as:

$$O = f(\mathrm{w^T c}) = \begin{cases} 1, & if\ x \geq \theta \\ 0, & if\ x < \theta \end{cases}$$

Where θ is called the *threshold level*. A node with such a transfer function has a *linear threshold unit* with binary outputs.

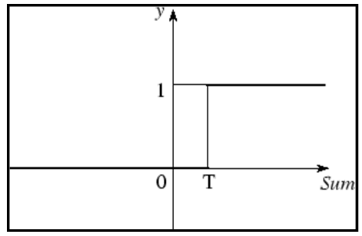

Figure 4- A binary function with threshold T

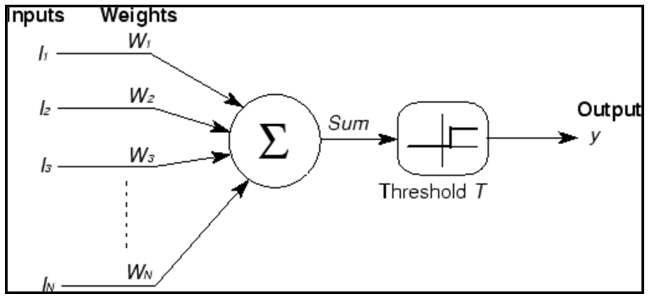

Figure 5 - A demonstration of how multiple inputs to a cell are combined and compared against a threshold function so that the appropriate output can be chosen

For example, let's use the adjacency matrix of FCM in Figure 3 again, and let's assume that the threshold for all the concepts is θ=0.5. If only concept C_1 initially gets activated, changes in the system would be computed as follows:

Iteration 1, $[1 \quad 0 \quad 0]$

Iteration 2, $$[1 \quad 0 \quad 0]\begin{bmatrix} 0 & .2 & .5 \\ 0 & 0 & 0 \\ 0 & -.6 & 0 \end{bmatrix} = [0 \quad 0 \quad 1]$$

{C_1=0 no input, C2= 0 since 1x0.2=0.2≤ 0.5, C3=1 since 1x0.5=0.5≥ 0.5}

Iteration 3, $$[0 \quad 0 \quad 1]\begin{bmatrix} 0 & .2 & .5 \\ 0 & 0 & 0 \\ 0 & -.6 & 0 \end{bmatrix} = [0 \quad 0 \quad 0]$$

{C_1=0 no input, C2= 0 since 1x -0.6=-0.6 ≤ 0.5, C3=0 no input}

Other transform functions have also been introduced to generate a continuous range of outputs. An example would be the Sigmoid curve, a form of logistic functions that generates an output between [-1, +1] for any input variable (t) as follows:

$$S(t)= \frac{1}{1+e^{-bt}}$$

Also known as the Sigmoid squashing function, this form of the logistic transform function has been widely used in the FCM literature since it fits better with fuzzy variables in real-world systems. Neither initial inputs to the system (often from expert sources) nor outputs associated with a real-world phenomena are "black and white"; in contrast, as was suggested earlier, they are better expressed with a "shade of gray" and "fuzziness" (Antonie J. Jetter 2006), for which the Sigmoid function is a perfect fit.

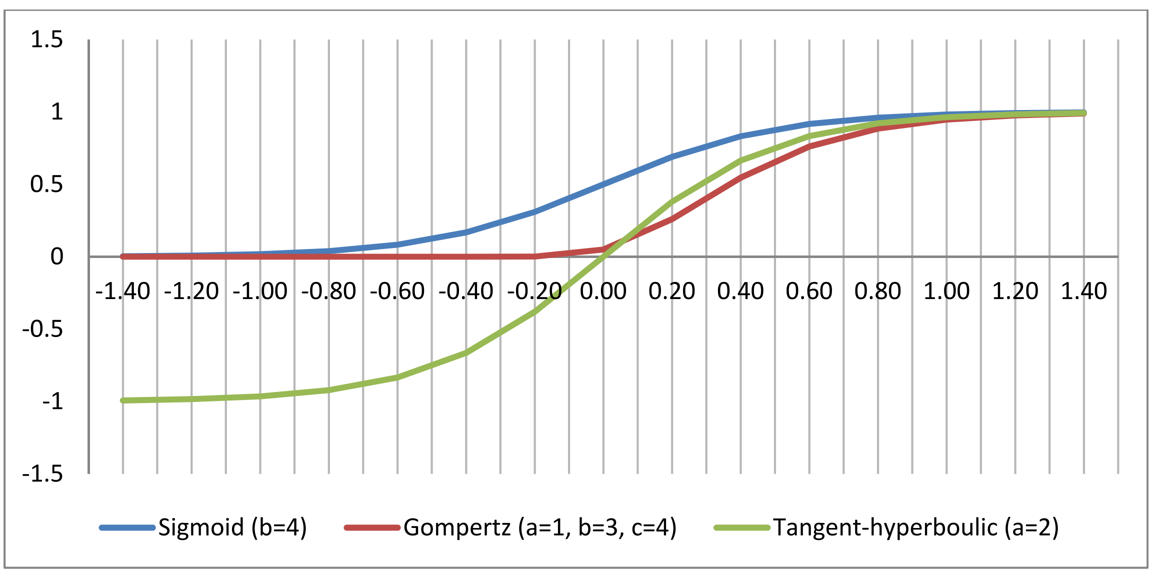

Figure 6 - Comparison of Sigmoid function, Gompertz function, and tangent hyperbolic function

Gompertz function $G(t) = ae^{-be^{-ct}}$ and hyperbolic function, Y(t)=a Tanh(t), are some other commonly used transform functions in the FCM and ANN practices. While Sigmoid and Gompertz functions generate outputs in the range of [0,1], tangent hyperbolic is capable of yielding a broader range of [-1,1] (see Figure 6).

3.2.5. Temporal characteristics of FCM

While using FCM, time units of edges in between the nodes need to be similar to be able to use a connection matrix that updates all the concept values in each and every iteration. For instance, when modeling a quadruped walking (Motlagh et al. 2012) with concepts defined as legs, all the interactions between concepts take place in a fraction of a second, whereas in an FCM of the adoption of solar energy technologies (A. Jetter and Schweinfort 2011), the time scale for all the effects are months or years. Since in both of these applications time scales are consistent, there would be no problem using FCM.

In case that an FCM includes inconsistent temporal associations, then a method proposed by Park and Kim (Park and Kim 1995) can be used that uses discrete values representing the time unit of each edge and how long it takes before the effect transfers to the destination node. Experts could be asked about the time units, and responses could be fitted into two or three categories such as "*normal,*" "*long,*" and "very *long.*" Then for long and very long edges, one or two dummy concepts would be used respectively between the two concepts to delay the effect until the second or third iteration. For any m>1 delay units, between nodes i and j, m-1 dummy concepts need to be added between nodes i and j to imply the time lags.

Another attempt to embody the time unit differences into the FCM is by Tsadiras et al. (Tsadiras, Margaritis, and Mertzios 1995), in which a memory capability or a decay mechanism is also added to the concepts traits. The state of a concept is not only determined by the magnitude of signals from causal concepts, but also by its tendency to keep the previous iteration's value. The lower the memory decay rate, the longer it takes for the concept to change based on the input from other concepts. In an extreme form, a concept with a memory decay of zero can be *held* or *clamped* to its initial value. This technique has been used frequently in modeling the systems with different time units as well as the systems in which initial inputs could be held at a specific level regardless of the dynamics of the system representing an exogenous factor.

3.2.6.Collective or augmented FCMs

Although cognitive maps were initially intended to visualize the perception and cognition of an individual – an expert in a domain or a stakeholder – soon the literature took the natural step of augmenting several FCMs into one integrated collective fuzzy cognitive map of multiple sources. This is aligned with the main goal of many FCM projects: to explore and study complex phenomena that, in many cases, no single expert has all relevant knowledge about. The collective FCM instead allows for integrating FCMs of different experts, not only to assure the phenomenon is observed from multiple aspects but also to reduce the error by triangulation in overlapping concepts. The triangulation process, in general, takes benefit of multiple perceptions to clarify the meaning of concepts and to verify the repeatability of an observation or interpretation (Stake 2000).

Augmentation can potentially be performed on two levels: first, identifying and consolidating the relevant concepts and connections and second, identifying the magnitudes of the relationships or, in other words, weights of the links. While integration at the first level could be as simple as including all the concepts introduced by all experts, it might be more of a challenge when it comes to integrating the connections (second level). Still, a simple mathematical average of the values of a connection proposed by experts could be used as a representative of the reality (Dickerson and Kosko 1993). This also aligns well with the rationale of exploratory modeling as explained in 3.1.

The second level of augmentation employs learning algorithms, which is explained in the following section, to replace the role of the experts to identify the connections between concepts and their magnitudes based on the initial inputs or expected outcome from the system – which would be a fixed-point state of the concepts, or a limited cycle of multiple states.

On the other hand, it has been shown (Miao and Liu 2000) that any FCM with loops can be divided into simple FCMs, and this could be used for studying a complex real-world FCM in multiple simpler chunks and assisting the experts in building a consensus on these simpler FCMs. In fact, another approach in integrating multiple FCMs is encouraging experts to work as a group to find the shared concepts and common connections and later polish the differences to find a consensus on a single FCM.

Another useful technique for combining the multiple FCMs into one is nested FCM. In a nested FCM, a concept consists of sub-concepts, and each sub-concept may have a specific effect on other concepts. For instance, if survival threat for dolphins could cause them to avoid predators or evade predators based on the level of threat, it means that the threat concept could be broken to sub-concepts with two different outputs based on the level of the threat (Dickerson and Kosko 1993). In integrating FCMs, the source of variations in individual FCMs might be due to observing these types of non-linear causal effects at different levels.

3.2.7. FCM as the method for exploratory modeling

Overall, three qualities make FCM suitable choice for exploratory modeling and this study: first, as a system modeling technique, it is a good match when the system is viewed as non-linear because there are multiple interactions in between variables, feedbacks, feedforwards, loops, and therefore mediation effects. Second, it is relatively easy for a non-familiar reader to understand the system components of an FCM model and how it works, which makes it easy to update, validate or expand the model. Third a large number of scenarios can be run for different sets of parameters (in the case of FCM: different initial values and weights) in order to find patterns and formulate new hypotheses.

However, to my knowledge, FCM has neither been used for organizational research on ambidexterity, which is dominated by regression analysis as the quantitative research method of choice, nor for exploratory modeling, which is often done with system dynamics. The following paragraphs compare both methods to FCM to explain how FCM is a suitable candidate for fulfilling the objectives of the proposed research.

a) **FCM vs. regression analysis**. A system of independent variables, mediators and dependent variables can be modeled using regression models. However, when working with regression methods, it is possible to over-simplify the system to a set of direct correlations and overlook the mediators, or real causes, as actual independent variables. Instead, FCM employs a holistic view when modeling reality. It starts with a bigger picture by collecting all the relationships before prematurely trying to prove or disprove the existence of any given causalities. This disparity in practicing FCM and regression analysis is partially rooted in the different approaches to theory development that accompany these two methods; *theory first* (deductive research), or *theory later* (inductive research). When certain constructs and hypotheses are proposed and then the researcher tests them against the target phenomenon, research is theory first. In contrast, in theory later approach, the phenomenon of interest is observed first, and then relevant components to the participants are identified, and final theory is proposed (Goel et al. 1997; Zenobia and Weber 2012). The cognitive mapping phase of FCM modeling is a powerful means to discover different aspects of phenomena and key concepts within the system and eventually formulate the relationship in between them. Regression analysis starts from an already established hypothesis of the relations between two or more variables and tries to statistically reject or accept the hypotheses in a deductive approach. Therefore, while FCM in the proposed research is used in an inductive setting to observe the phenomenon of ambidexterity from hundreds of perspectives (peer-reviewed articles from multiple research streams) and then develops a theory, regression analysis in the context of ambidexterity is most often used to test a theory against the sample data (De Clercq, Thongpapanl, and Dimov 2014; He and Wong 2004b; Jansen et al. 2009; Patel, Messersmith, and Lepak 2013; Yang, Zheng, and Zhao 2014).

b) **FCM vs. system dynamics (SD)**. Although system approaches and particularly system dynamics (SD) potentially fulfill similar objectives, FCM is slightly more adaptable to the nature of this research for two reasons. First, since SD is represented based on the *stocks* and *flows* of variables, maintaining the compatibility in between dimensions is a highly crucial matter in which any violation puts the validity of the model at risk (Senge 1980; Oliva 1996; Qudrat-Ullah 2005). FCM, on the other hand, is a more conceptual and therefore dimensionless modeling technique that makes it more adept at representing qualitative data (Antonie J. Jetter and Kok 2014). This is not to overlook that there are studies that have adopted system dynamics to model qualitative or conceptual systems (Richardson 1991; Barlas 1996; Coyle 2000; Luna-Reyes and Andersen 2003), but it highlights the fact that non-dimensionality of the FCM gives it a natural compatibility for representing the conceptual and cognitive models. Second, when compared with system dynamics, FCM is a relatively easier method to be comprehended by non-familiar readers. On the surface, FCM is a causal diagram that could be presented to an expert panel with none or minimal knowledge of the method for the purpose of validation or future executives for the sake of simulations, updates, and expansions. Some (Isaacs and Senge 1992; J. D. Sterman 1994) have discussed a risk to the simulations, so-called *Video-Game Syndrome,* where the model is perceived as being too complex to be understood by the user. In such scenarios, like playing a video game, instead of reflecting on why their actions failed to produce the intended results, users simply keep experimenting until their score improves. The high degree of readability of FCM will decrease the risk of videogame syndrome when the simulation model is used as an interactive decision support system for managers and practitioners in the field with different levels of familiarity with the method.

4. Research Design

The starting point for any FCM modeling project is a cognitive map, which is subsequently translated into a quantitative model that is calibrated, tested, and refined. Multiple frameworks for FCM modeling exist in the literature that are similar in principle: Overarching steps often include preparation (clarification of objectives and information needs, plans for knowledge elicitation), knowledge capture in the form of cognitive maps, translation of cognitive maps into FCM models that show concepts and positive or negative causal links between them, FCM calibration (i.e. weight assignment) and testing, and model use and interpretation (Muhammad Amer, Antonie Jetter, and Tugrul Daim 2011; Antonie J. Jetter and Kok 2014). Similar processes are also used in related fields. For example, Nadkarni and Shenoy (Nadkarni and Shenoy 2004) analyze texts to create system models with Bayesian networks. They employ the following steps: data elicitation, extracting model concepts and causal relationships to construct causal maps, modifying the causal maps to create Bayesian networks, and deriving parameters for the Bayesian map model (Nadkarni and Shenoy 2004). The research design for the current study borrows from these best practices but puts more emphasis on the test and analysis phase to satisfy the requirements of an exploratory modeling approach.

While Figure 7 represents all the steps and flow of this research in a graphical and concise form, a detailed explanation of all these steps is provided in the following sections.

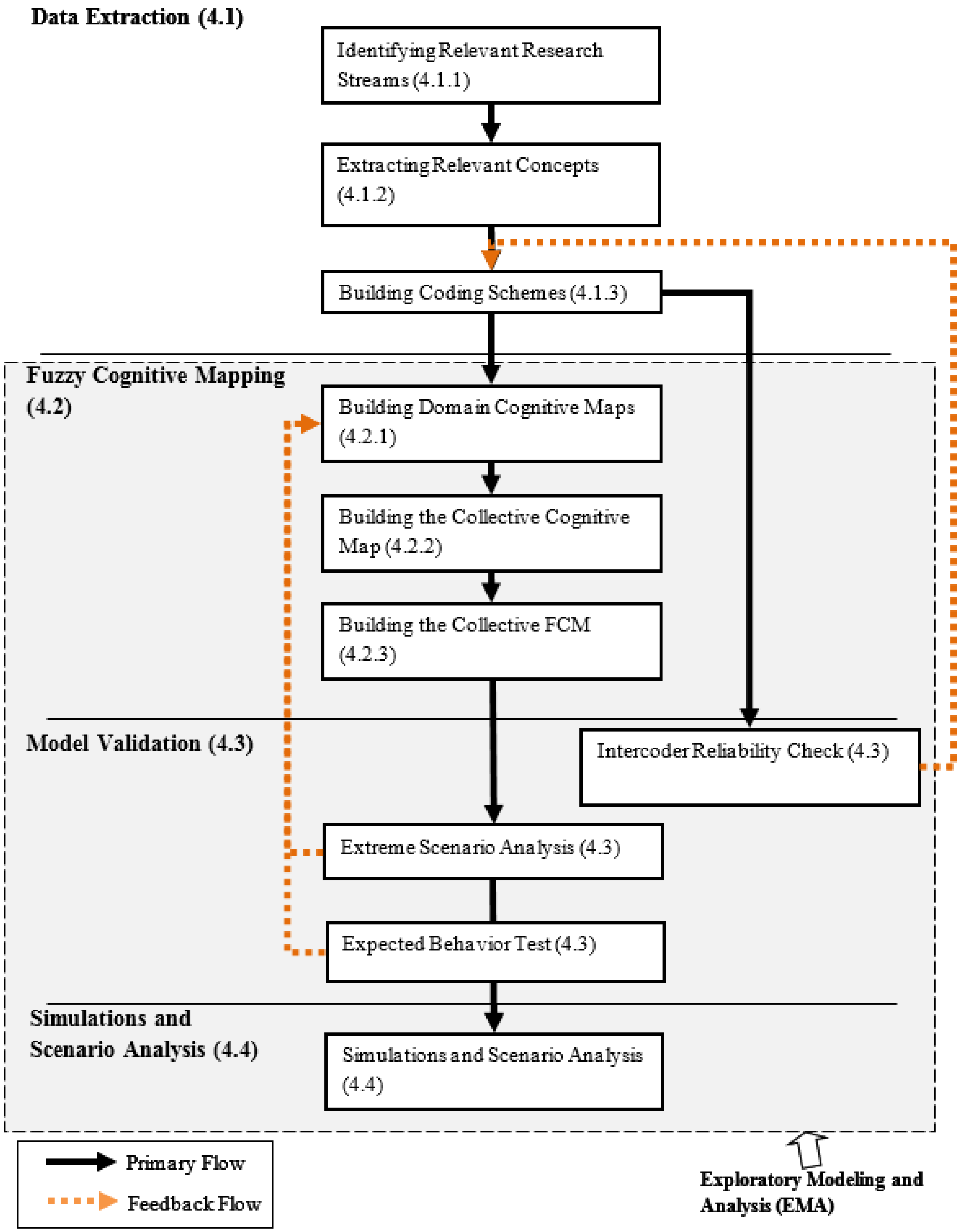

Figure 7- A Flow Chart of the Research Design

4.1. Data extraction

Extracting data from the literature was done in four steps: identifying the research streams from which relevant data may be extracted, extracting the relevant concepts from the research streams, building coding schemes, and creating initial cognitive models that reflect the insights gained from the literature. All steps are explained in the following sections. They are furthermore documented in detail in a separate article (Alizadeh and Jetter 2017), which is included in Appendix 0.

4.1.1.Identifying relevant research streams

The literature streams identified in the framework in Figure 1 served as the starting point for the first research step. For each research domain, I used a keyword search of Google Scholar to identify domain-specific articles with keywords such as ambidexterity, innovation, exploration, exploitation, and performance. I read these articles for content and additional references (more than 200 articles). In total 122 articles were included in the analysis as shown in Table 3.

Stream of research	# of articles	Articles included in the analysis
Organizational theory	63	(He and Wong 2004b; Birkinshaw and Gibson 2004; Gibson and Birkinshaw 2004; C. A. O'Reilly and Tushman 2004; W. K. Smith and Tushman 2005; Jansen, Van Den Bosch, and Volberda 2006; Isobe, Makino, and Montgomery 2004; Holmqvist 2004; Auh and Menguc 2005; Mom, Van Den Bosch, and Volberda 2007; Uotila et al. 2009; Govindarajan and Trimble 2010a; Piao 2010; Menguc and Auh 2008; Yu and Khessina 2012; Geerts, Blindenbach-Driessen, and Gemmel 2010; Chang and Hughes 2012; Fatehi and Englis 2012; H. Wang and Li 2008; Han and Celly 2008; Kim, Song, and Nerkar 2012; Schultz, Schreyoegg, and von Reitzenstein 2013; Eriksson 2013; Li and Huang 2013; Patel, Messersmith, and Lepak 2013; Kitapçi and Çelik 2014; Tamayo-Torres, Gutierrez-Gutierrez, and Ruiz-Moreno 2014; Yang, Zheng, and Zhao 2014; C. L. Wang and Rafiq 2014; C.-H. Wang and Hsu 2014; Raisch and Birkinshaw 2008; Andriopoulos and Lewis 2009; De Clercq, Thongpapanl, and Dimov 2014; Abebe and Angriawan 2014; Ylinen and Gullkvist 2014; Choi and Lee 2015; Reichert and Zawislak 2014; Abebe and Angriawan 2014; Oborn et al. 2013; C. A. O'Reilly and Tushman 2013; Markides 2013; Junni et al. 2013; Hung and Chou 2013; Volchenkov et al. 2013; Birkinshaw and Gupta 2013; Chang and Hughes 2012; Yamakawa, Yang, and Lin 2011; Lisboa, Skarmeas, and Lages 2011; Raisch et al. 2009; Lucas and Goh 2009; C. O'Reilly and Tushman 2008; Han and Celly 2008; O'Cass and Ngo 2007; Volberda 1996; Lubatkin et al. 2006; Gupta, Smith, and Shalley 2006; Gilsing and Nooteboom 2006; Gilbert 2005; Jansen, Van Den Bosch, and Volberda 2005; Ebben and Johnson 2005; Atuahene-Gima 2005; Siggelkow and Levinthal 2003; C. M. Christensen and Overdorf 2000; Adler, Goldoftas, and Levine 1999; Lewin, Long, and Carroll 1999; Volberda 1996; Levinthal and March 1993)
Creativity theory	12	(Miron-Spektor and Beenen 2015; Amabile 1988, 1997; Higuchi, Miyata, and Yuizono 2012; Parjanen 2012; Bharadwaj and Menon 2000; Taggar 2002; Hargadon and Bechky 2006; Baer 2014; Silvia et al. 2008; Sagiv et al. 2010; G. F. Smith 1998; Birdi, Leach, and Magadley 2012; Karakas and Kavas 2008; Savransky 2000, 2000; Gadd 2011)
Product Innovation	10	(Takeuchi and Nonaka 1998; Cooper 1990; Valle and Vázquez-Bustelo 2009; Ikujiro Nonaka and Von Krogh 2009; Cooper, Edgett, and Kleinschmidt 2004; Coulon 2005; Koufteros, Vonderembse, and Jayaram 2005; Conboy and Fitzgerald 2004; Barczak, Griffin, and Kahn 2009; McDermott and Handfield 2000)
Project Management	12	(Liberatore and Titus 1983; Gann and Salter 2000; Keegan and Turner 2002; Terziovski and Morgan 2006; Highsmith and Cockburn 2001; Blindenbach-Driessen and Van Den Ende 2010; Lenfle and Loch 2010; A. Jetter and Albar 2015; Gann and Salter 2000; Shenhar and Dvir 2007; Kwak 2005; Koskela and Howell 2002)
Open innovation	8	(Busarovs 2013; H. W. Chesbrough 2003; Huizingh 2011; K. Lakhani and Panetta 2007; Bogers and West 2012; H. Chesbrough 2006; Hippel and Krogh 2003; Hung and Chou 2013)
Knowledge-based theory	11	(Gloet and Terziovski 2004; I. Nonaka 1994; Erden et al. 2014; Madsen, Mosakowski, and Zaheer 2003; Von Krogh, Nonaka, and Rechsteiner 2012; Cohen and Levinthal 1990; Darroch and McNaughton 2002; Ikujiro Nonaka and Toyama 2003; Collins and Smith 2006; Fındıklı, Yozgat, and Rofcanin 2015; Johannissson 1998)
Human resource management	6	(Chen and Huang 2009; R. Mitchell, Obeidat, and Bray 2013; D. Wang and Chen 2009; Fındıklı, Yozgat, and Rofcanin 2015; Laursen and Foss 2003; Damanpour 1991)

Table 3- Articles included in this study

4.1.2.Extracting relevant concepts

From each of the articles identified above, I extracted relevant concepts for building the FCM model. In line with the objectives of the research, identifyed concepts that contribute, directly or indirectly to ambidexterity. Through my literature review (see Chapter 2), I had already identified 32 key concepts of interest (see Table 1). I was interested in additional concepts and relationships, and thus used an exploratory approach which approaches the texts with the question "What does the text contain?" (Carley and Palmquist 1992). I focused my analysis on one question: What practices, methods, tactics, and factors have been suggested to have an impact (positive or negative, direct or indirect) on ambidexterity?

For instance, the following excerpt from (Birkinshaw and Gibson 2004, p. 214) embeds the answer to this question.

"We argue that discipline, stretch, support, and trust are interdependent, complementary features of organization context that are non-substitutable, and therefore all four must be present in order for a business unit to become ambidextrous, and subsequently, to perform well."

The text thus names four concepts (discipline, stretch, support, and trust) that belong to organizational context. It also names the concept ambidexterity and the concept performance. I therefore considered the text excerpt to be relevant for my work.

Another example to illustrate this approach is the quotation below from (Jansen et al. 2006, p. 16):

"Hypothesis 2b that proposed a positive relationship between formalization and a unit's exploitative innovation is supported (β = 0.18, p < .01)."

This text talks about two concepts that are connected: "formalization" and "exploitative innovation", which both are relevant for the purpose of my research.

In some instances, the authors of the paper did not make explicit reference to impacts on ambidexterity, however they mentioned impacts on concepts that are recognized to affect ambidexterity. For instance, consider the text below, which describes such an indirect effect:

"…alliance provides a firm with access to its partners' knowledge which helps the firm increase R&D productivity. However, findings differ regarding the positive impact of alliance in firm performance…" (Erden et al. 2014, p. 2779).

The authors do not mention ambidexterity. They propose a relationship between [business] alliances and an increase in R&D productivity. They do not reach a conclusion as to whether or not this also increases firm performance. However, R&D productivity is known in the literature to have a link to ambidexterity. The text thus mentions three relevant concepts for this research: alliance, R&D productivity, firm performance.

4.1.3.Building coding schemes

The 122 publications identified in the first research step contain a large number of statements about individual concepts and relationships between them. Adopted from Nadkarni and Shenoy (Nadkarni and Shenoy 2004), I employed a *filtering* or *aggregation* process to decide which part of the text to code, and what words to use. To ensure reliability of this process, I developed a *coding scheme* that set the rules for how to document concepts and relationships○terms that the article used. For example, in the first excerpt above by (Birkinshaw and Gibson 2004, p. 214), the term "discipline" is used, while the second excerpt (Jansen et al. 2006, p. 16) uses the term "formalization". I preserved both terms, resulting in the following codes:

Discipline + → [Ambidexterity][1]

Formalization + → Exploitation

(Arrows show cause-and-effect relationships; + and – denote if the second concept increases or decreases as a result of an increase of the first concept.) In a second step, I identified identical concepts with different names but essentially identical meaning. For example, initially my codebook contained the terms "exploration" and "exploratory innovation", which I later consolidated to "exploratory innovation". On other occasions, I kept terms separate after evaluating their meaning in context. For example, I initially consider to consolidate the terms "discipline" and "formalization" but found their meaning different in the context of ambidexterity. My approach to consolidation was conservative in order to stay loyal to the text, resulting in a total of 374 unique concepts across all research streams.

To ensure consistency and reliability of my work, I developed a codebook for each research stream, as outlined by (Crabtree and Miller 1992). I continuously updated the codebook

[1] (The brackets denote that I modified the verbatim term "ambidextrous" to a noun "Ambidexterity")

and applied the updated codes as I gained new insights from the literature. The final codebook is documented in appendix 0.

4.1.4.Intercoder Reliability

I used a consistent and traceable coding process and also tested the internal validity of my work, using the concept of intercoder reliability. Intercoder reliability "is a measure of the extent to which independent judges make the same coding decision in evaluating the characteristics of messages"(Lombard, Snyder-Duch, and Bracken 2004). It is an accepted means to ensure qualitative research reliability, especially when content analysis is performed (Tinsley and Weiss 1975; Lombard, Snyder-Duch, and Bracken 2004; Burla et al. 2008; Albar 2013), although guidelines on proper execution of the process are limited (Lombard, Snyder-Duch, and Bracken 2002). In essence, to establish intercoder reliability, text segments are presented to different coders, who perform the coding task without knowledge of how other coders have coded the text. When independent coders evaluate the characteristics of the content in the same way and therefore apply the same codes, intercoder reliability is achieved (Hycner 1985; Kurasaki 2000; Lombard, Snyder-Duch, and Bracken 2002; Yin 2013). A small disagreement between these multiple coding processes is generally expected, and as a rule of thumb, while the intercoder reliability of 90% or above is always acceptable, a percentage between 80% and 90% is acceptable in most situations. Intercoder reliability of 67% to 80% is a gray area that might be acceptable in some situations, including exploratory studies, but may put the reliability of the research at risk (Lombard, Snyder-Duch, and Bracken 2002; Neuendorf 2002; Riff, Lacy, and Fico 2014).

To establish the inter-coder reliability of this research, I used an online survey to ask a panel of eight researchers[2] to read text excerpts and agree or disagree with how they were coded. MentalModeler[3], an online software, was used for visualizing the causal relations, while Qualtrics[4] was used for sending out the surveys.

All the collected cause-effect relationship were presented to the expert panel for verification through 326 questions. Obviously a answering a questionnaire with such large number of questions would have exhausted anybody's patience. So 326 questions were broken into 7 questionnaires. Each researcher received a different questionnaire with 41 questions. Taken together, these questions covered all the text excerpts that were used in this study. Figure 8 shows a sample question sent to the expert panel. The complete list of questionnaires could be found in the dedicated online sharefolder [5] for this dissertation.

An inter-coder reliability test with such a design tends to produce relatively high agreement among coders: they only need to look a short text excerpts, which tend contain fewer concepts than longer passages. Also, they do not need to select appropriate codes themselves. Accordingly, I set a target of at least 90% agreement.

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[2] Researchers consisted of a set of fellow Ph.D. students of engineering and technology management department at PSU
[3] www.mentalmodeler.org
[4] https://www.qualtrics.com/
[5] https://drive.google.com/open?id=1FM2Eak9nRSn0CF2sWyUahxU0_K96DiQF

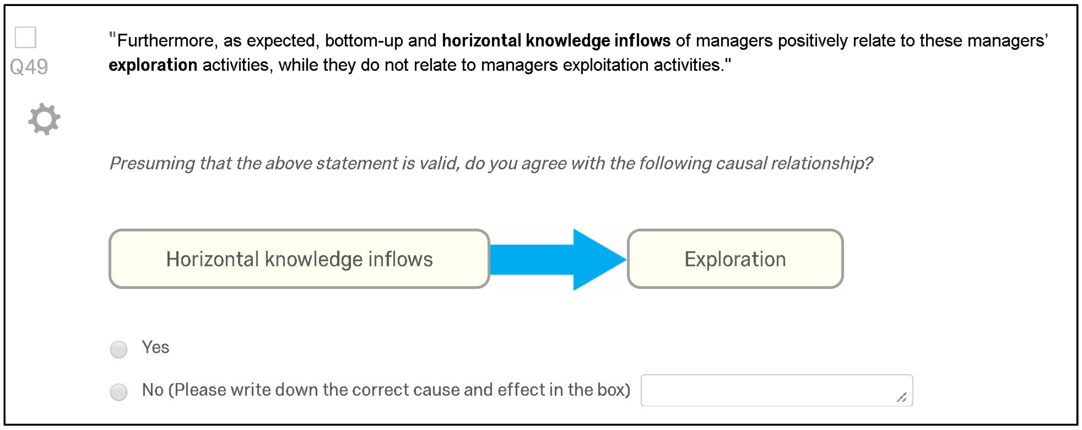

Figure 8- An example of questions sent out through inter-coder reliability check survey

Of 326 code assignments, only 17 were challenged. Upon a closer look and by considering the comments received, I determined that seven of the comments were valid and addressed the issue in the model. In the other ten cases, I did not agree with the coder and left the model unchanged. These questions along with reviewers' comments, responses and final modifications are documented in Appendix B. Based on the results, a *simple percentage metric* was calculated as 94.6% and since higher than 90%, disagreement was considered in acceptable range (Lombard, Snyder-Duch, and Bracken 2002; Neuendorf 2002; Riff, Lacy, and Fico 2014).

4.2. Fuzzy Cognitive Map Modeling

Fuzzy Cognitive Map Modeling was performed in three steps. In the first step, I created cognitive maps of each of the seven domains extracted in the previous phase. In the second step I combined these different cognitive maps into a single collective cognitive map of ambidexterity. In the third step I converted the final cognitive map to a fuzzy cognitive map (FCM) by assigning weights to the causal connections. In the following sections, all of these steps are discussed in detail.

4.2.1.Building domain cognitive maps

The coding process resulted in seven different, domain-specific codebooks, which I used to code the research articles for each domain. In as subsequent step, I visualized the insights about concepts and causal connections that I had extracted from the articles as cognitive maps. I drew these maps using Mental Modeler software.

In the subsequent research steps, I switched the perspective from documenting the research literature to creating a useful system model for exploratory analysis. This required that I interpreted the data from the perspective of a system modeler: Some cognitive maps contained detailed concepts that were rather limited in scope because they were sub-concepts to a broader, more general concept. In these cases, I had to decide what granularity is appropriate for the purpose of the model: Too much granularity leads to very large models with few connections between them. Each concept by itself will have a rather small impact on the system but the underlying broader concept may actually be overrepresented. Too little granularity, however, leads to a high-level map with broad category concepts that may be comprehensive, yet difficult to interpret. I selected the appropriate level of granularity and documented these changes in the cognitive map, as well as in my research memos.

Need for interpretation also arouse because some cognitive maps consisted of “islands’ (or clusters) of closely connected concepts, which often stem from the same body of literature, with few or no connections to other “islands”. Insular groups of concepts can be caused by the nature of research articles, which are typically focused on details and make “bigger picture’ connections almost in passing, in the introduction or conclusion & outlook. In other cases, the literature may not yet have established any links between insular concepts, leaving it up to the researchers to propose hypotheses about causal relationships. In either case, such gaps can result in models that do not represent the system under study adequately because the model ignores indirect effects and feedback cycles.

I used two techniques for visually identifying and investigating gaps in the cognitive maps, which I characterize as “isolated graph analysis” and “receiver-only concept analysis” (Alizadeh and Jetter 2017). In the former analysis, I aimed to identify isolated clusters of concepts that were not connected to other concepts. In the latter analysis, I looked for concepts that only had ingoing arrows, even though they were not one of the output variables of the model. If my analyses showed that there were gaps and that a connection to other concepts/concept clusters seemed plausible and important, I checked the literature to find descriptions of these missing connections. In some instances, this lead me to modify the cognitive maps by adding additional concepts and connections. If I could not find anything in the literature, I added plausible concepts and connections myself so that they became part of my exploratory analysis.

4.2.2.Building the collective cognitive map

The purpose of my study is a holistic, exploratory model of organizational ambidexterity. I therefore had to integrate the seven domain-specific cognitive maps into a single research model – the collective cognitive map. My process of map integration was qualitative: I used the domain map on organizational theory, which contained the largest number of concepts and connections, as a starting point. If a concept in this initial map was also included in other maps, I added all in- and outgoing connections from the other map to the initial map. In some instances, this required that I also added new concepts to the initial map. (Because I had standardized concept names in the step before, this process was straightforward).

While I used a purely qualitative approach, it implements a standard practice in FCM modeling (Tan and Özesmi 2006; Salmeron 2009): researchers create adjacency matrices of identical size for each map they want to merge. To determine the causal links in the combined (aka "augmented") matrix, they frequently add all weights for each connection and divide it by the number of contributing matrices. The following example, from (Salmeron 2009) illustrates this:

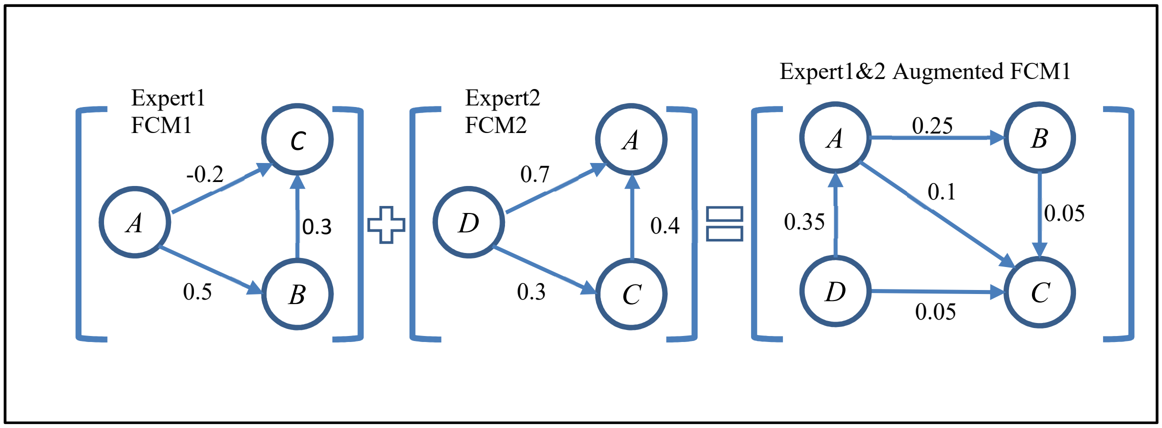

Figure 9- Adding Cognitive Maps, redrawn from (Salmeron 2009)

The same approach applies if the adjacency matrices are not weighted but only have values of 0 (no connection between the two concepts), -1 (negative causal link between the concepts) and +1 (positive causal link between the concepts). In this case, the augmentation process can be used to determine weights (Kosko 1988a, 1988b; Taber 1991). Also, an unweighted collective FCM can be generated by assigning the following values: a) 1 if one or more of the contributing adjacency matrices give an edge weight of 1 and the rest are 0, b) 0 if all the adjacency matrices assign an edge weight of 0, and c) -1 if one or more of the contributing adjacency matrices give an edge weight of -1 and the rest are 0.

In theory, it is also possible that a contributing adjacency matrix assigns an edge value of +1, while another assigns a value of -1. In my qualitative approach, this would have resulted in two arrows between the two concepts – one with a plus sign and one with a minus sign. However, in my study, this did not occur.

4.2.3.Building the collective FCM

The difference between a cognitive map and a fuzzy cognitive map is the FCM's capacity to not only to represent the existence and sign of causal relations but also the strength of the relationship. Strength of the relationship itself is a function of the connection weights and squashing functions.

Initially, I had planned to have weights assigned by a panel of experts: to this end, I identified authors of research publications that are pertinent to my topic and sent them individualized online survey. Each survey contained an excerpt of the collective cognitive map and asked the participant to assign weights for the connections in this subset of the model. My plan was to use this information to (1) identify connections that the experts were uncertain about and that should subsequently be researched through exploratory modeling, and (2) identify connections that could be included in the model with the average of all expert assigned weights because the experts assigned the same or very similar weights. As reported in Appendix IV, I encountered several difficulties: First, few experts responded to the survey at all. Some emails bounced, some experts never responded, others declined to participate because they found the questions difficult, out of their field of expertise, or too time-consuming to answer. As a result, I only have an expert-assigned weight for 263 of 458 connections (57%). I also did not receive *multiple* data points for each causal connection and therefore could not use the agreement among the experts as a measure of uncertainty.

I therefore decided to rely on the computational capacity of exploratory modeling and investigate alternative model structures not only for some, but for all 458 connections in the model. Because I had carefully deduced the sign and direction of causal links from the existing literature and had validated the model structure (see section 4.3), I did not want to explore model structures that changed the sign of connections: if I had determined that there was a positive causal link, all exploratory models should also contain a positive causal link, albeit with different weights.

I prepared two sets of models with 100 models each:

Set 1 contains models in which edge weights were randomly selected from the interval of [-1, -0.75] for negative edges and [0.75, 1] for positive edges. These models assume that all connections that are derived from the literature are rather strong and there is little uncertainty. This is not unlikely because academic research typically reports on factors or practices that have strong contributions on an outcome of interest. Research that shows only minor impacts is simply less likely to be published.

Set 2 contains models in which edge weights were randomly selected from the interval of [-1, 0) for negative edges and (0, 1] for positive edges. These models assume very high uncertainty about edge weights. This high uncertainty accounts for the fact that the literature currently does not take a system view and rarely investigates the interdependencies among the factors that contribute to ambidexterity. Accordingly, little is known about the system structure.

I developed my own simulation package in R: Using a uniform distribution function, it generated the two sets of 100 random adjacency matrices. (The uniform distribution allowed equal chances for all weights. I chose it because there is no prior knowledge about the quantitative characteristics of the causal relations of the FCM).

In this study I generated 200,000 random initial vectors and ran them through 100 random model structures. Altough the quantity of model permutations is less than some other exploratory modeling projects, some of which investigated around 20,000 permutations of the model (Jan H. Kwakkel and Pruyt 2013) for a model of 20 to 30 variables, in my case of 366-nodes and 481-edges FCM, even 1000 permutation of the model structure reached the computational limitations[6]. But as discussed in chapter 6, it was shown that in my FCM model results were much less sensitive to the changes in the weights of the connection than morphology of the model—existence or not existence of causal connections. In fact in results of running the simulation for a set of 1000 models with different adjacency matrices showed negligible difference with a set of 100 models, a sign of saturation.

The last factor effecting on the strength of a relationship is the transfer function—also known as squashing function—as discussed in section 3.4.2. For the reasons explained there, a hyperbolic tangent function was used for all the nodes in the FCM with the exception of the "organizational ambidexterity" node. The transfer function was specified as following to produce a range of [-1,+1] for the same domain, where *t* is the input signal from the connection and *Y* represents the value of the node:

$$Y(t) = 2\text{Tanh}(\text{t})$$

Figure 10 provides a visualization of this transfer function.

[6] 1000 permutation on 481 connections, generated an adjacency matrix as large as 1.2GB memory. A 20,000 permutation of such large model, would generate an adjacency matrix as large as 24 GB memory.

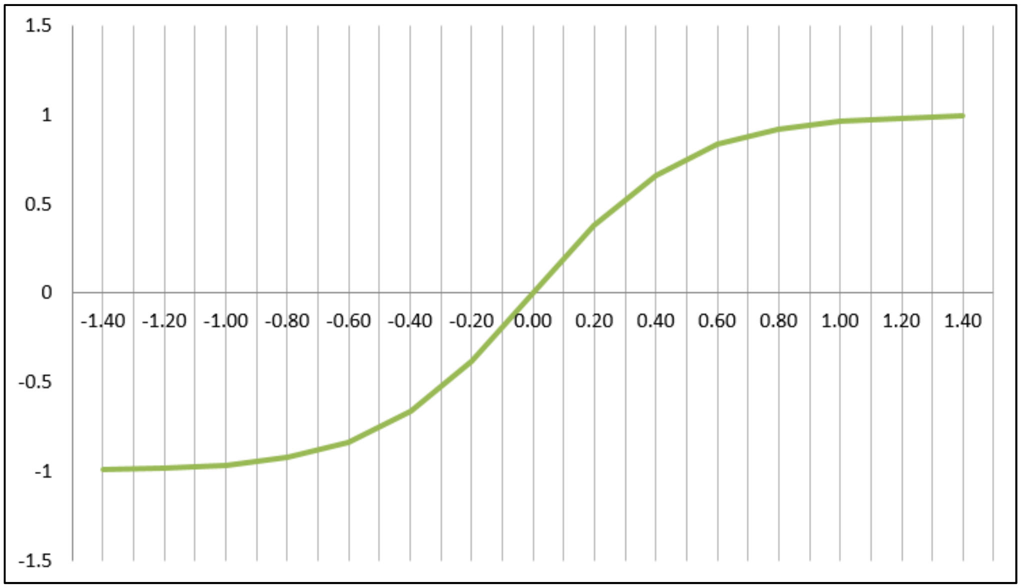

Figure 10- Hyperbolic tangent transfer function used to build the FCM

The case for the "organizational ambidexterity" node was different since as discussed in chapter 1, based on definition a balance and relatively higher than average "exploitative innovation" and "exploratory innovation" are needed at the same time to yield to "organizational ambidexterity". Thus positive signals from both nodes at the same time needed to be sensed by the "organizational ambidexterity" node in order to increase its value. To meet these criteria I customized the Gompertz function $G(t) = ae^{-be^{-ct}}$ for two input variables $G(x, y) = ae^{-be^{-cxy}}$ and then specified it as $G(x, y) = e^{-20e^{-10xy}}$. As a result a degree of organizational ambidexterity could be achieved only if both input nodes—exploitative and exploratory innovations—see a positive change more than 50%. Also closer the value of these two nodes leads to higher organizational ambidexterity. See Figure 11 for a representation of the value of organizational ambidexterity in regard to value of its two input nodes.

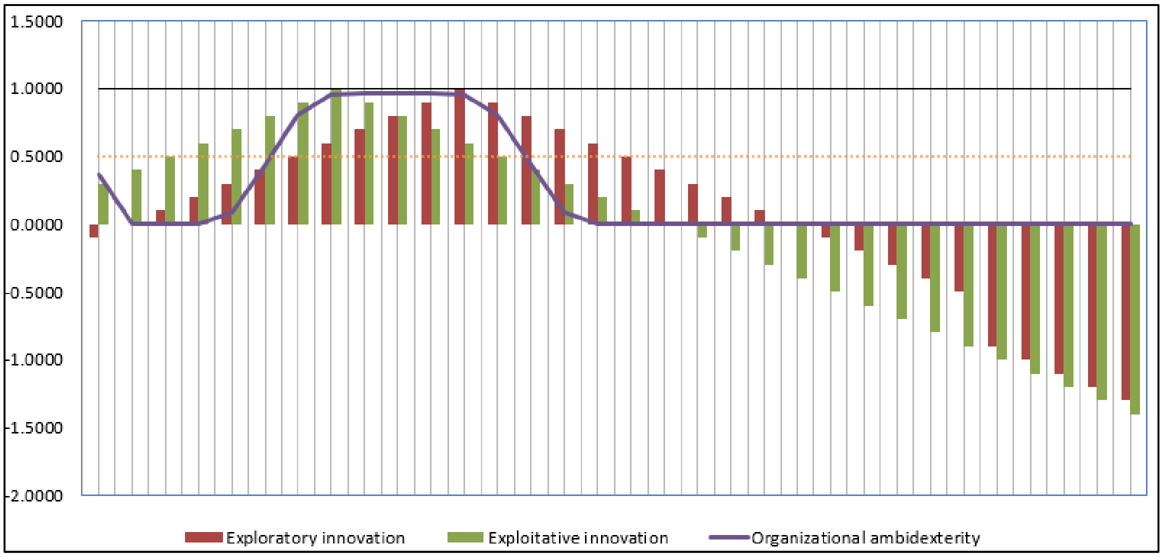

Figure 11- A representation of the value of organizational ambidexterity in regard to value of its two input nodes

4.3. Model validation

There is an ongoing discussion in the literature about reliability and validity of scientific research in general and in the context of modeling in particular. Reliability is typically defined as the stability of findings and is enabled by research tools that produce repeatable and consistent results, whereas validity refers to the truthfulness of findings, i.e. whether the research results accurately describe the real world (Whittemore, Chase, and Mandle 2001). The concept of validity as truthfulness is controversial in qualitative research (Whittemore et al. 2001), which often deals with uncertainty, subjective interpretation and pluralism of interpretations. Qualitative researchers therefore emphasize rigor of the research approach, rather than the validity of the outcome. Their criteria for research rigor include credibility, fittingness, auditability, conformability, relevance, transferability, plausibility, neutrality, and authenticity (Morse et al. 2008; Yvonna S. Lincoln and Guba 1985; Yvonna Sessions Lincoln and Guba 2000; Altheide and Johnson 1998).

Validity as truth is also criticized by researchers who create system models, leading Sterman to observe that: "all models are wrong...they are small imitations of the real thing" (Sterman 2002, p.501). Accordingly, he proposes to judge models not based on their validity, which may be impossible due to our fundamentally limited understanding of complex systems, but based on their usefulness for the decision problem at hand. Usefulness, in turn, requires that the model provides an adequate representation of the real-world, which is achieved through a rigorous research process.

Rooted in this point of view, I do not attempt to validate model results against "the truth," e.g., by using statistical techniques to compare the model fit against data. This would be impossible and defy the purpose of the exploratory modeling approach which I chose because so little is known about the structure of the real-world phenomenon of ambidexterity. Instead, I use a mixed approach to ensure research rigor, as is recommended in qualitative research (Yvonna S. Lincoln, Lynham, and Guba 2011; Creswell and Miller 2000). It includes a check for plausibility, internal validity (also: reliability), and behavioral validity.

Internal validity or reliability is a concern at the data extraction phase. Therefore, intercoder reliability was evaluated and reported in section 4.1.4. To identify possible discrepancies between findings of the simulation and how the real system functions, which would put in question the validity of the model, I used extreme scenario analysis and expected behavior test.

Extreme scenario analysis, also known as extreme-condition test or extreme-policy analysis, is a powerful and established method within the system science literature that enables a comparison between model behavior under extreme conditions and experts' judgment (Senge 1980; Schoemaker 1993; J. Sterman 2000). The assumption of such analysis is that under extreme conditions, "one may be quite sure what would happen even if no real-life example has been observed. Therefore, the better a model passes a multiplicity of extreme-policy tests, the greater can be confidence over the range of normal policy analysis" (Senge 1980 p. 27).

Expected behavior test is known as a structure-oriented behavior test, which evaluates the validity of the structure of the model by comparing expected outcomes of the real world as understood by the experts and models outcome patterns in certain cases (Senge 1980; Barlas 1989). The entire model or a sub-model could be used for expected behavior test simulation (Barlas 1996). The expected behavior is captured qualitatively as patterns rather than quantities. Under certain conditions, experts may expect the outcome variable to have a fall, a rise, a fall followed by a rise, a delayed fall, a delayed rise or oscillation (Carson and Flood 1990). I am reporting on both analyses in chapter 5.3 and 5.4.

4.4. Simulations and scenario analysis

To implement the exploratory modeling approach, four distinct activities were required: (1) selection of initial vectors of interest, (2) random generation of adjacency matrices within the plausible range for all weights (explained in section 4.2.3), which results in a multitude of FCM models, (3) running the multitude of FCM models for the initial vectors, and (4) analyzing the results. The four steps are explained in the following.

4.4.1 Selection of the initial vectors

For any FCM network with N concepts, one can choose 2^N activating vectors that include all the possible combinations of the initial values of the concepts when initial values are only limited to 0 or 1. This means that for an imaginary FCM with 40 concepts initial states could be defined in more than one trillion (1.995e+12) ways. Feeding this massive amount of combinations into the model requires excessive computing resources and can lead to outputs that are difficult to interpret. Moreover, because FCMs have meta-rules, input variations do not always lead to variations in outputs, so that a lot of the results would be redundant. Accordingly, it is important to strategically select the right subset of initial values (Jan H. Kwakkel, Haasnoot, and Walker 2015; J. Kwakkel and Haasnoot 2015). There are fundamentally two strategies for achieving this: One strategy is to randomly select a subset of initial vectors from all the possible permutations. This assumes that this smaller set of vectors will allow me to observe patterns that are similar to an observation of all permutations. A second strategy is to select input vectors based on *plausible* managerial strategies. A manager would likely not attempt to change a large number of largely different variables at a time but focus efforts on coherent strategies, such as "focus on human resources", "reorganize departments", or "implement open innovation principles". However, without involving managers in this study it is difficult to formulate such plausible strategies. I therefore focused on the first strategy and only did a limited test of the second strategy by running the model with an input vector that represents a focus on open innovation.

4.4.1.1 Random initial vectors

There are 371 concepts in the model that can either be activated (+ 1 or -1) or off (0). (I chose to not consider "in-between" activation levels in the interval of [-1, 0, 1]). A random assignment of these values means that, on average, half of all concepts (185.5) would be activated to their full extend regardless. This is likely unrealistic in a real-world setting, where companies cannot do all and fewer variables can be expected to be active at the same time. It is also problematic because 50% of the concepts (i.e. all activated concepts) would be clamped, effectively rendering large parts of the model inactive. Moreover, exploratory and exploitative innovations have a 25% probability to both be activated at the same time. Thus, ambidexterity would be high in a quarter of all cases, regardless of other concepts.

To resolve the issue, I therefore assigned a probability for every given concept to be activated at p=0.05. This means that I studied the impact of initial vectors that activate an average of 18.5 concepts (np=371*0.05=18.5). Figure 12 shows the distribution: the x-axis shows the number of concepts that were activated in each class, the y-axis shows the frequency (i.e. the number of vectors in each class). The minimum number of concepts that were activated in an initial vector was 6, the maximum number was 33.

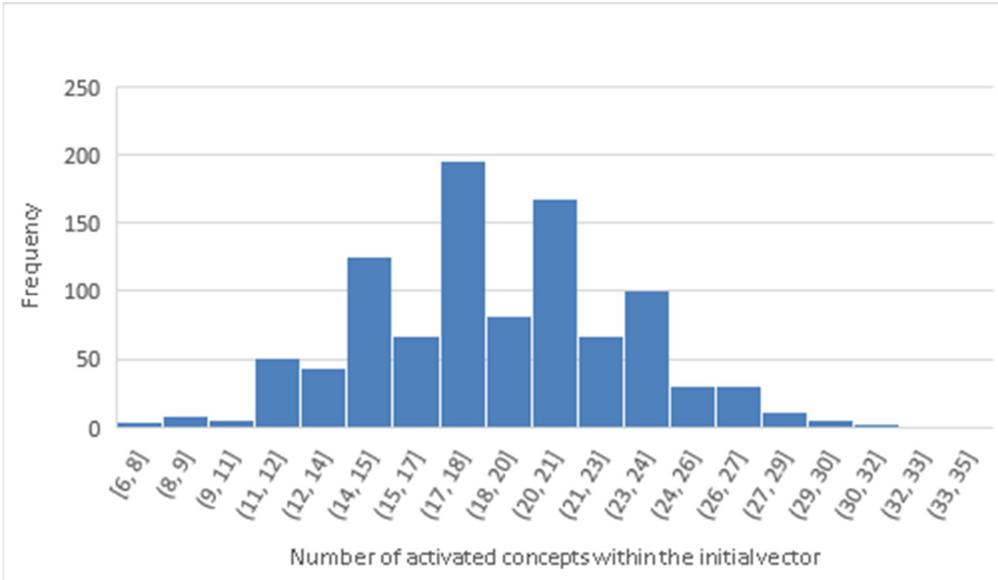

Figure 12- Distribution of sum of 1000 randomly selected initial vectors (P=0.05)

This set of 1000 randomly generated initial vectors was used in simulation and results is explained ahead. Table 4 provides a glimpse of processing time and memory needed for generating different size of initial vector sets.

Table 4- Time and memory used for generating initial vector permutations of the FCM with 371 concepts

# of Initial vectors	Process time	Memory size
1000	1 S	728 kb
100,000	25 S	70.8 Mb
1000,000	250 S	708 Mb

Hardware used for simulations above: HP Workstation, Core i7 processor, and 64Gb RAM.

4.4.1.2 Initial vector to represent managerial intervention

A comprehensive model of ambidexterity can be used to test hypotheses that are proposed in the literature. It can also provide a "sandbox" for managers to examine their ideas for achieving ambidexterity through computational experiments. In both cases, an initial vector is constructed. It represents the combination of input variables of the research hypothesis or the planned managerial intervention. There is no limit to the number of hypotheses or managerial ideas that could be tested with the model. However, such experiments are only meaningful if they are carefully constructed. I therefore focused my attention on only one case.

For this case, the literature of open innovation was used to examine the behavior of the system when a set of practices, which are suggested in the literature, are represented as an initial vector and fed into the system. Please refer to section 5.6 for the details of simulation and results.

4.4.2 Generation of the adjacency matrix

Please refer to section 4.2.3 for details.

4.4.3 Running the FCM for all the acceptable initial values

Furthermore, as explained in 3.1, I analyzed the behavior of the landscapes resulting from all the plausible permutations of initial vectors and numerous adjacency matrices.

Plausible permutations of initial vectors only includes concepts that have impacts on others in a network. Therefore receiver-only concept analysis (ROCA) as described in Appendix III was used to exclude concepts that have only inward links—such as outcome variables—and the concepts that only have outward link to this group of concepts. Thus 107 concepts were identified, as depicted in Figure 13, with no impact on the value of concepts of the interest such as exploitative innovation, exploratory innovation and ambidexterity. This step also eliminated a large set of unnecessary calculations and shortened the simulations time.

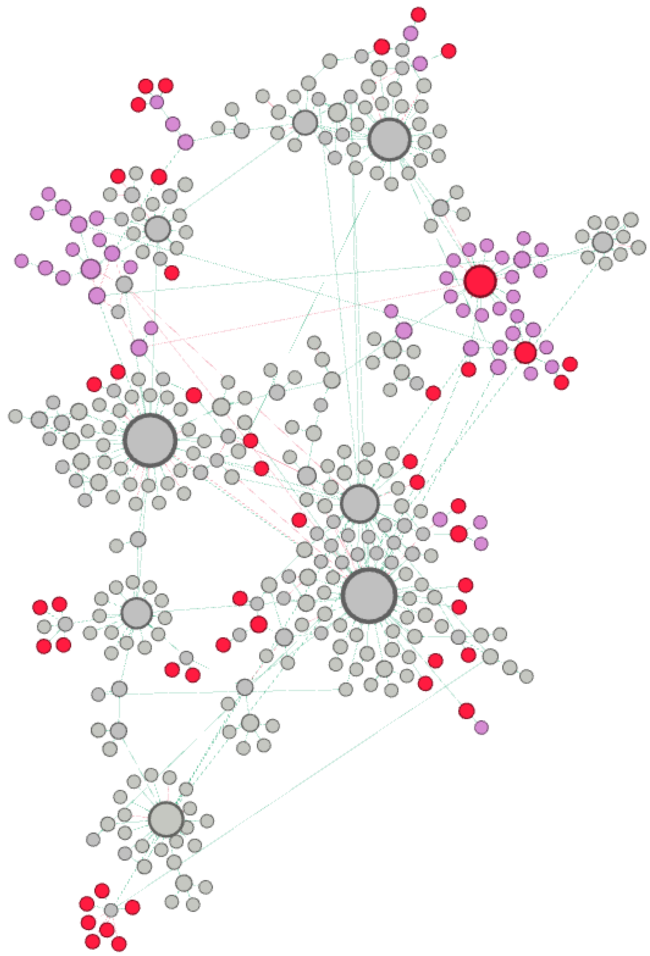

Figure 13- Concepts excluded from the initial vector permutations. Concepts with no outward connections (red) and predecessor concepts only causing the first group (magenta)

The number of possible permutations of the initial combinations could be calculated as 180,352,320 (all the combinations of 4 activated concepts out of 258 concepts). For the list of these concepts refer to

Appendix E- Domain and collective cognitive maps memo. This step alongside identifying the initial values which lead to the landscapes of interest –using mathematical filtering or visualization techniques—are the two typical steps per (Jan H. Kwakkel, Auping, and Pruyt 2013) for scenario discover.

4.4.4 Visualization of the results

The key question of visualization is to identify meta-rules (Dickerson Kosko) that govern the behavior of the system. Specifically, I am interested to see a) how many scenarios balance exploration and exploitation (i.e. achieve ambidexterity), b) how may scenarios perform well with regard to one aspect but at the expense of the other (i.e. low exploration/high exploitation and vice versa), c) how many scenarios result in low performance in both aspects, and d) what theoretically possible positions in the scenario space are not populated. Answering these questions makes it possible to contribute to ambidexterity theory.

I used five type of visualization techniques to answer the questions above:

1) *Scatter plot*: I generated scatter plots using the R.Plotly package to visualize the outcomes of my simulation runs. I plotted each simulation result against two axes, i.e. the amount of exploitation and the amount of exploration. (See Figure 42).

2) *Cluster map*: I generated cluster maps, using the R.Plotly package, for visualizing different groups of scenarios that contained similar scenarios and were distinctly different from other scenario groups. This visualization also gave me information about the frequency of each scenario type. (See Figure 52).

3) *Heat map:* I generated heat maps, using the R.ggplot2 package for visualizing the density of scenarios in an area that covers all possible combinations of exploration and exploitation. (See Figure 49).

4) *Topology map*: It was generated by combining the capabilities of R.ggplot2 and R.Plotly packages to visualize third parameters of Organizational ambidexterity as

elevation layers for all the scenarios with different value of exploitative and exploratory innovation. (See Figure 48).

In addition to these visualizations, which directly contribute to answering the questions posed above, I also developed:

5) *Pulse diagram*: A pulse diagram shows the activation levels of different concepts for each iteration of the simulation. I developed this visualization using R, to study the system behavior in general with introducing a specific initial vector. (See Figure 26).

5 Simulations and results

5.1. Building domain cognitive maps

Using the developed framework for extracting and building cognitive maps from the text (Alizadeh and Jetter 2017) as explained in Appendix C- Content Analysis using Fuzzy Cognitive Map (FCM), seven domain cognitive maps were emerged from the following literature streams: organizational theory (Figure 14), knowledge-based theories (Figure 15), human resource management (Figure 16), product innovation and NPD (Figure 17), project management (Figure 18), open innovation & distributed innovation (Figure 19), and creativity theories (Figure 20).

All the forming steps as well as the challenges to build an FCM through text are described in details in Appendix E- Domain and collective cognitive maps memo. In the nutshell, as a strategic choice, I remained faithful to the original text and followeded clear and repeatable steps for any modifications in the FCM. Therfore many of these steps could also be done without human intervention in an automated way in the future.

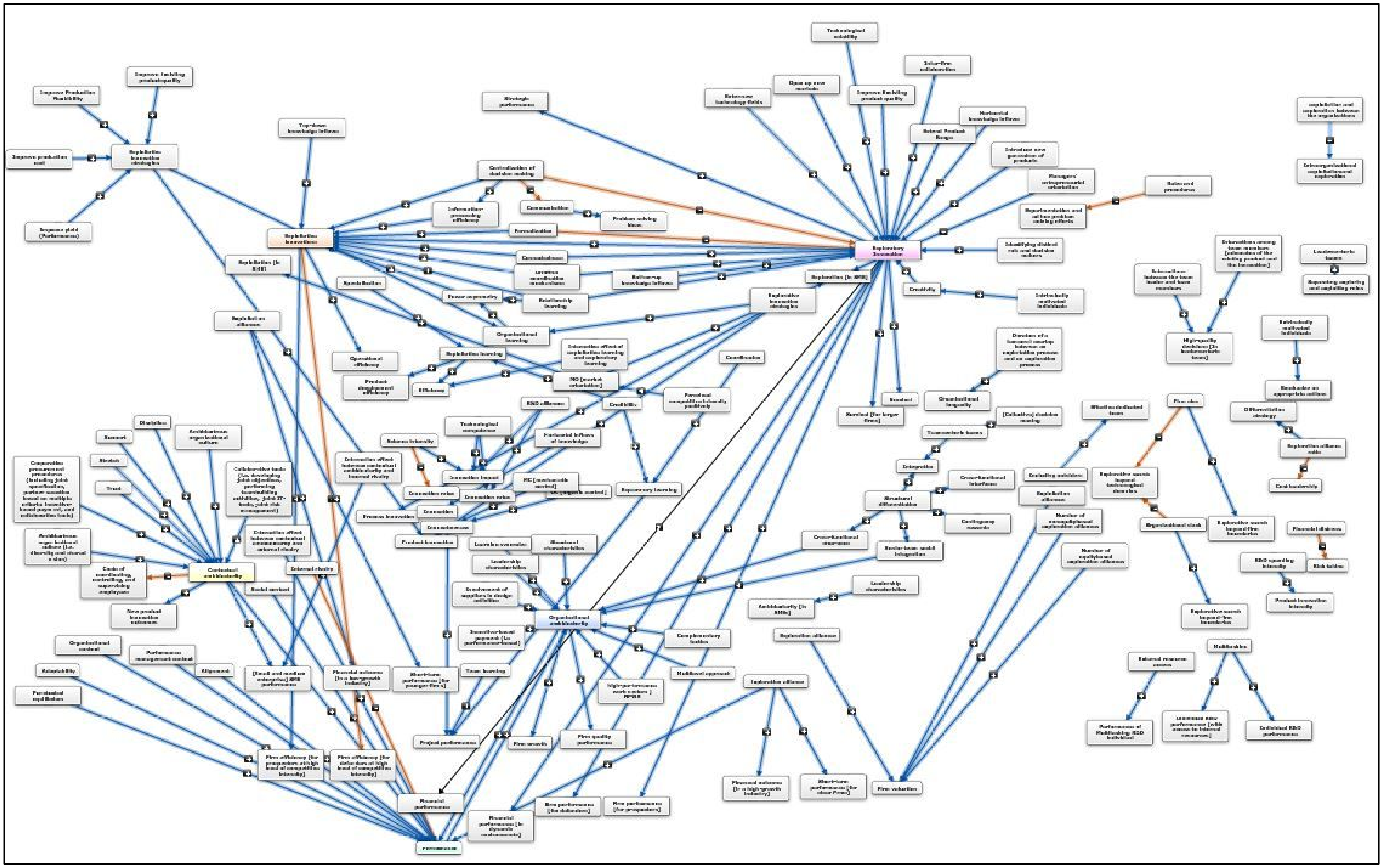

Figure 14- Organizational theory domain cognitive map

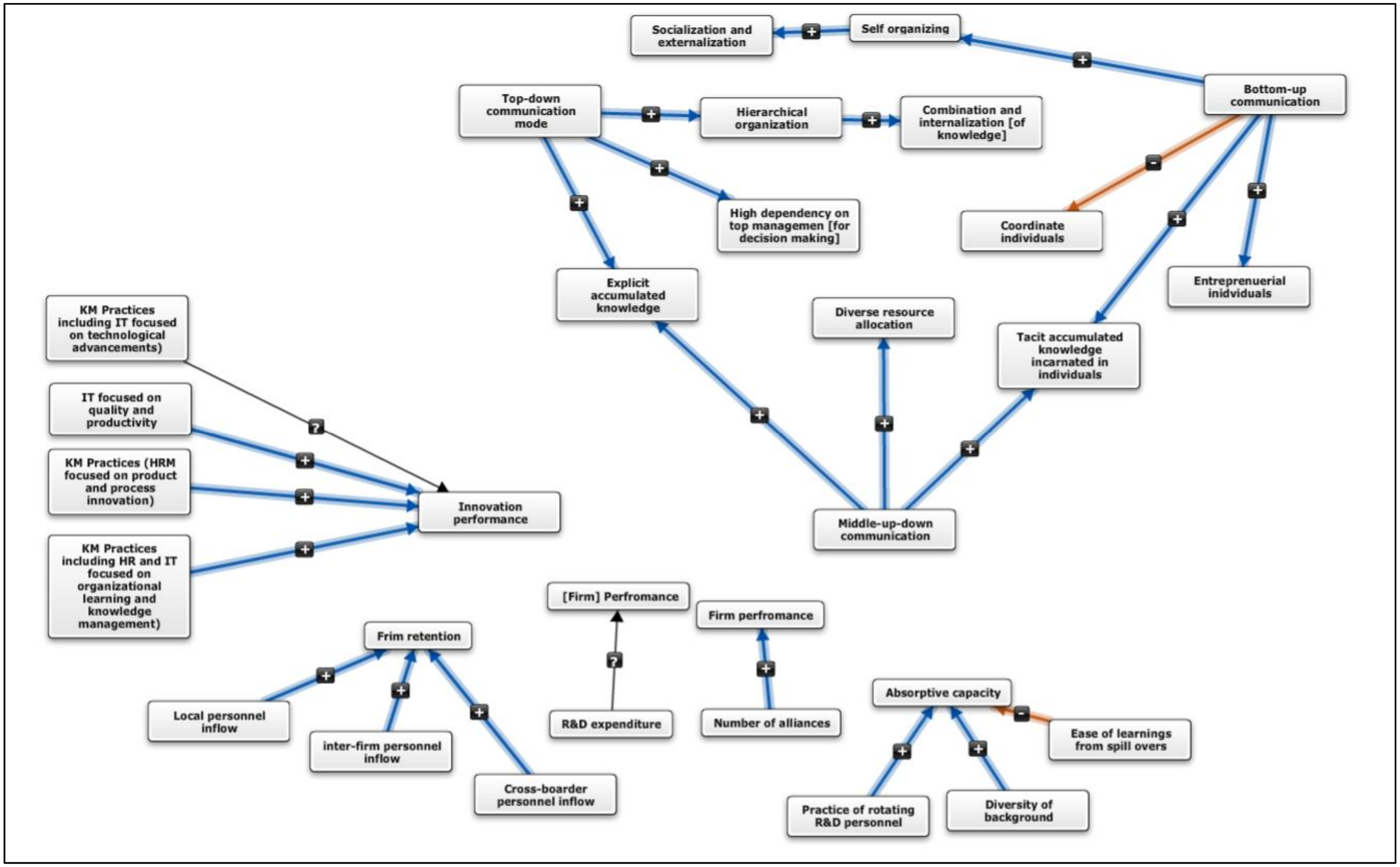

Figure 15- Knowledge based theories domain cognitive map

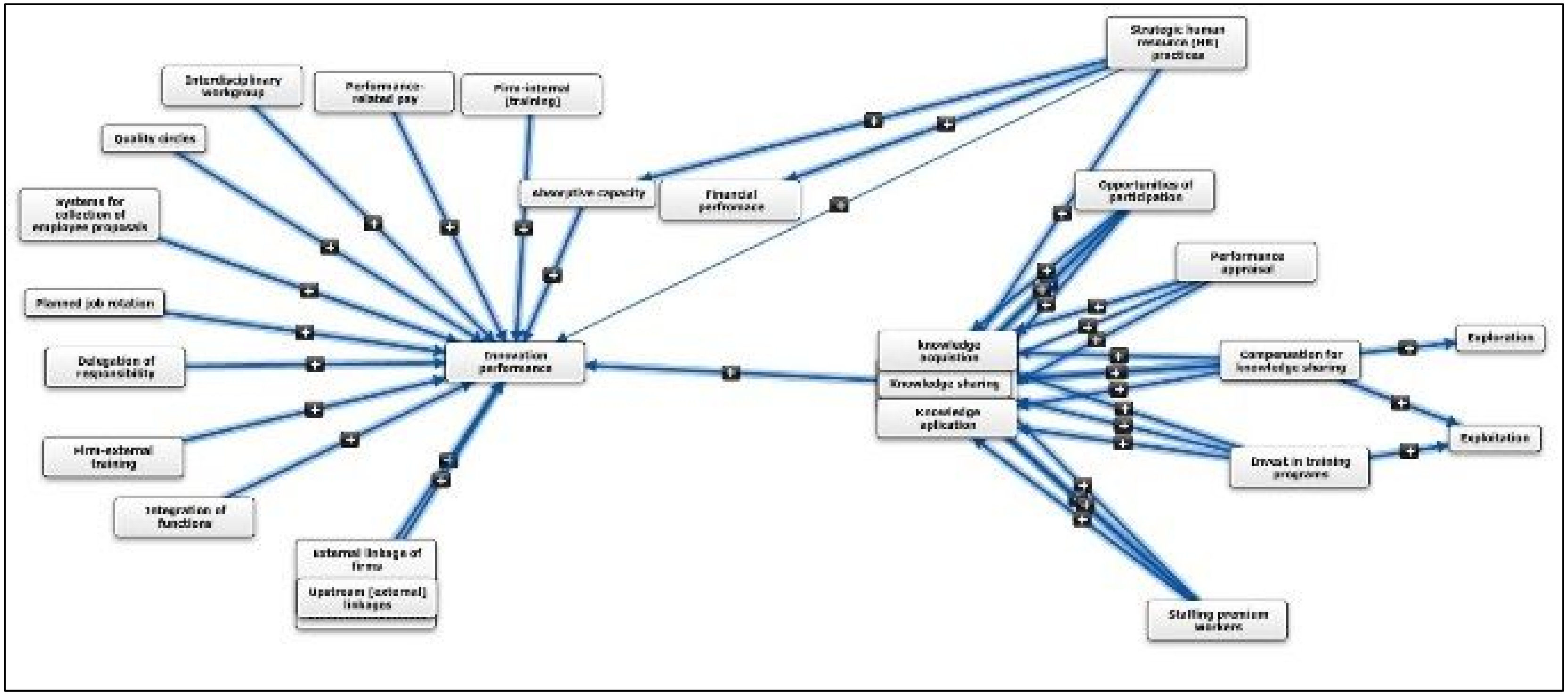

Figure 16- Human resource management domain cognitive map

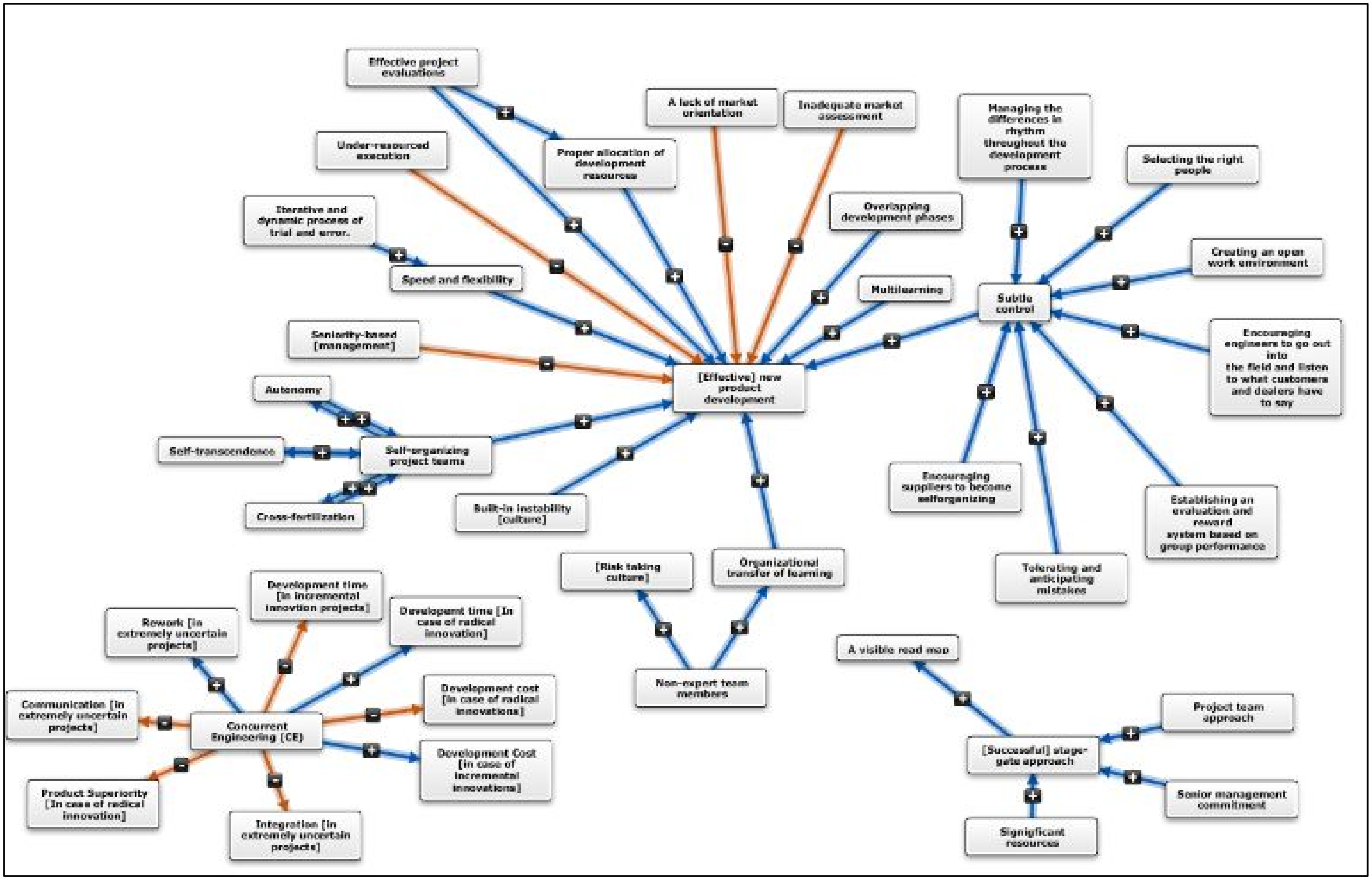

Figure 17- Product innovation and NPD domain cognitive map

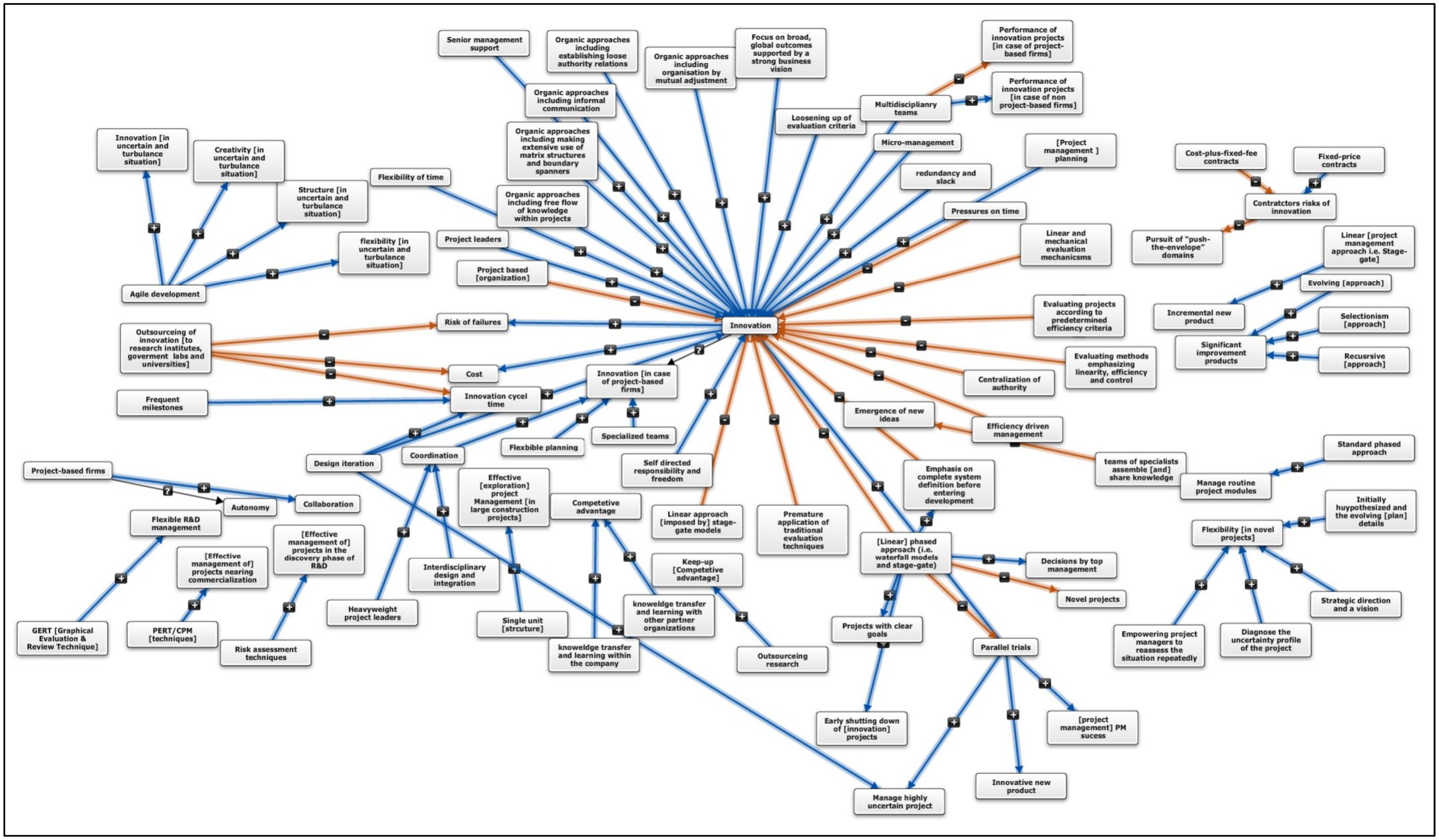

Figure 18- Project management domain cognitive map

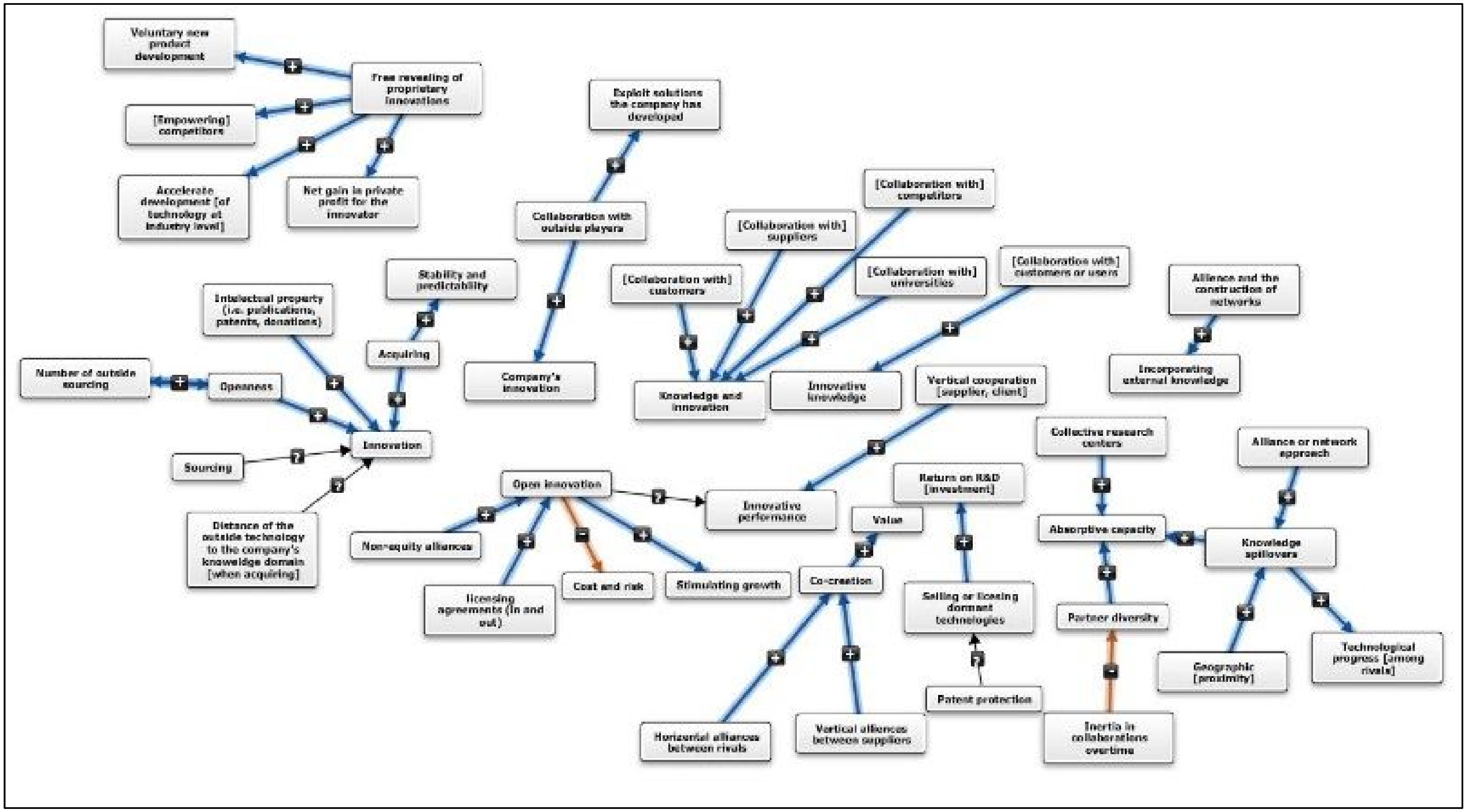

Figure 19- Open innovation and distributed innovation domain cognitive map

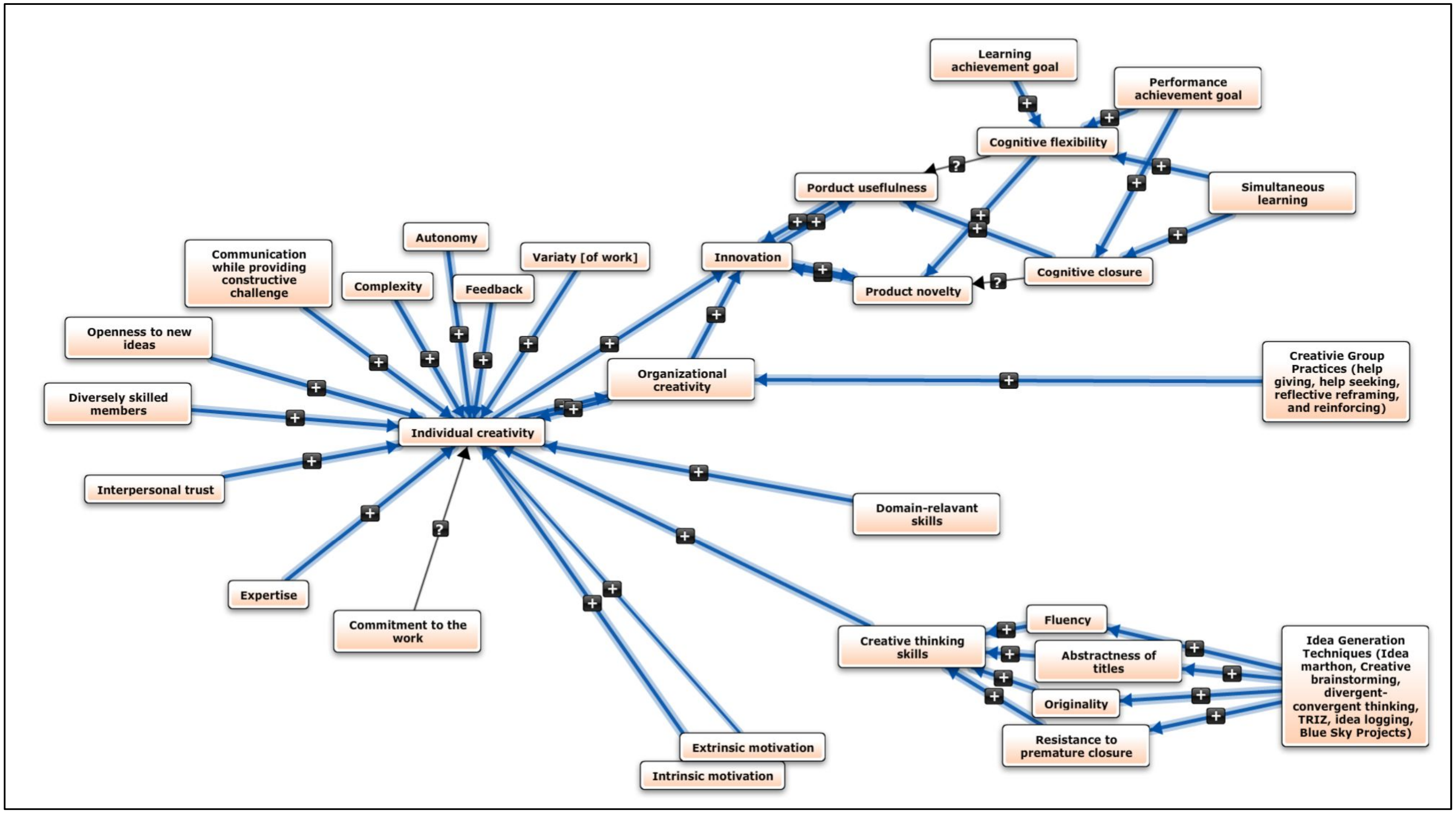

Figure 20- Creativity theory domain cognitive map

5.1 Building the collective cognitive map

Applying the same method used at the domain level, the collective cognitive map emerged finally as an FCM of 366 concepts as shown in Figure 21. For the list of concepts represented in this collective cognitive map see Appendix . Gephi[7], a powerful tool was used for developing and visualizing this large network. Force Atlas and NoOverlap algorithems were among the tools used within Gephi to convert the primary spagetti network to a comprehnsible and visually engaging cognitive map (see Figure 21).

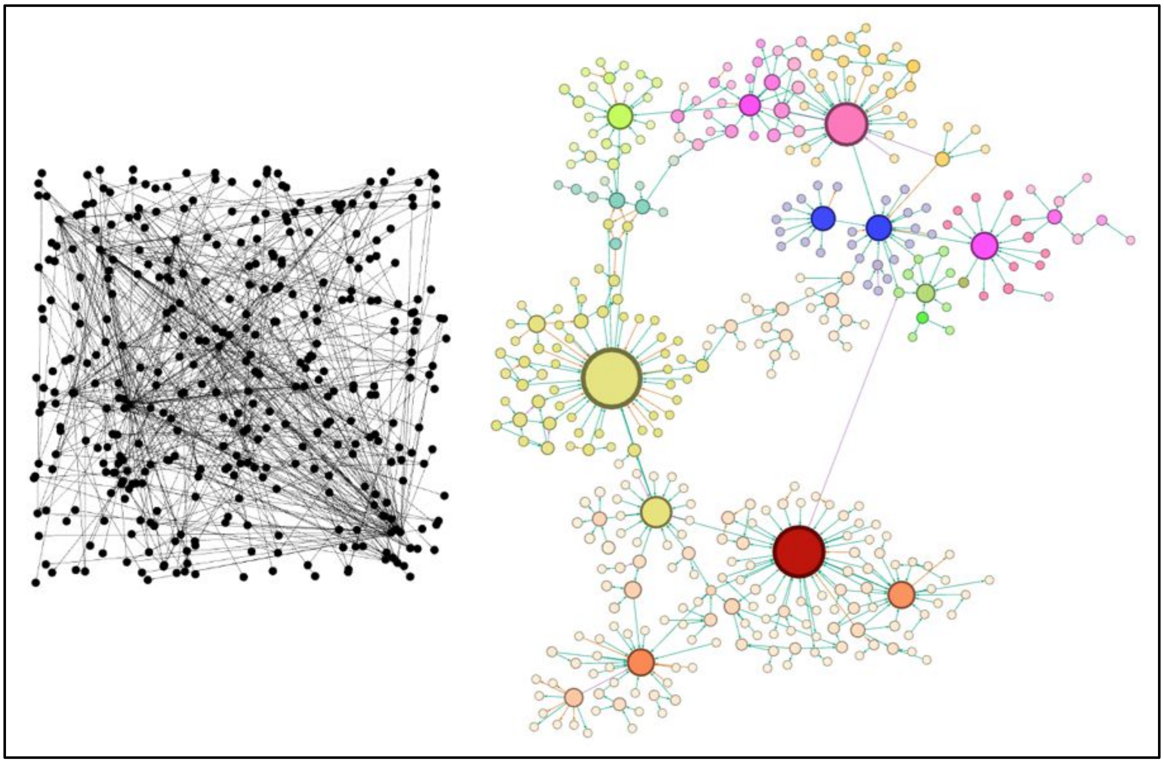

Figure 21- First Collective cognitive map emerged from consolidating 7 domain cognitive maps. Gephi was used to convert the initial network (left) to a comprehensible and visually engaging collective cognitive map (right)

[7] https://gephi.org/

5.2 Building the collective FCM

See the details at 4.2.3.

5.3 Extreme scenario analysis

Extreme scenario analysis is defined and used by the researcher in order to check the reliability of the created FCM model. Two categories of extreme scenarios were defined and used as following to examine the reliability of the final model and tuning the model, if needed, to ensure that model conforms to the expected behavior in those extremes conditions.

For the first case, following concept as main contributors to exploration known—as suggested in the literature, see 4.3–were sought after to be included in initial vector: search, variation, risk taking, experimentation, play, flexibility, discovery, and innovation. Following concepts were found to match the above terminology and were excited in the initial vector: *Explorative search beyond firm boundaries*, *Explorative search beyond technological domains*, *Parallel trials*, *Iterative and dynamic process of trial and error, Risk taking, [Risk taking culture], Experimentation and ad hoc problem-solving efforts, Flexibility of time, Speed and flexibility, Flexibility [in novel projects], Cognitive flexibility, Product innovation, Open innovation.* V_i shows the list of concepts included in this initial vector and their initial value:

$$
V_i = \begin{bmatrix} V1 \\ V2 \\ V3 \\ V4 \\ V5 \\ V6 \\ V7 \\ V8 \\ V9 \\ V10 \\ V11 \\ V12 \\ V13 \end{bmatrix} = \begin{bmatrix} Explorative\ search\ beyond\ firm\ boundaries \\ Explorative\ search\ beyond\ technological\ domains \\ Parallel\ trials \\ Iterative\ and\ dynamic\ process\ of\ trial\ and\ error \\ Risk\ taking \\ [Risk\ taking\ culture] \\ Experimentation\ and\ ad\ hoc\ problem-solving\ efforts \\ Flexibility\ of\ time \\ Speed\ and\ flexibility \\ Flexibility\ [in\ novel\ projects] \\ Cognitive\ flexibility \\ Product\ innovation \\ Open\ innovation \end{bmatrix} = \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix}
$$

Figure 22- Concepts included in the initial vector for the extreme scenario analysis

Table 5 shows the list of concepts affected by this initial vector based on 1000 times simulation. The average value of the concept in all the iterations and robustness is given.

For a discussion on robustness value used in this simulation see section 5.5 but in summary Robustness Value (RV) for the case of this study was formulated as, the percentage of the range of changes in the outcome value of a concept across iterative simulations with changes in FCM adjacency matrices.

$$RV_{C_{ij}} = 1 - \frac{Max(C_{ij}) - Min(C_{ij})}{2}$$

C_i: Concept ith at the jth iteration of FCM simulation and 2 is the range of possible values from -1 to 1.

For instance, concept C_5 that gets a value ranging from 0.44 to 0.87 in 8th iterations of FCM simulations—with a unique initial vector but random adjacency matrices—has a robustness value of:

$$RV_{C_{ij}} = 1 - \frac{0.87 - 0.44}{2} = 0.785 = 78.5\%$$

So obviously higher robustness for a concept, means with higher confidence an initial scenario attains a specific value despite all the potential turbulence in the system (connection weights).

Table 5- Results of first extreme analysis simulation, concepts with changed values

Concept	*Change*	*Robustness*
Organizational ambidexterity	0.938	95.59%
Exploratory Innovation	1	99.99%
Exploitative innovations	0.921	95.56%
Innovation	0.99	99.80%
Innovation [in case of project-based firms]	0.178	55.24%
[Effective] new product development	0.940	97.06%
Product novelty	0.998	97.06%
Product usefulness	0.952	55.33%
Exploitative innovation strategies	0.939	97.06%
Innovative performance	0.909	62.75%
Performance	0.996	95.86%
Financial performance [in dynamic environments]	0.938	97.05%
Operational efficiency	0.920	95.58%
Project performance	0.924	96.05%
Risk of failures	0.00071	55.80%
Strategic performance	0.939	97.05%
Firm efficiency [for defenders at high level of competitive intensity]	-0.921	95.51%
Firm efficiency [for prospectors at high level of competitive intensity]	0.920	95.47%
Power asymmetry	0.923	95.64%
Cost	0.0047	55.26%
Exploratory learning	0.938	97.06%

Concept	Change	Robustness
Financial performance	0.188	55.24%
Firm growth	0.925	95.71%
Organizational learning	0.925	96.07%
Organizational longevity	0.940	97.05%
Firm performance [for prospectors]	0.937	97.06%
Firm performance [for defenders]	0.938	97.06%
Firm quality performance	0.925	95.40%
Firm valuation	0.940	33.17%
Stimulating growth	0.939	97.06%
Value	0.912	70.63%
Manage highly uncertain project	0.938	97.06%
[project management] PM success	0.938	97.05%
Innovative new product	0.939	97.06%

When studying the results of the extreme scenario test it becomes clear, surprisingly, not only *exploratory innovation* was increased, but also *exploitative innovation* experienced an increased value and found to be robust at 95.56%. Consequently, organizational ambidexterity showed extremely positive and robust at 95.59%. This results is different from the perspective of March, O'Reilley, Tushman and most other influential contributors to the field.

To re-examine the validity of this results, it was hypothesized that two concepts of *Product innovation* and *Open innovation* might have been the concepts that impacted the exploitative innovation and they are primarily results of an organization and not the parameters that could be directly manipulated. To test the hypothesis, same initial vector as described above but without these two variables were used for another simulation iteration.

With the new changes, still *exploitative innovation* and *organizational ambidexterity* demonstrated similar behavior. But this time cost showed to be consistently (robust at 97.05%) increased as well. Based on the feedback, the interaction of ‘Exploratory innovation”, “Exploitative innovation” and “Organizational ambidexterity” was reexamined on the FCM. Some issues with the model and corrective modifications were hypothesized as follows:

1. There was a direct positive connection from “Exploitative innovation” to “Exploratory innovation” but no direct connection to “Organizational ambidexterity.” Based on the definition of “organizational ambidexterity,” a balance between both “Exploitative innovation” and “Exploratory innovation” causes the OA. (Refer to (He and Wong 2004a) as an example for the operationalization of OA). A connection was added to FCM to fix the issue.
2. Similarly, there was no direct causal relation from “Exploratory innovation” to OA. A connection was added to FCM to fix the issue.
3. Also “Innovation” hub found to be not connected to OA at all. That implies that increase or decrease in innovation in an organization doesn’t impact the organizational ambidexterity. To fill the gap, a direct connection was needed from “Innovation” to both “Exploitative innovation” and “Exploratory innovation.”

4. “Knowledge and innovation” hub was also not connected by any mean to the OA. To fill the gap, a direct connection was added to “Innovation” which meant connecting it to OA through “Innovation.”

5. The biggest problem comes from the direct causal relationships to OA. If we accept that a balance between “Exploitative innovation” and “Exploratory innovation” leads to OA, all other direct connections need to be removed from OA concept since they directly impact the OA and falsely increase or decrease its value through the simulation. Thus connections from following concepts to OA were removed:

a. Senior team social integration
b. Cross-functional interfaces
c. Structural characteristics
d. Leadership characteristics
e. Involvement of suppliers in design activities
f. Incentive-based payment (i.e. performance-based)
g. [High-performance work system] HPWS
h. Multilevel approach
i. Complementary tactics
j. Learning synergies

The only input to OA would be “Exploratory innovation,” “Exploitative innovation” and “Performance.” All the above concepts, however, directly got connected to both “Exploratory innovation”, and “Exploitative innovation.” All the new connections received

+1 values except for the connection from [High performance work system] HPWS to Exploratory innovation that received the value of -1.

Revised FCM was used for a second extreme scenario analysis with the identical initial vectors used in the previous round: *Explorative search beyond firm boundaries, Explorative search beyond technological domains, Parallel trials, Iterative and dynamic process of trial and error, Risk taking, [Risk taking culture], Experimentation and ad hoc problem-solving efforts, Flexibility of time, Speed and flexibility, Flexibility [in novel projects], Cognitive flexibility, Product innovation,* and *Open innovation*. Table 6 shows the list of concepts that changed, their average changes and robustness based on 1000 times simulation, in contrast with the results from round 1.

Table 6- Results of 1st and 2nd round of the extreme analysis simulations

	Round 1		*Round 2*	
Concept	*Change*	*Robustness*	*Change*	*Robustness*
Organizational ambidexterity	0.938	95.59%	0.99	96.10%
Exploratory Innovation	1	99.99%	1	99.99%
Exploitative innovations	0.921	95.56%	0.99	96.00%
Innovation	0.99	99.80%	0	100%
Innovation [in case of project-based firms]	0.178	55.24%	0.93	96.12%
[Effective] new product development	0.940	97.06%	0.94	97.07%
Product novelty	0.998	97.06%	0.99	99.98%
Product usefulness	0.952	55.33%	0.99	99.98%
Exploitative innovation strategies	0.939	97.06%	0.939	97.08%
Innovative performance	0.909	62.75%	0	9.21%
Performance	0.996	95.86%		
Financial performance [in dynamic environments]	0.938	97.05%	0.939	95.9%

	Round 1		Round 2	
Concept	*Change*	*Robustness*	*Change*	*Robustness*
Operational efficiency	0.920	95.58%	0.938	95.71%
Project performance	0.924	96.05%	0.939	97.06%
Risk of failures	0.00071	55.80%	-0.00375	55.42%
Strategic performance	0.939	97.05%	0.938	95.95%
Firm efficiency [for defenders at high level of competitive intensity]	-0.921	95.51%	-0.939	95.80%
Firm efficiency [for prospectors at high level of competitive intensity]	0.920	95.47%	-0.939	95.99%
Power asymmetry	0.923	95.64%	0.922	95.63%
Cost	0.0047	55.26%	0.0042	54.83%
Exploratory learning	0.938	97.06%	0	100%
Financial performance	0.188	55.24%	0.938	96.02%
Firm growth	.925	95.71%	0.938	95.75%
Organizational learning	.925	96.07%	0.925	96.08%
Organizational longevity	.940	97.05%		
Firm performance [for prospectors]	.937	97.06%		
Firm performance [for defenders]	.938	97.06%		
Firm quality performance	.925	95.40%		
Firm valuation	.940	33.17%		
Stimulating growth	.939	97.06%		
Value	.912	70.63%	-0.004	
Manage highly uncertain project	.938	97.06%		
[project management] PM success	.938	97.05%		
Innovative new product	.939	97.06%		

Results still do not show the expected pattern, on the further scrutiny, it was realized that

1. Causal effect relationship was added from “Innovation” to “Exploitative innovation” and “Exploratory innovation”.

2. “Parallel trials”, “Iterative and dynamic process of trial and error”, “Speed and flexibility”, “Flexibility [in novel projects]”, and “Cognitive flexibility” has direct or indirect positive impact on “Exploratory innovation” but they also have the opposite impact on “Exploitative innovation” and “Efficiency”. Yet the latter relationship was overlooked in the model. Also, as shown in the picture below, “Speed and flexibility” is shown to have a positive impact on “Exploitative innovation strategy,” which is believed to be wrong. This concept itself has a positive impact ultimately on “Exploitative innovation.” Therefore, exciting the “Speed and flexibility” concept also increased the value of the “Exploitative innovation” which found to be incorrect.

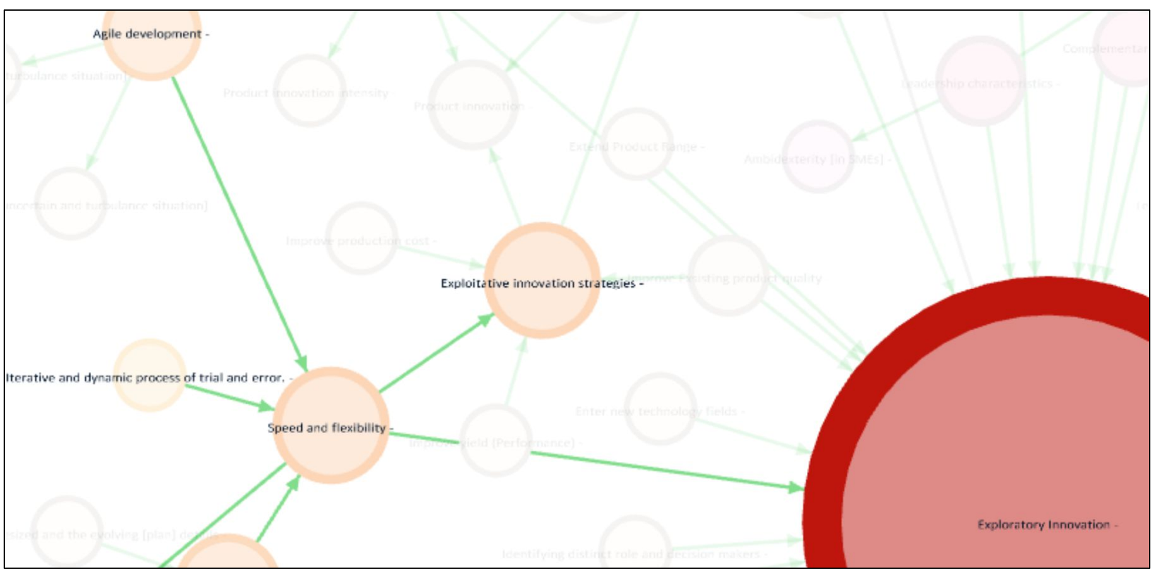

Figure 23- “Speed and flexibility” found to have a positive impact on “Exploitative innovation strategy” which ultimatelty positively impacts the “Exploitative innovation”

3. Also all the factors causing the “innovation” in innovation hub found to be essentially indifferent to the fate of exploratory or exploitative innovation.

To address the above issues, following changes were implemented again:

1. “Speed and flexibility” impact on “Exploitative innovation strategies” changed to -1
2. “Efficiency” and “Product development efficiency” are redundant. The first concept is merged into the latter one.
3. “Operational efficiency” merged to Product development efficiency. Therefore a positive relation was added from “Exploitative innovation” to “Product development efficiency.”
4. A negative relation was added from “Exploratory innovation” to “Product development efficiency.”
5. A positive relation was added from “Exploitative innovation” to “Product development efficiency.”
6. A positive relation was added from “Product development efficiency” to “Exploitative innovation” and a negative relation to “Exploratory innovation.”
7. A negative relation was added from “Parallel trials” to “Product development efficiency.”

Revised FCM was used for the 3rd iteration of the extreme scenario analysis with the identical initial vectors used in the previous round. Results are provided in Table 7.

Table 7- Results of 1st, 2nd and 3rd round of the extreme analysis simulations

	Round 1		*Round 2*		*Round 3*	
Concept	*Change*	*Robustness*	*Change*	*Robustness*	*Change*	*Robustness*
Organizational ambidexterity	0.938	95.59%	0.99	96.10%	0	4.01%
Exploratory Innovation	1	99.99%			0.9999	99.99%
Exploitative innovations	0.921	95.56%	0.99	96.00%	-0.997	95.95%
Innovation	0.99	99.80%	0	100%	1	99.79%
Innovation [in case of project-based firms]	0.178	55.24%	0.93	96.12%	0.939	97.03%
[Effective] new product development	0.940	97.06%	0.94	97.07%	0.938	97.06%
Product novelty	0.998	97.06%	0.99	99.98%	0.9980	97.09%
Product usefulness	0.952	55.33%	0.99	99.98%	0.998	97.06%
Exploitative innovation strategies	0.939	97.06%	0.939	97.08%	0.938	97.06%
Innovative performance	0.909	62.75%	0	9.21%	0.912	0.6077
Performance	0.996	95.86%			0.996	84.01%
Financial performance [in dynamic environments]	0.938	97.05%	0.939	95.9%	0.938	97.05%
Operational efficiency	0.920	95.58%	0.938	95.71%		
Project performance	0.924	96.05%	0.939	97.06%	0.92	96.06%
Risk of failures	0.00071	55.80%	-0.00375	55.42%	-0.004	55.32%
Strategic performance	0.939	97.05%	0.938	95.95%	0.938	97.05%
Firm efficiency [for defenders at high level of competitive intensity]	-0.921	95.51%	-0.939	95.80%	0.938	95.76%
Firm efficiency [for prospectors at high level of competitive intensity]	0.920	95.47%	-0.939	95.99%	-0.938	95.76%
Power asymmetry	0.923	95.64%	0.922	95.63%	-0.922	95.84%
Cost	0.0047	55.26%	0.0042	54.83%	-0.012	55.42%
Exploratory learning	0.938	97.06%	0	100%	0.938	97.06%
Financial performance	0.188	55.24%	0.938	96.02%	0.939	97.05%
Firm growth	0.925	95.71%	0.938	95.75%	0.923	30.14%
Organizational learning	0.925	96.07%	0.925	96.08%	-0.925	96.07%
Organizational longevity	0.940	97.05%			0.970	93.96%
Firm performance [for prospectors]	0.937	97.06%			0.938	97.06%

Concept	Round 1		Round 2		Round 3	
	Change	Robustness	Change	Robustness	Change	Robustness
Firm performance [for defenders]	0.938	97.06%			0.939	97.06%
Firm quality performance	0.925	95.40%			0.923	32.33%
Firm valuation	0.940	33.17%			0.996	70.12%
Stimulating growth	0.939	97.06%			0.938	97.08%
Value	0.912	70.63%	-0.004		0.912	71.28%
Manage highly uncertain project	0.938	97.06%			0.939	97.05%
[project management] PM success	0.938	97.05%			0.9708	97.08%
Innovative new product	0.939	97.06%			0.938	97.06%
Product development efficiency					-0.999	0.9707

Figure 24 and Figure 25 represent the results graphically when initial values are clamped in the simulation and when they are not clamped respectively. This time, all the results are following the patterns as expected, meaning while exploratory innovation value changed experienced a significant positive change (+0.999), exploitative innovation experienced a significant negative drop (-0.997). Organizational ambidexterity value did not change as a result.

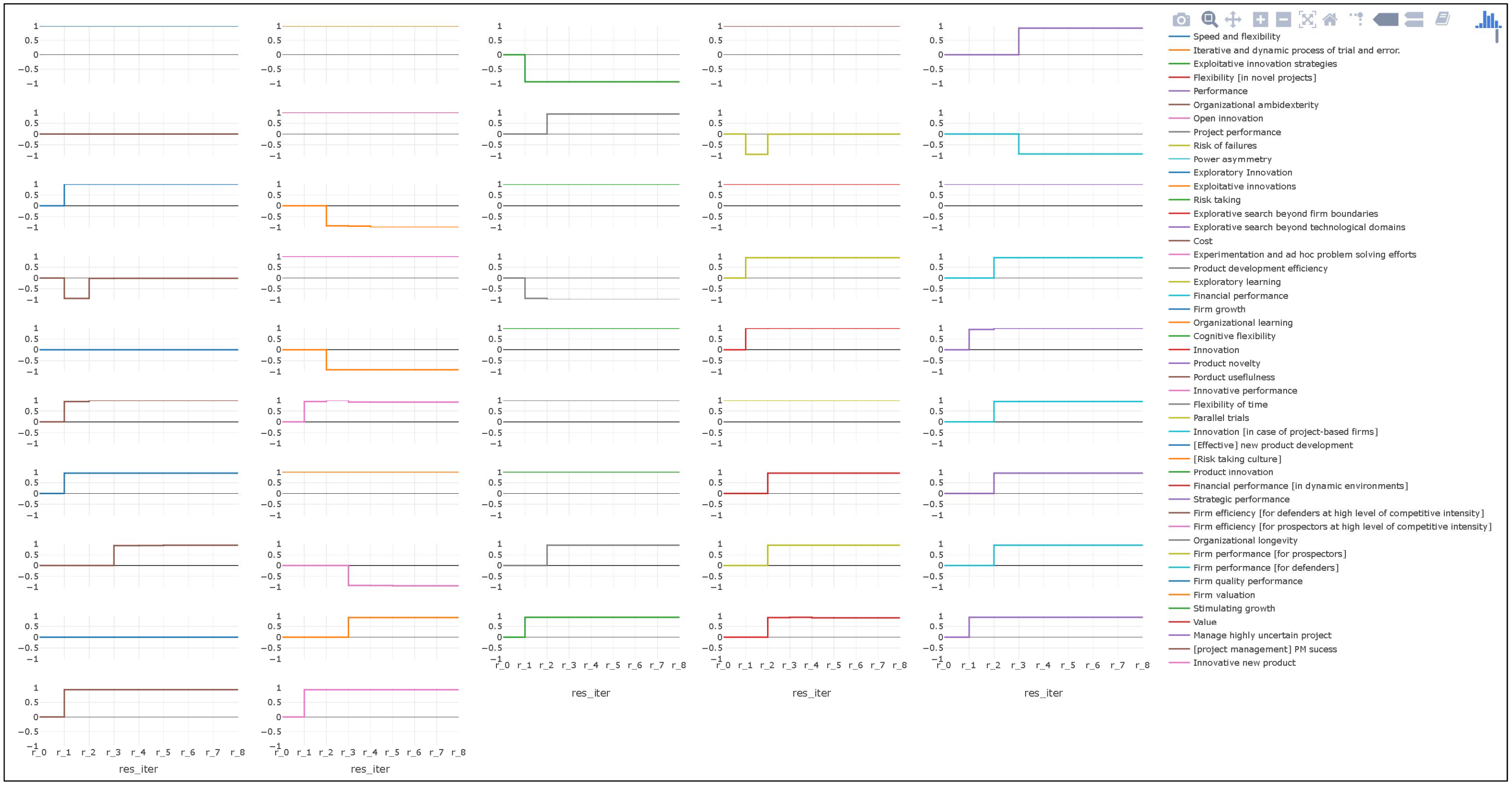

Figure 24- Results of 3rd exreme simulation with clampped initial values

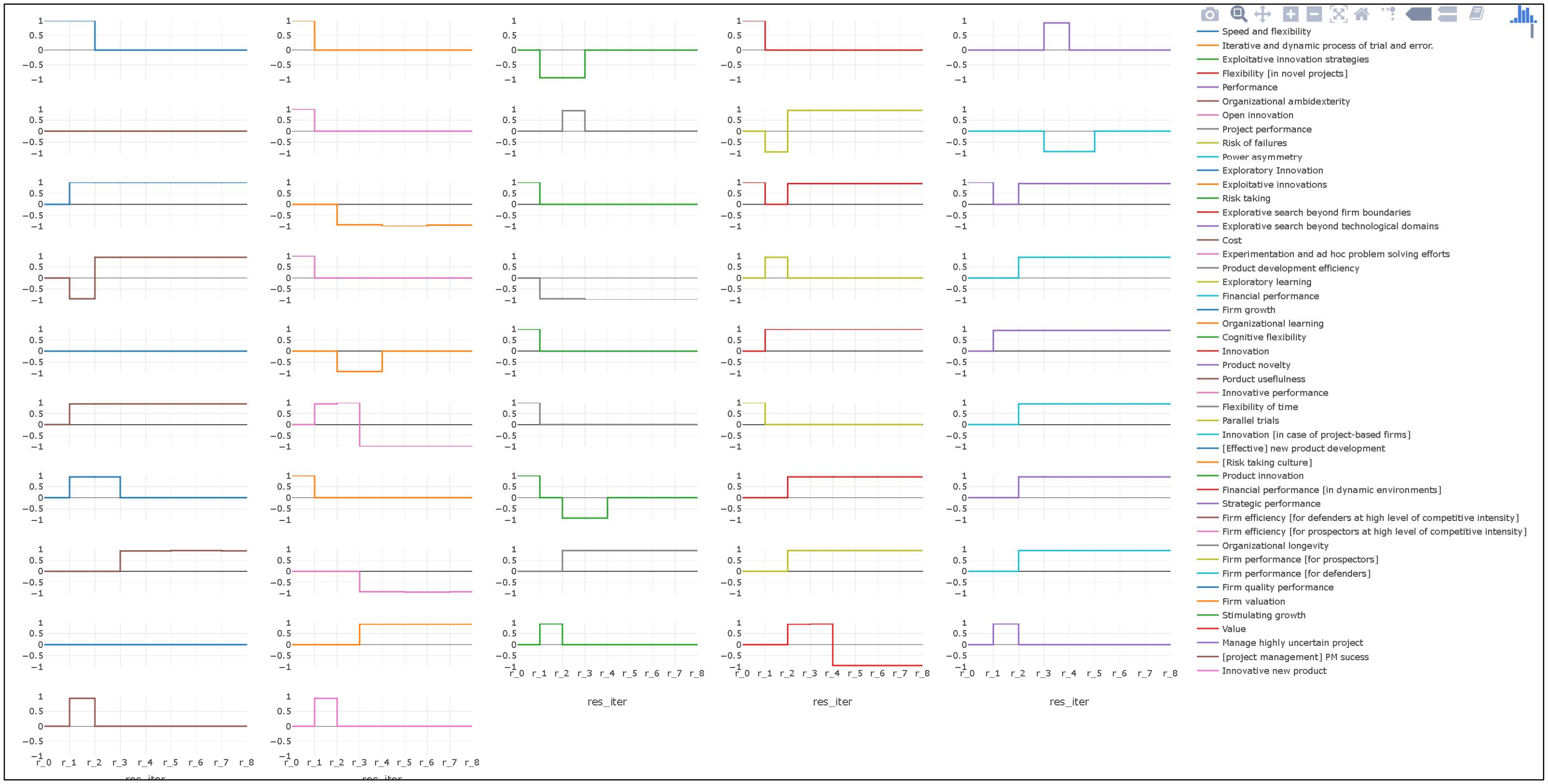

Figure 25- Results of 3rd exreme simulation without clampping the initial values

Next rounds of extreme scenario analysis were performed for the case of extreme exploitative innovation. Again, based on March's (1991), exploitation includes such things as refinement, choice, production, efficiency, selection, implementation and execution. For that reason, following concepts are chosen to be in the initial vector for the extreme scenario analysis. Following concepts in the model found to match the above terminology and were used as initial values this time: *Information-processing efficiency, Product development efficiency, Evaluating projects according to predetermined efficiency criteria, Evaluating methods emphasizing linearity, efficiency and control, Improve production cost, Quality circles, IT focused on quality and productivity, Improve Existing product quality, Improve yield (Performance), Costs of coordinating, controlling, and supervising employees (-1), Costs (-1).*

Results of this round of simulation were also found to follow the expected patterns. With a significant increase in the value of exploitative innovation (+0.997) this time but not a meaningful change in the value of Exploratory innovation (+0.0066) leading to a no ambidexterity. Therefore, Model is behaving as expected at this point. Figure 26 shows the changes in the value of some of the concepts with introducing such an initial vector and no clamping. Cyclic behavior of both exploitative and exploratory innovation values is an indicator of low robustness of the results, while the value of organizational ambidexterity barely increases from zero.

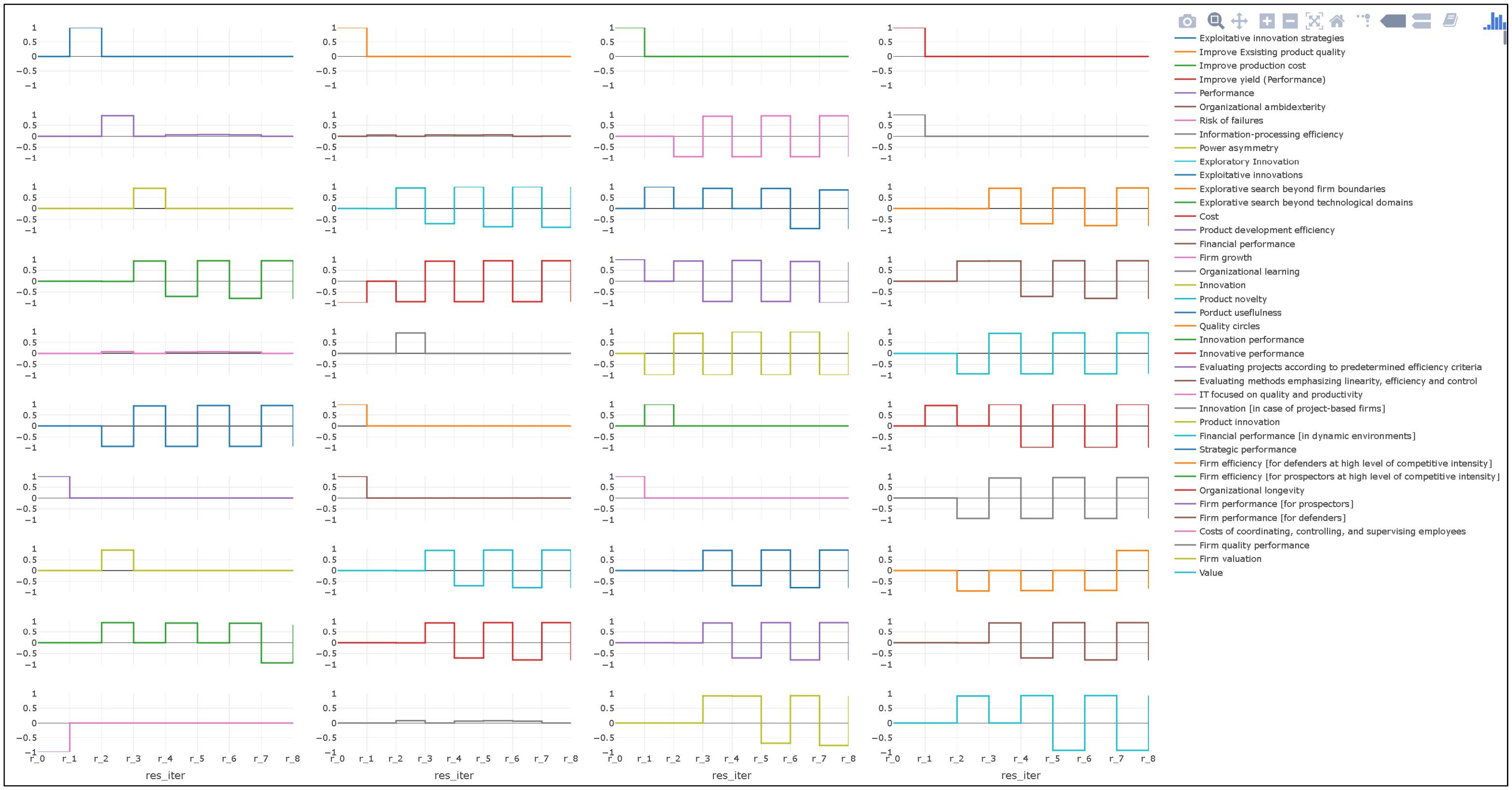

Figure 26- Results of 4th exreme simulation without clampping the initial values

5.4 Expected behavior test

Expected behavior test is known as a structure-oriented behavior test, which evaluates the validity of the structure of the model by comparing expected outcomes of the real world as understood by the experts and models outcome patterns in certain cases (Senge 1980; Barlas 1989). The entire model or a sub-model could be used for expected behavior test simulation (Barlas 1996). The expected behavior is captured qualitatively as patterns rather than quantities. Under certain conditions, experts may expect the outcome variable to have a fall, a rise, a fall followed by a rise, a delayed fall, a delayed rise or oscillation (Carson and Flood 1990).

Since the final FCM that emerged in this study, consists of 366 concepts, it was neither practical nor reasonable to run the expected behavior test on the entire model. Therefore, the model was broken into sub-models with a comprehensible number of concepts with some overlaps, before being examined.

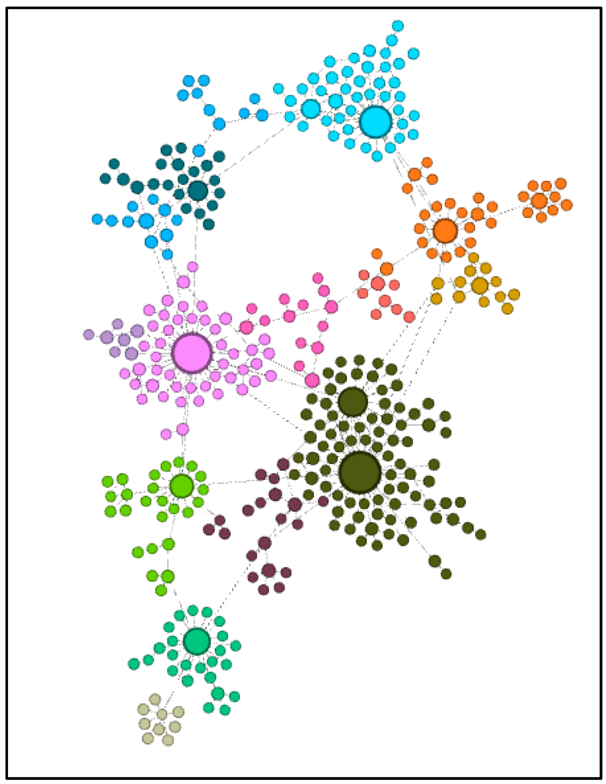

Figure 27- Modular classes determined by Gephi Modularity logic

Inspired by modularity classes suggested by Gephi as shown in Figure 27, the final FCM network was broken into 7 sub-FCM networks as discussed below. (See Figure 28, Figure 30, Figure 32, Figure 34, Figure 36, Figure 38 and Figure 40).

This approach ensured that the entire model was tested, although part by part, thus validity of the entire model was practically concluded from the validity of smaller sub-sets that are intelligible.

Sub-FCM1; From the list of 30 variables of creativity hub as shown in Figure 28, two variables, “autonomy” and “creative thinking skills” were activated–initial value was set as +1 and clamped. Expectation was to see the value of individual creativity to increase, which is what was observed as shown in Figure 29.

Sub-FCM2; From the list of 40 variables of new product development hub as shown in Figure 30 , two variables, “stage gate approach” and “a visible roadmap” were activated–initial value was set as +1 and clamped. Expectation was to see the value of new product development to increase, which is what was observed as shown in Figure 31.

Sub-FCM3; From the list of 94 variables of exploratory-exploitative hub as shown in Figure 32, two variables, “formalization” and “centralization of decision making” were activated–initial value was set as +1 and clamped. Expectation was to see the value of “exploitative innovation” to raise while the value of “exploratory innovation” drops, which is what was observed as shown in Figure 33.

Sub-FCM4; From the list of 62 variables of contextual ambidexterity hub as shown in Figure 34, three variables, “trust”, “stretch” and “discipline” were activated–initial value was set as +1 and clamped. Expectation was to see the value of “contextual ambidexterity” to increase, which is what was observed as shown in Figure 35.

.

Sub-FCM5; From the list of 45 variables of innovation performance hub as shown in Figure 36, two variables, “Bottom-up communication” and “high dependency on top management [for decision making]” were activated–initial value was set as +1 and -1 respectively and clamped. Expectation was to see the value of “knowledge and innovation” to increase, which is what was observed as shown in Figure 37.

Sub-FCM6; From the list of 40 variables of knowledge hub as shown in Figure 38, two variables, “contractors risk of failure” and “[Collaboration with] suppliers” were activated–initial value was set as -1 and +1 respectively and clamped. Expectation was to see the value of “knowledge and innovation” to increase, which is what was observed as shown in Figure 39.

Sub-FCM7; From the list of 59 variables of innovation hub as shown in Figure 40, two variables, “redundancy and slack” and “evaluating methods emphasizing linearity, efficiency and control” were activated–initial value was set as -1 and +1 respectively and clamped. Expectation was to see the value of “knowledge and innovation” to increase, which is what was observed as shown in Figure 41.

In conclusion, all the seven scenarios that were run using the sub-FCMs gave the expected results, indicating that these are compatible with an a priori understanding of how system works in the real life. The assumption is that since the behavior of the sub models have been verified, the model as a whole is also likely yield results consistent with a priori knowledge.

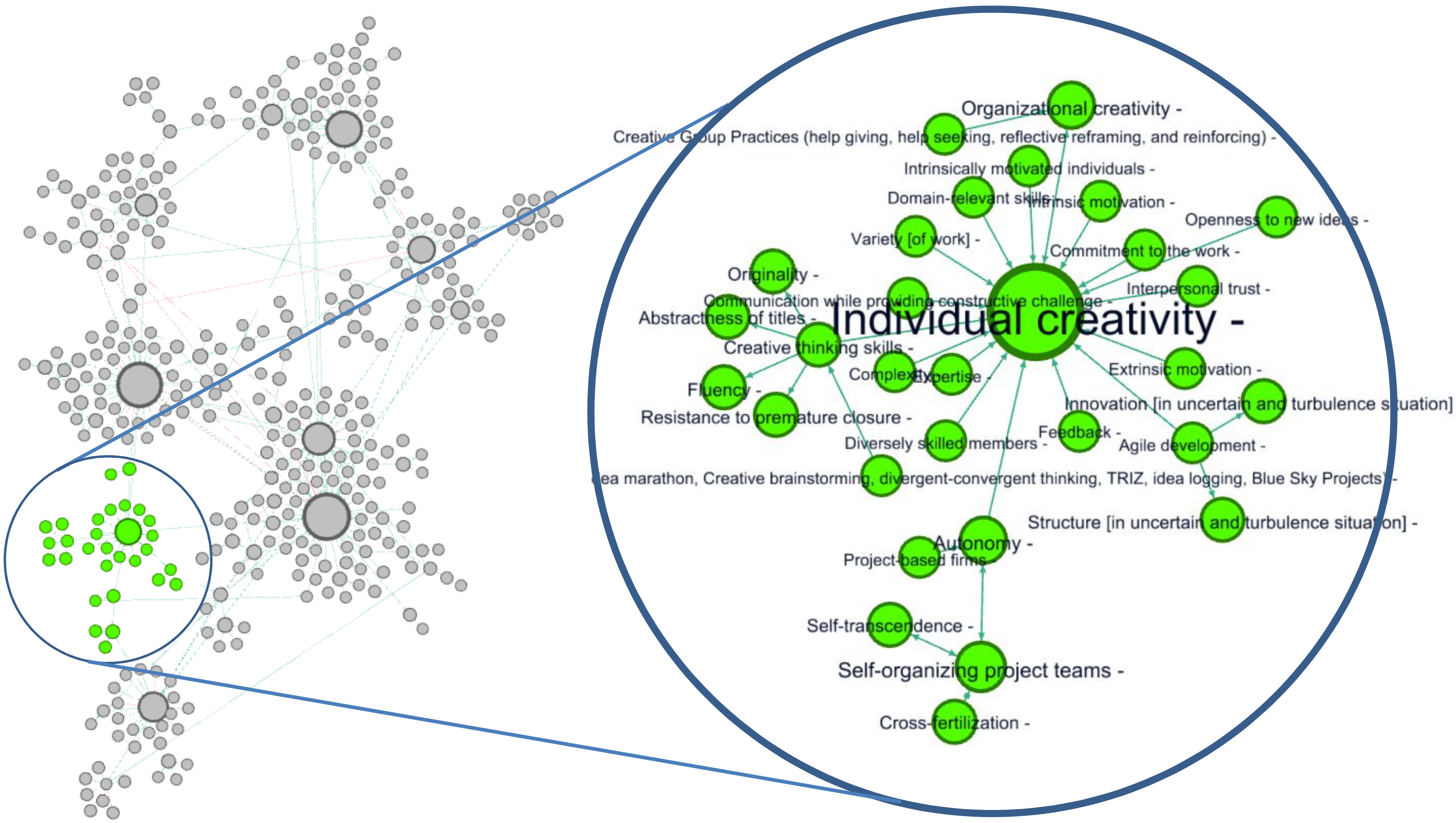

Figure 28-Sub-FCM1 Creativity hub as shown selected for the expected behavior tests

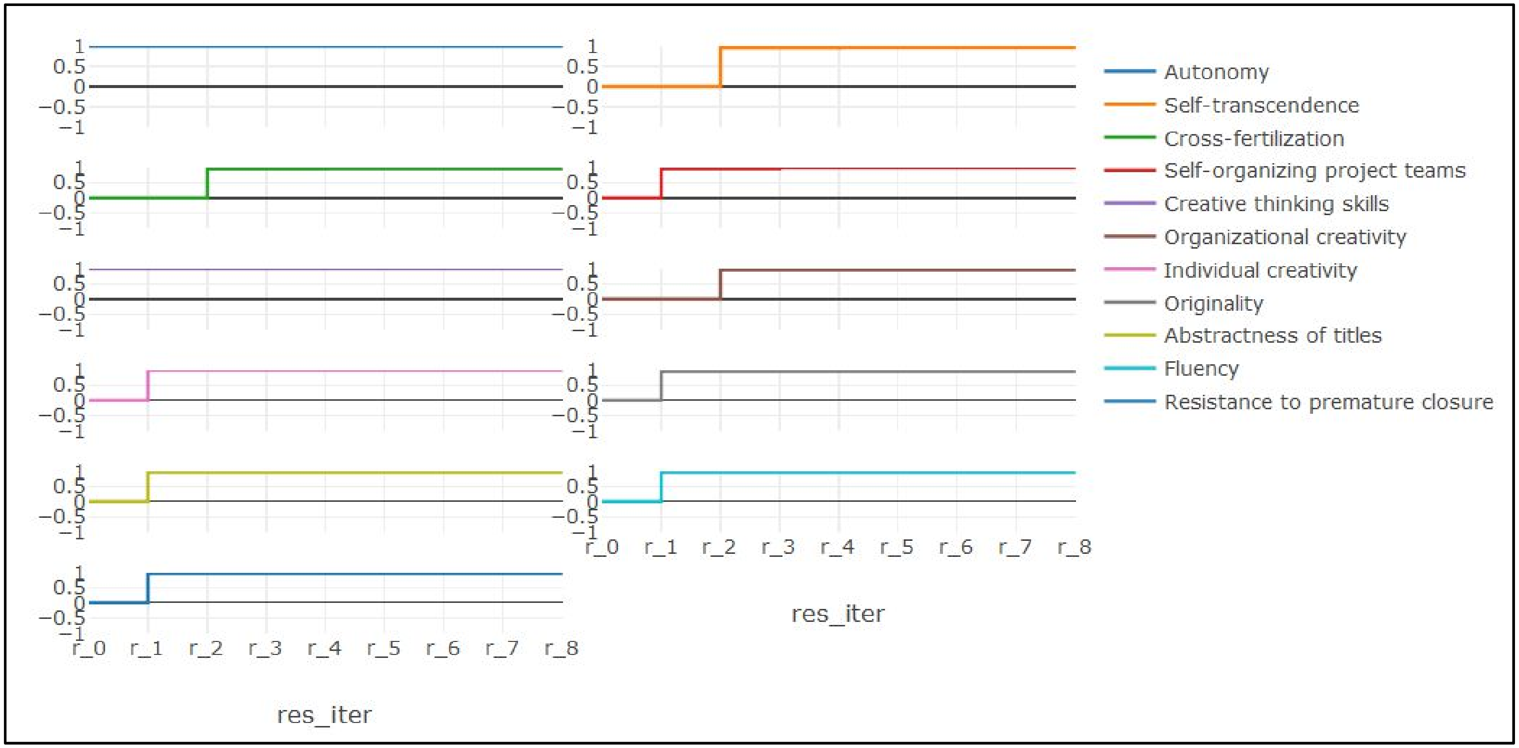

Figure 29- Value of the concepts that experienced changes through the expected behavior analysis of creativity hub (Sub-FCM1)

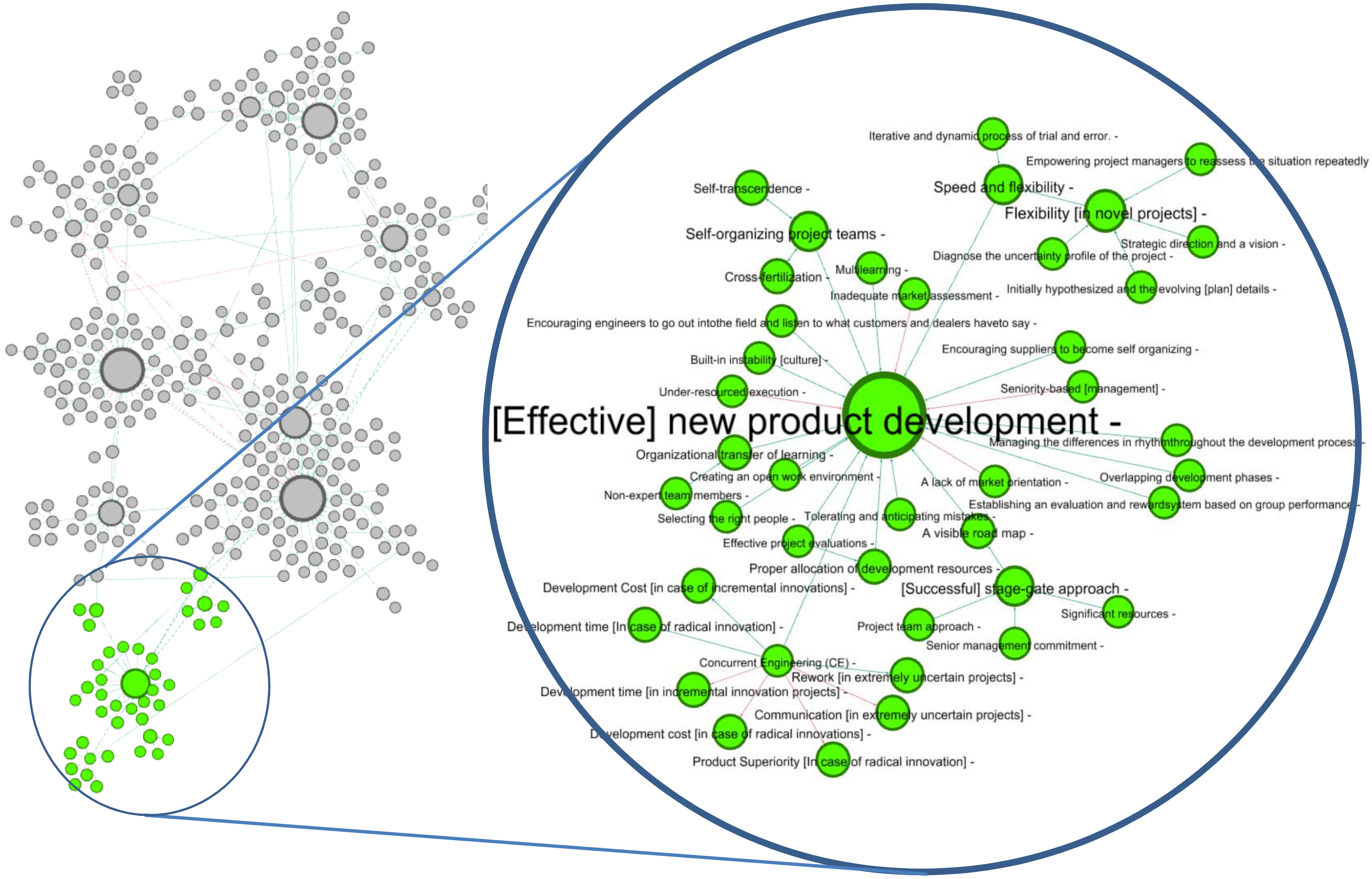

Figure 30-Sub-FCM2 New product development hub as shown selected for the expected behavior tests

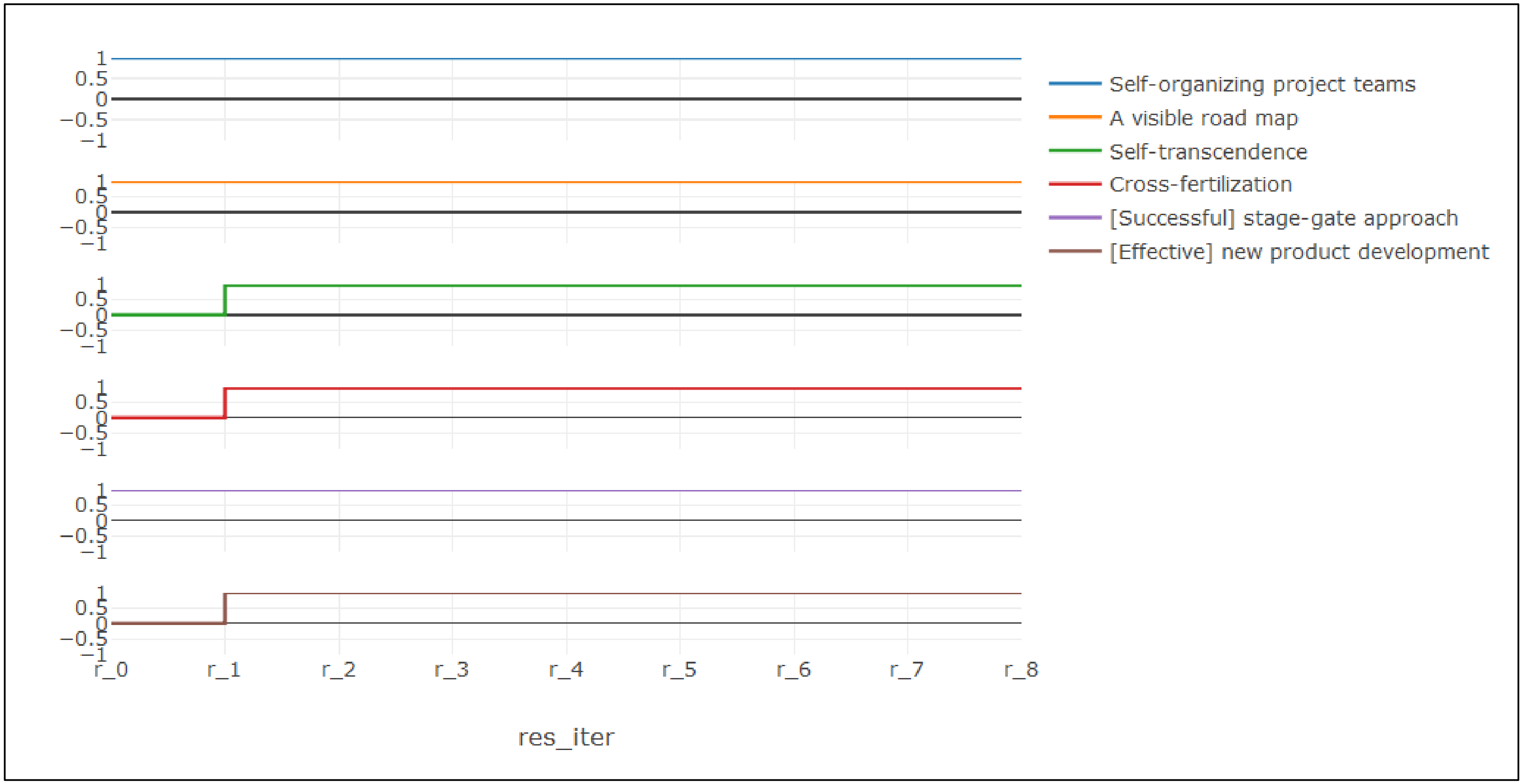

Figure 31- Value of the concepts that experienced changes through the expected behavior analysis of new product development hub (Sub-FCM2)

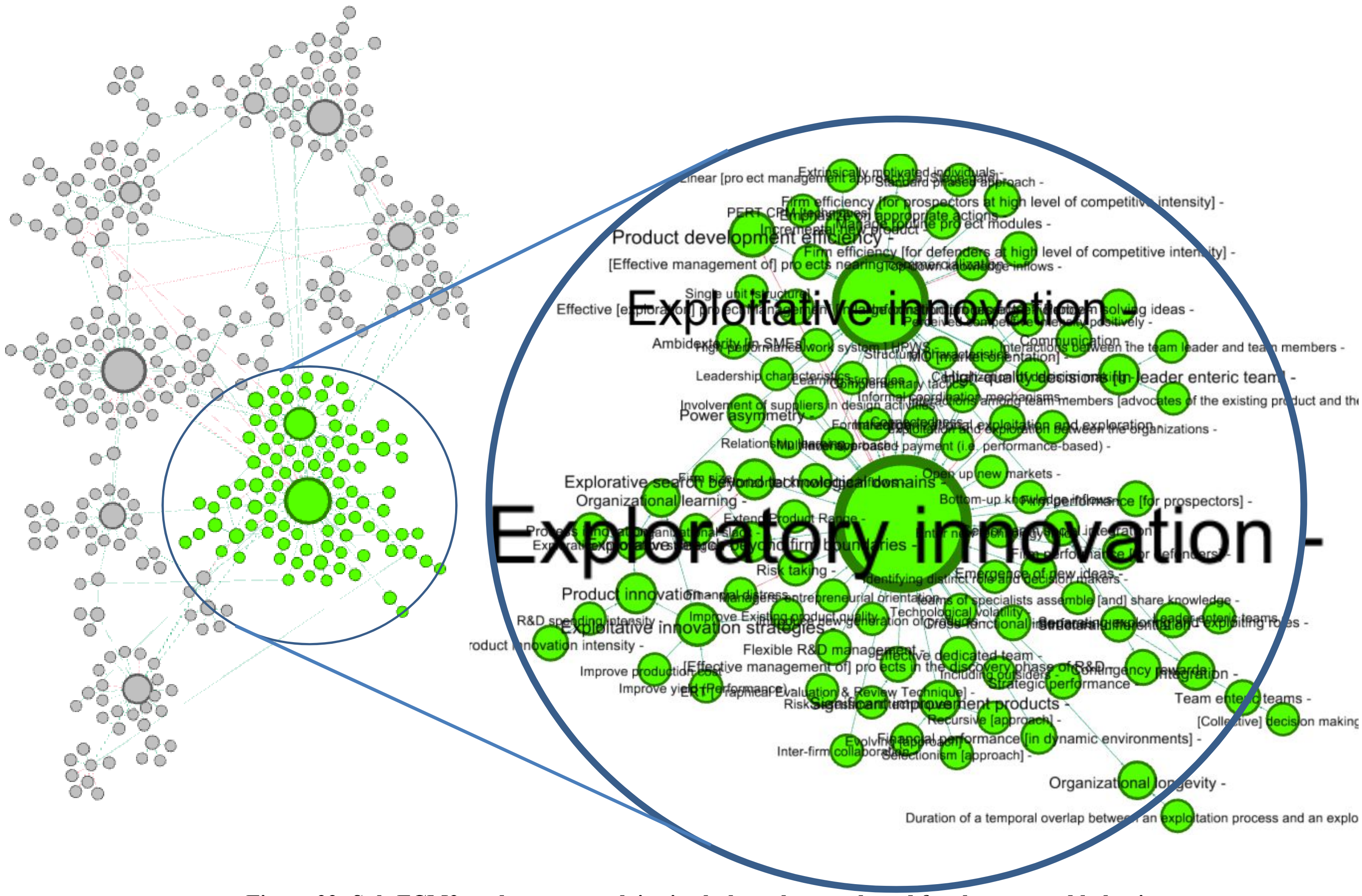

Figure 32- Sub-FCM3 exploratory-exploitative hub as shown selected for the expected behavior tests

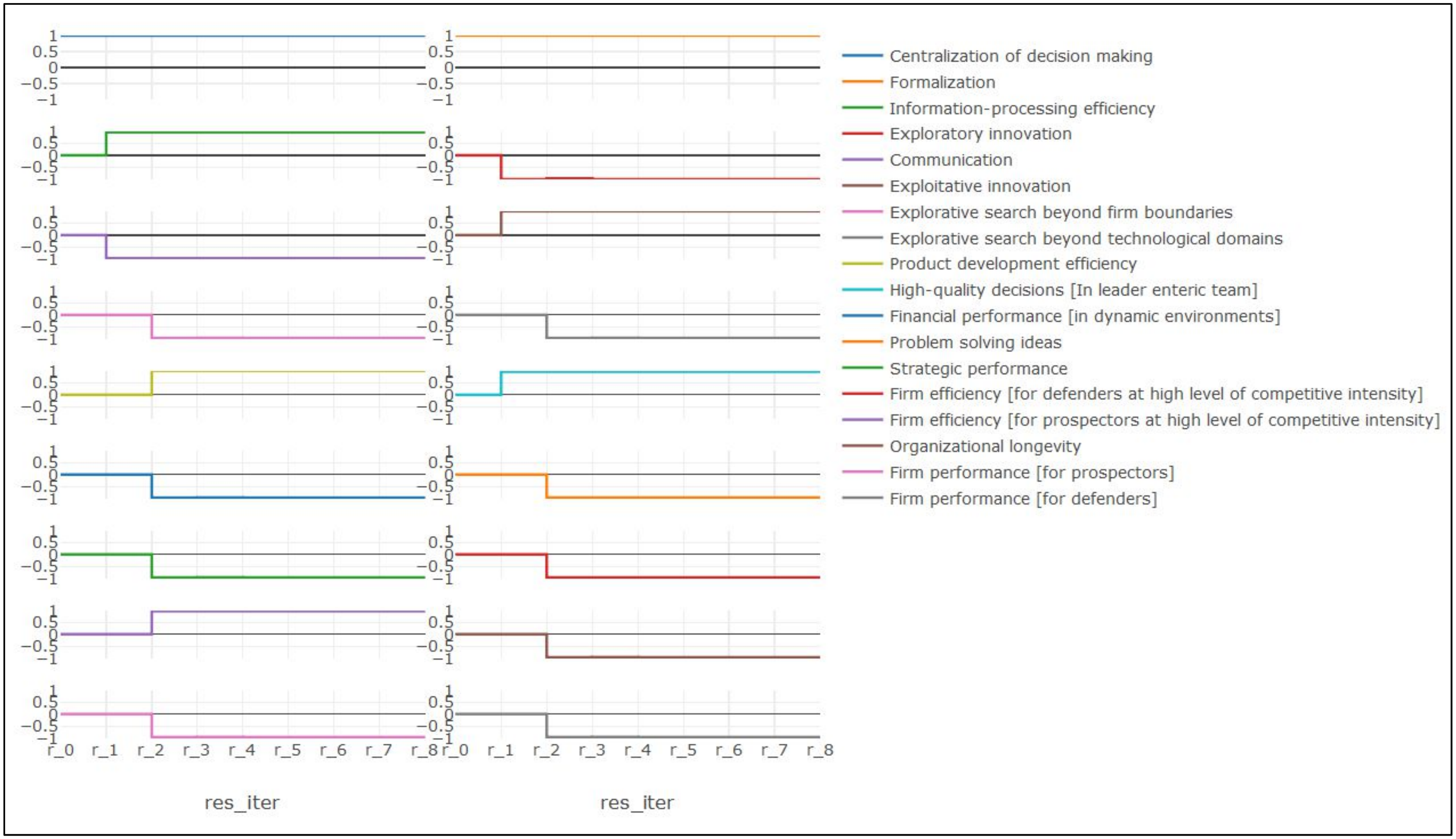

Figure 33 Value of the concepts that experienced changes through the expected behavior analysis of exploratory-exploitative hub (Sub-FCM3)

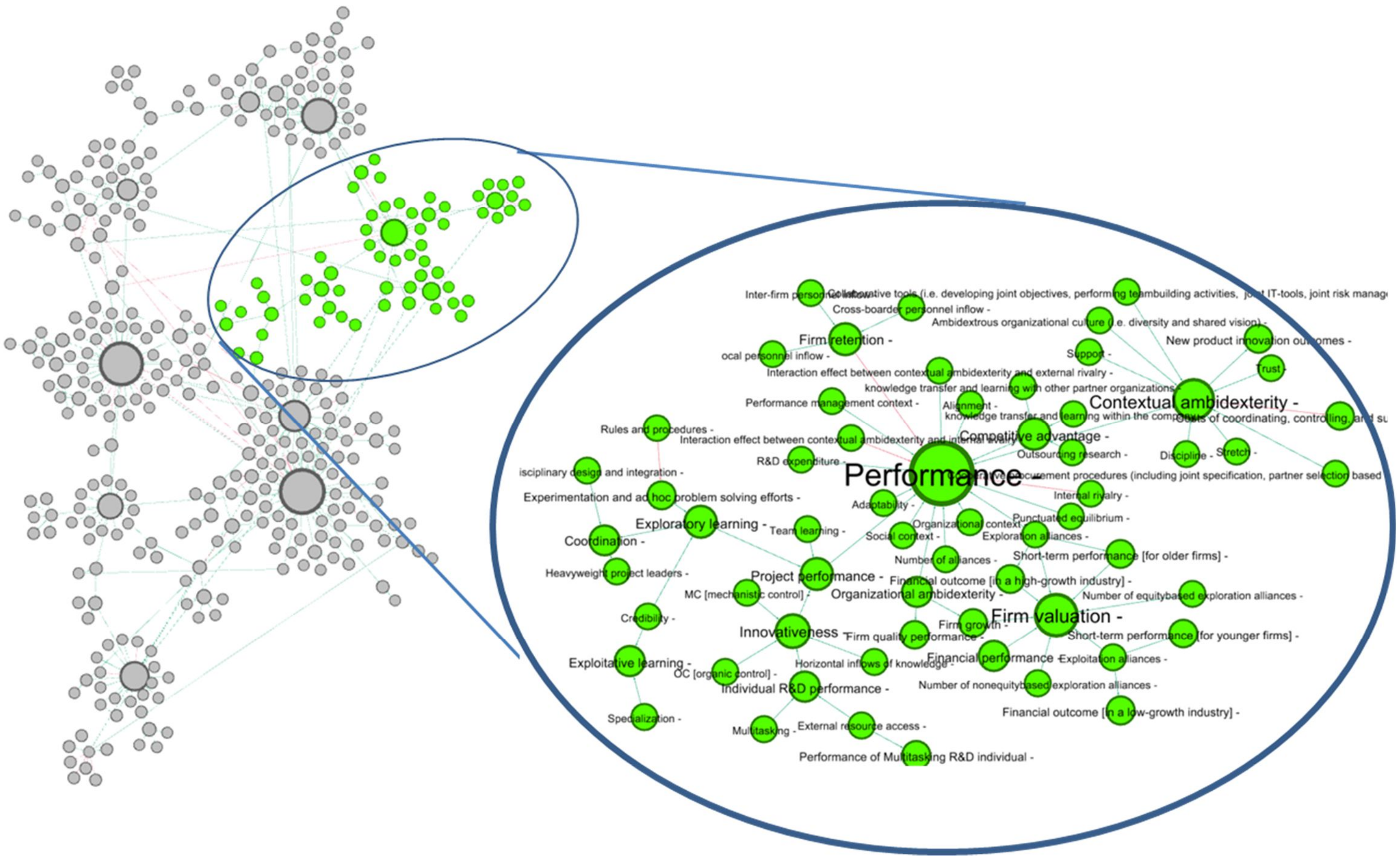

Figure 34- Sub-FCM5 Contextual ambidexterity hub as shown selected for the expected behavior tests

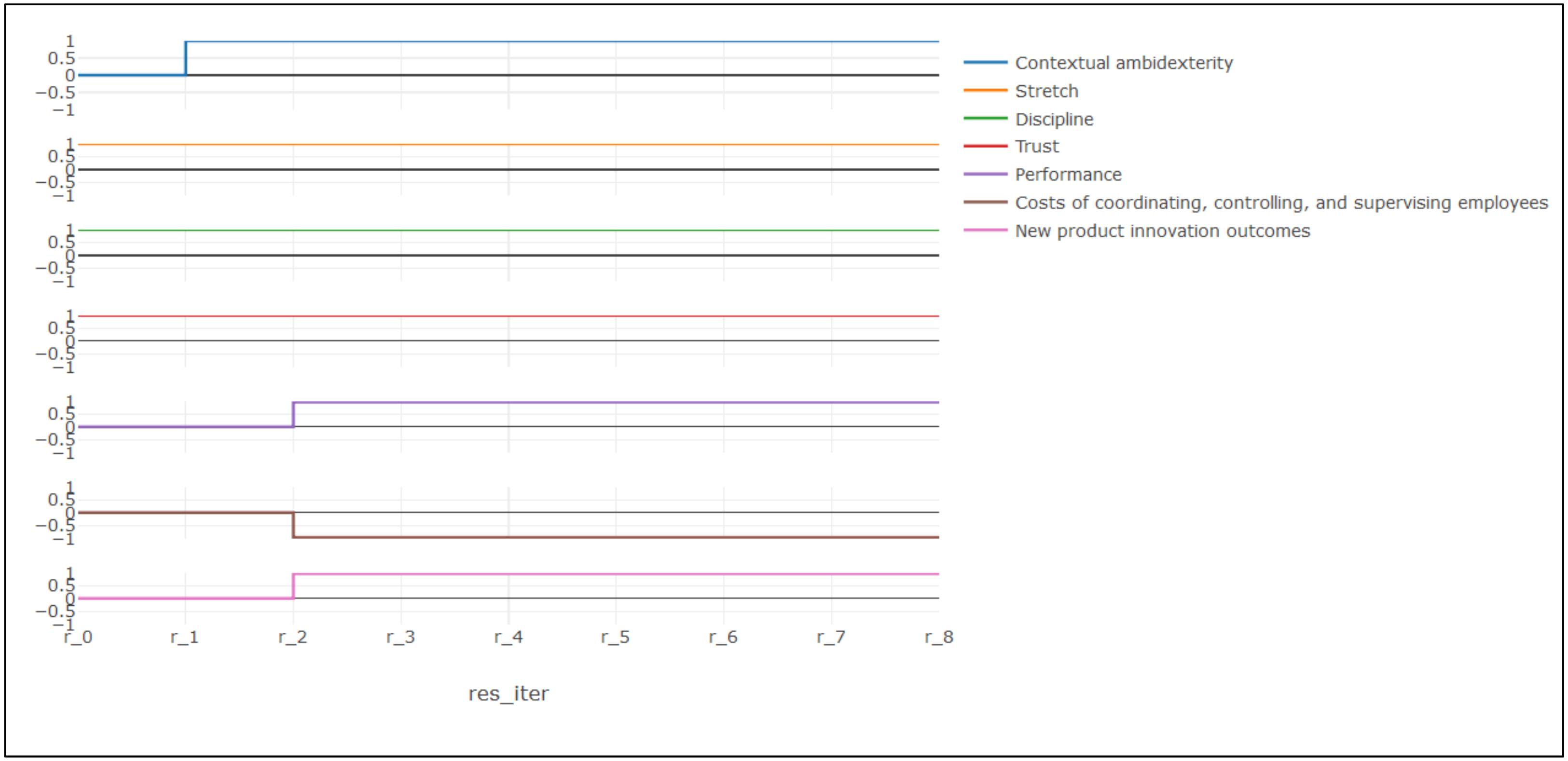

Figure 35- Value of the concepts that experienced changes through the expected behavior analysis of contextual ambidexterity hub (Sub-FCM4)

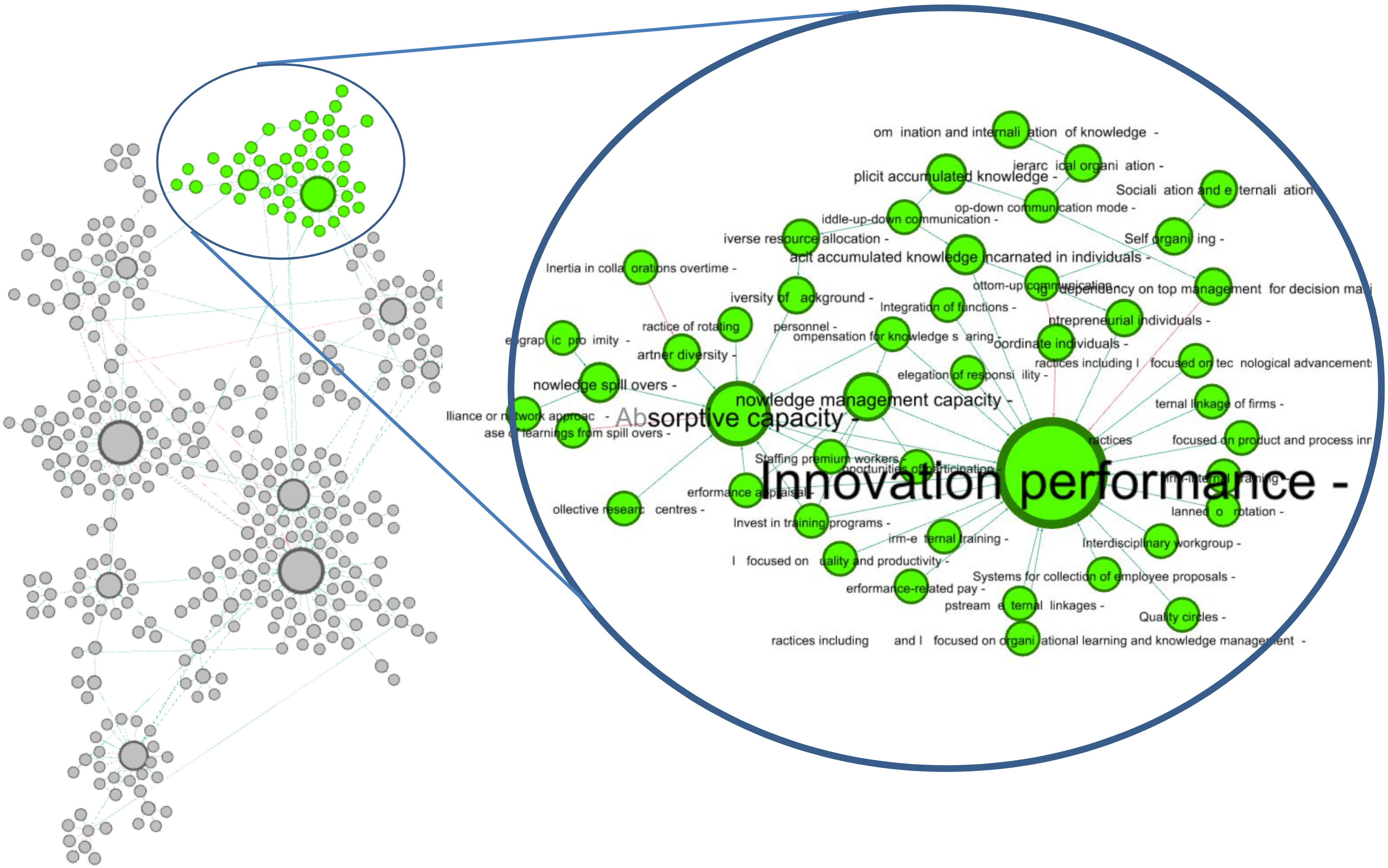

Figure 36- Sub-FCM5 innovation performance hub as shown selected for the expected behavior tests

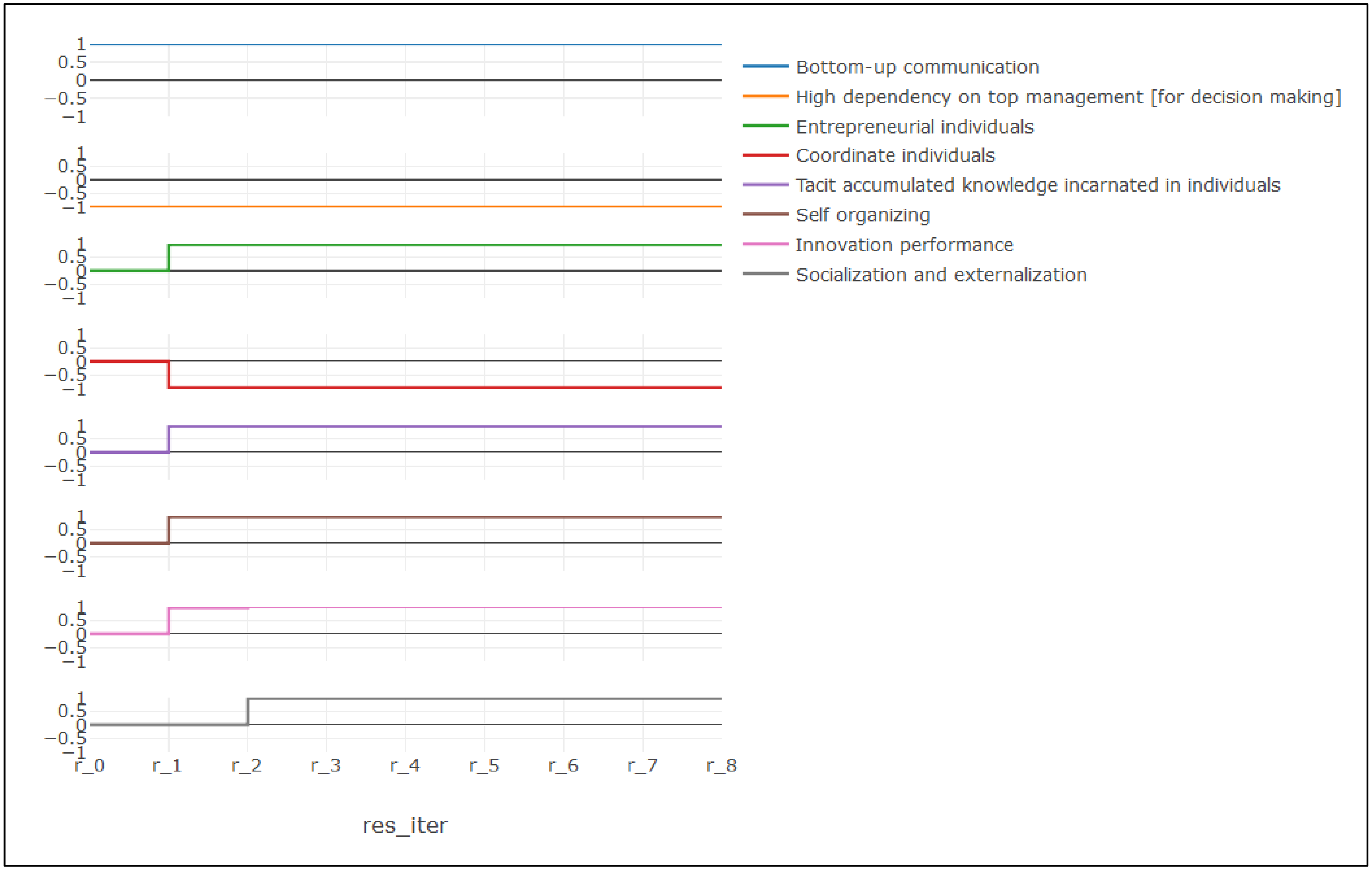

Figure 37- Value of the concepts that experienced changes through the expected behavior analysis of Innovation performance hub (Sub-FCM5)

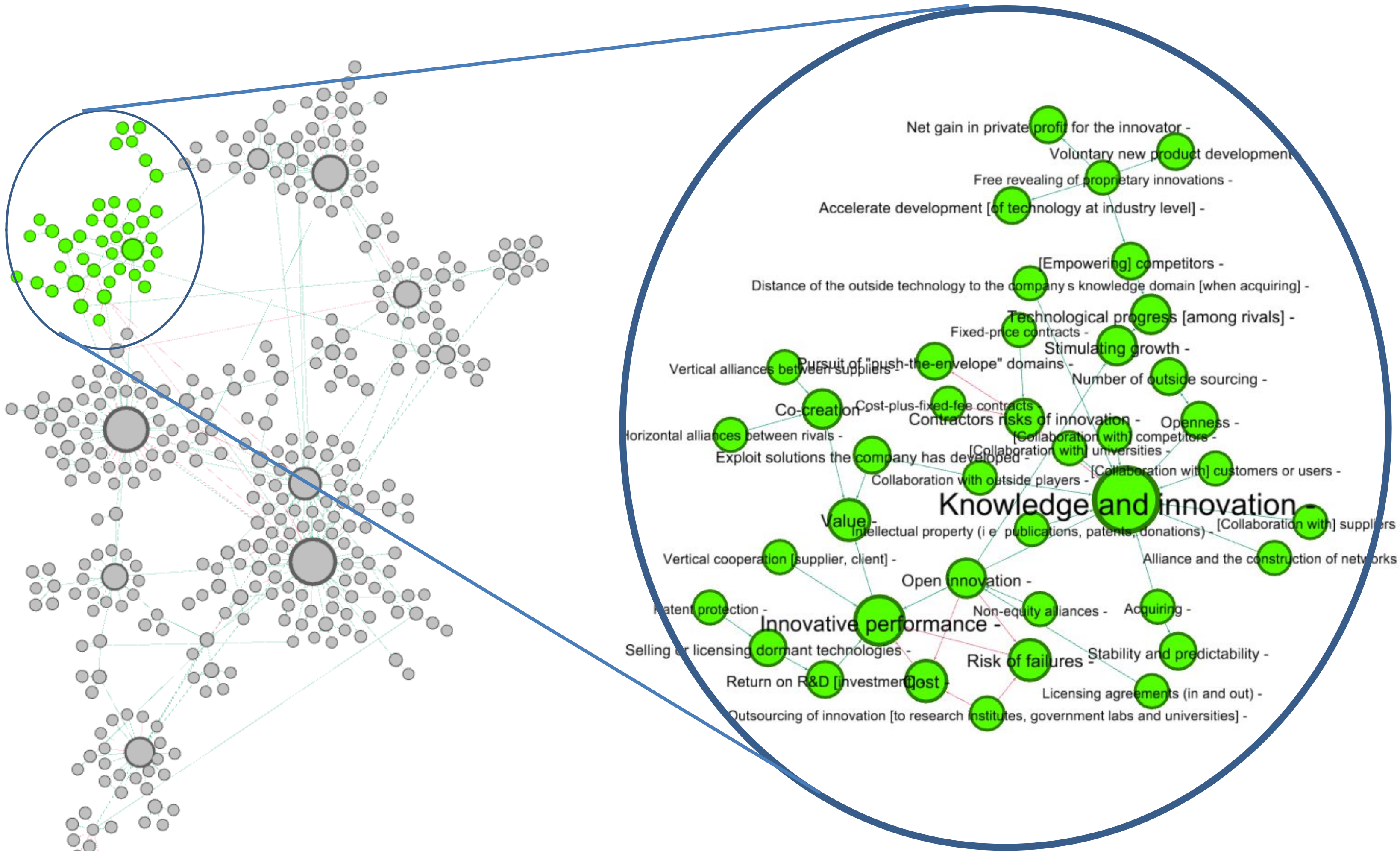

Figure 38- Sub-FCM6 Knowledge and innovation hub as shown selected for the expected behavior tests

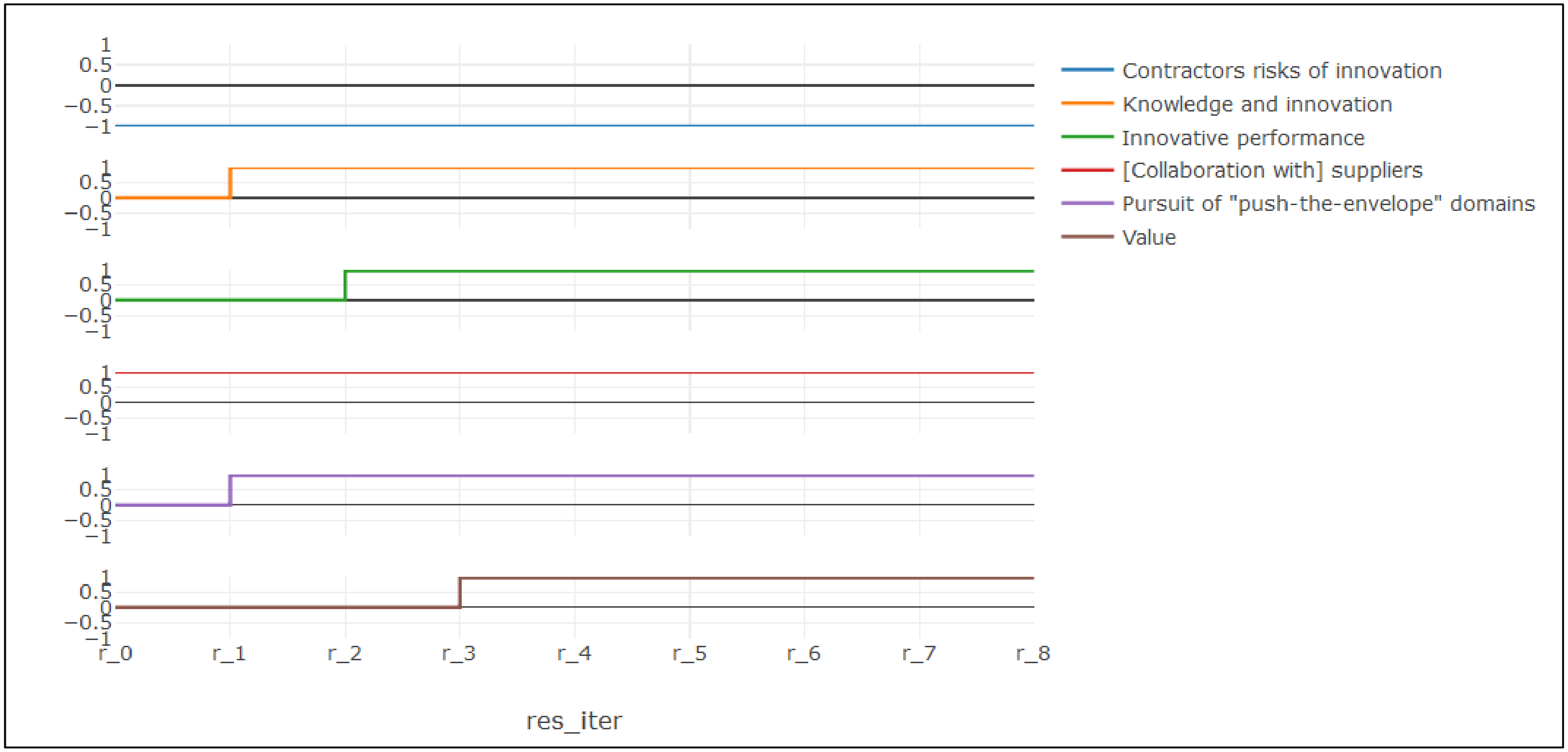

Figure 39- Value of the concepts that experienced changes through the expected behavior analysis of knowledge hub (Sub-FCM6)

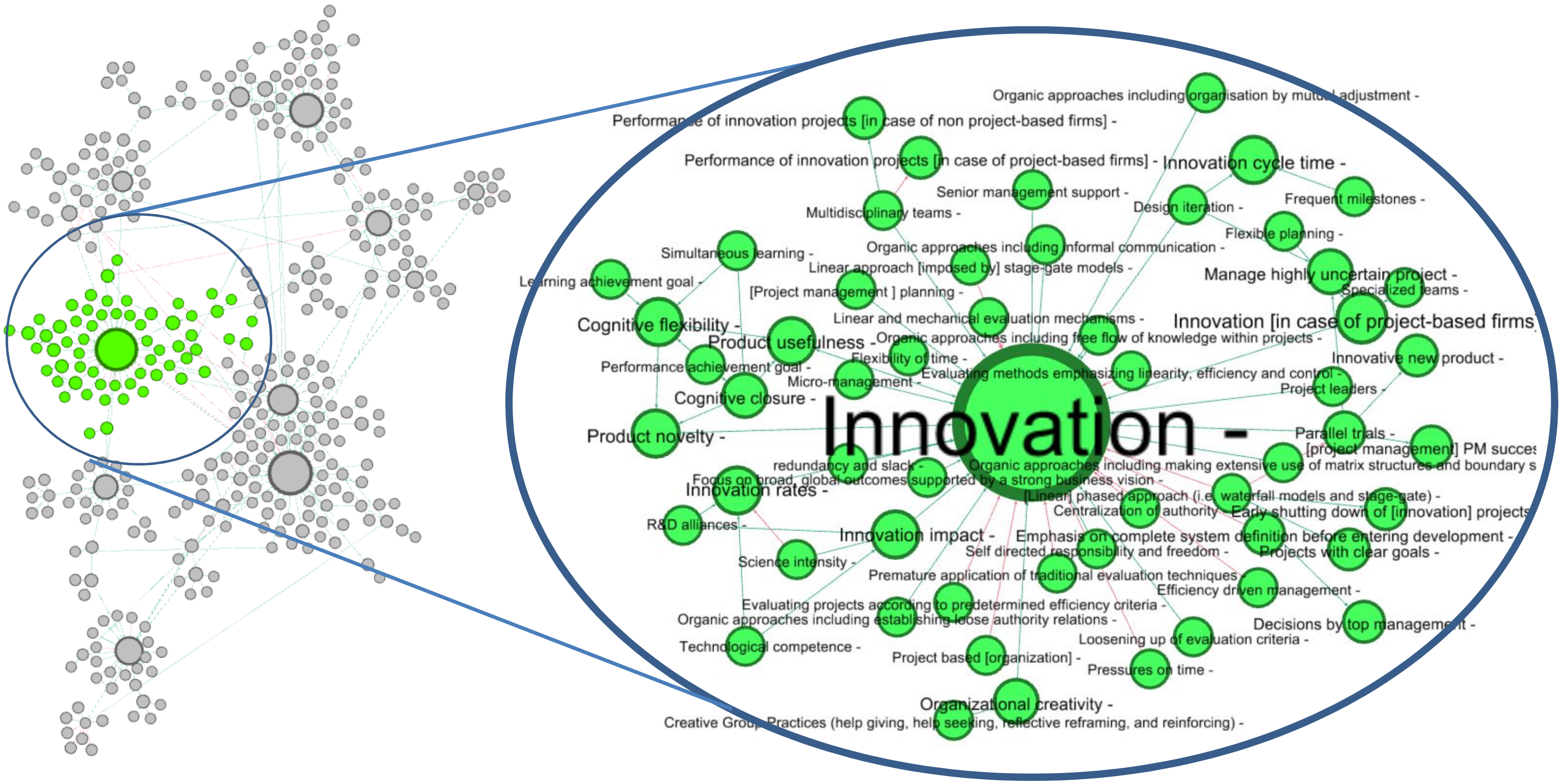

Figure 40- Sub-FCM7 innovation hub as shown selected for the expected behavior tests

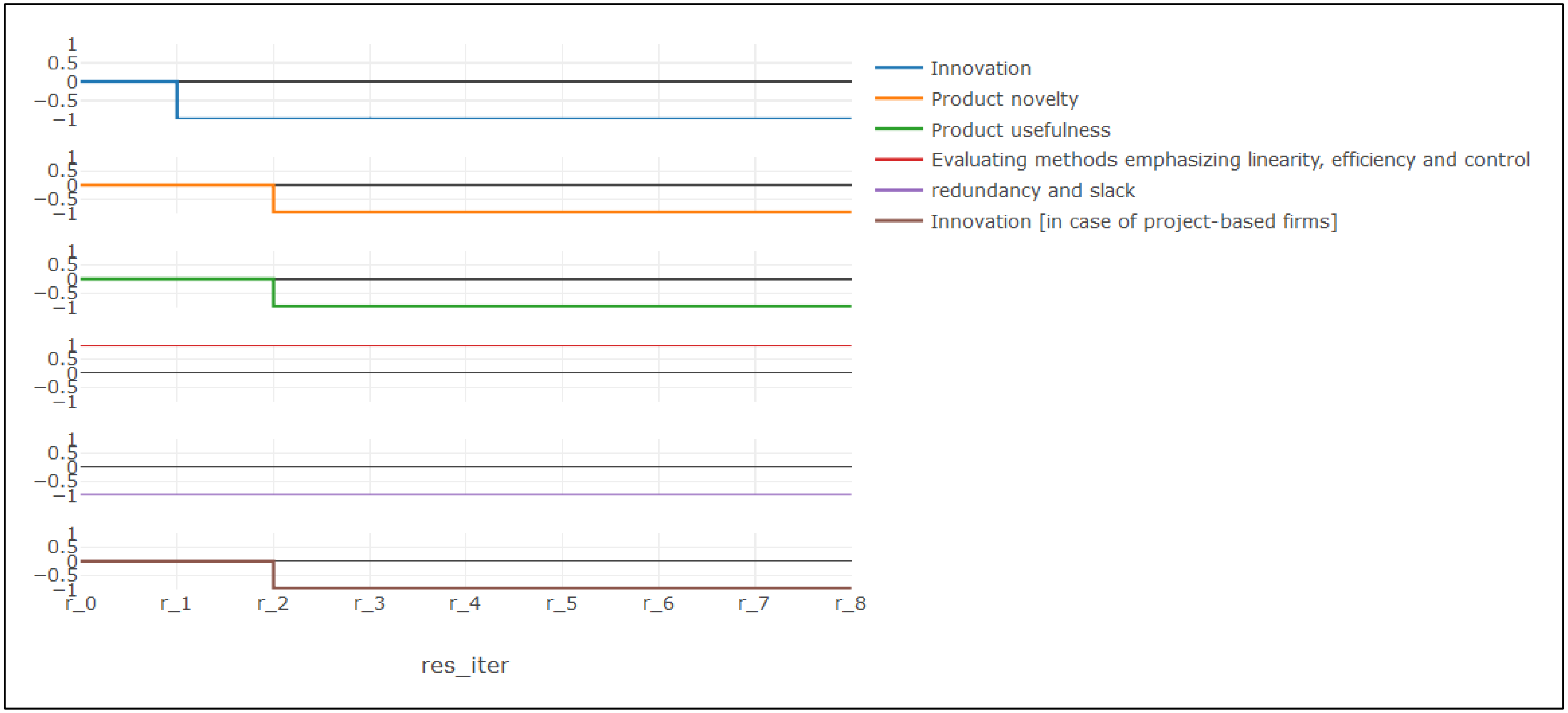

Figure 41- Value of the concepts that experienced changes through the expected behavior analysis of Innovation hub (Sub-FCM7)

5.5 Simulation using exploratory modeling and analysis

As it mentioned earlier, a simulation package was developed using R programming for the purpose of this study. This package runs FCM simulation, with a subset of possible permutations of initial state which, based on the simulation objective are determined either randomly or electively by the researcher. It provides options regarding the squashing functions, clamping constraints and adjacency matrices required for exploratory modeling. It is also providing expected behavior and extreme scenario analysis, with graphic visualizations of the results as presented in sections 5.3 and 5.4. This package is the first available exploratory FCM simulation package that could also be used outside of the purpose of this specific research.

As discussed in 4.4 the main goals of this research are to answer following questions:

a) What scenarios (initial vectors) lead to relatively higher ambidexterity

b) What scenarios (initial vectors) lead to relatively higher exploitative innovation and relatively lower exploratory innovations

c) What scenarios (initial vectors) lead to relatively higher exploratory innovation and relatively lower exploitative innovations

d) What scenarios (initial vectors) lead to relatively lower exploration and relatively low exploitation capabilities, and consequently leading to neither an innovative nor ambidextrous organization.

To answer these questions exploratory modeling and analysis approach was used. That implies that for every FCM calcualtion, weights of the conncetions in the model were randomly assigned within the acceptable range to count for deep uncertainity in the structure of model. For a positive connection, a random number in the range of (0,1] and for a negative connection, a random number in the range of [-1,0) was assigned to the conncetion. For every givien initial vector FCM simulation was repeated 100 times with adjacency matrices formed based on these random conncetion weights.

Exploratory modeling and analysis (EMA) is based on the notion that only input scenarios that yield to highly consistent results even with such turbulances in the model structure, are robust enough to be considered as acceptable solution or scenarios for a given research questions.

Consequently a metric of robustness is needed for an EMA. This metric is often used in the last step of EMA, also known as *trade-off* analysis, in which different solutions—initial vectors in case of this study—are compared across their outcomes through simulation iterations to find the ones that lead to consistent outcomes despite the random changes in model parameters (Jan H. Kwakkel, Haasnoot, and Walker 2016; Herman et al. 2015).

Robustness value (RV) for the case of this study was formulated as the percentage of the range of changes in the outcome value of a concept across iterative simulations with changes in FCM adjacency matrices:

$$RV_{C_{ij}} = 1 - \frac{Max(C_{ij}) - Min(C_{ij})}{2}$$

C_i: Concept i^{th} at the j^{th} iteration of FCM simulation and 2 is the range of possible values from -1 to 1.

For instance, concept C_5 that gets a value ranging from 0.44 to 0.87 in the 8^{th} iteration of FCM simulations with unique initial vectors, but random adjacency matrices have the robustness value of:

$$RV_{C_{5,8}} = 1 - \frac{0.87 - 0.44}{2} = 0.785 = 78.5\%$$

If the $C_{5,8}$ represents the value of Organizational ambidexterity concepts, initial vectors that not only lead to a relatively high Organizational ambidexterity (like $C_{5,8} \geq 0.5$) but also high robustness value such as $RV_{C5,8} \geq 0.99$ would be as of interest.

With a measure of robustness in hand, the simulation could be performed in pursue of answers to research questions. While section 5.6.1 provides the simulation results categorized by research questions as explained above, Section 5.6.2 provides the results for the case study of a managerial intervention as explained in 4.4.

5.6 Simulation results

5.6.1 Search for acceptable scenarios

200,000 initial vectors were generated with an expected value of 4 activated concepts, from all potential concepts of the collective FCM as explained in section 4.4.1 (FCM Rev 8-3).

These 200,000 initial vectors then were fed into the FCM for 100 times with randomly generated adjacency matrices as explained in sections 4.4.2 and 4.4.3[8].

Figure 42 is a scatter plot that visualizes how these 200,000 initial vectors yielded differently when it comes to exploitative innovation (X-axis) and exploratory innovation (Y-axis). First quadrant (upper right) of the map is where initial vectors produced positive change value for both types of innovation. Second quadrant (lower right) consists of initial vectors that produced positive change in exploitative innovation but negative change in exploratory innovation. Third quadrant (lower left) embodies all initial vectors that produced negative change in the value of both exploitative innovation and exploratory innovation. Finally, forth quadrant (upper left) depicts the initial vectors that changed the value of exploratory innovation in the positive direction while changed the value of exploitative innovation in the negative direction.

[8] Calculation of adjacency matrices and the exploratory FCM took 2.5 hours for this simulation with an HP Zbook G3 and a Core i7 processor.

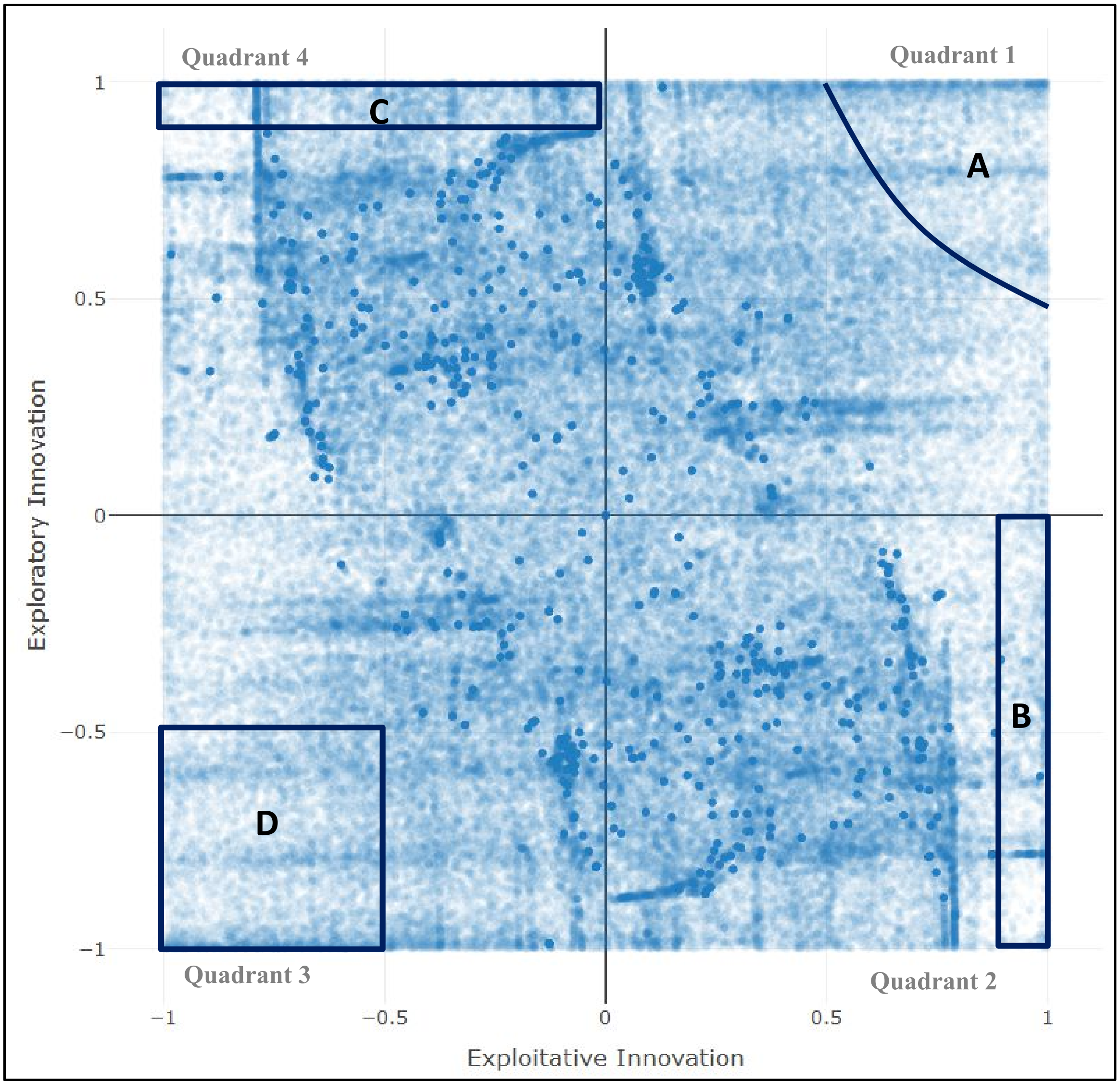

Figure 42- A scatter plat to visualize how 200,000 randomly generated initial vectors with an expected value of 4 activated concepts resulted differently in exploitative innovation (X-axis) and exploratory innovation (Y-axis). Zone A, consists of scenarios that significantly increase ambidexterity, Zone B, consists of scenarios that significantly increase exploitative innovation but decrease the exploratory innovation. Zone C, consists of scenarios that significantly increase exploratory innovation but decrease the exploitative innovation. Zone D consists of scenarios that significantly decrease both exploitative and exploratory innovation.

To have a relatively higher organizational ambidexterity not only both types of innovation needs to be significantly high they need to be in balance. A squashing function as explained in section 4.2.3 was defined to generate the value for the organizational ambidexterity a scenario generates based on the value it produces for both types of innovation. In Figure 42, curved line at the top corner makes 10 elevation zones with different organizational ambidexterity value ranging from less than 0.1 in the bottom left to more than 0.9 in top right. Initial vectors in each zone yield to the same value of organizational ambidexterity as represented for their elevation zone.

While clusters of highly concentrated scenarios show no effect on either types of innovations, or positive impact on one type in the cost of the other, a very small subset increased both type of innovations significantly. By having this information, and to answer each of the research questions, I only needed to look at right quadrants of the diagrams above. Initial vectors in the pertinent quadrants that satisfies the robustness condition provide reliable solutions to a given research question as is explained next. I also a looked for common concepts in between each sets of solutions for any higher level of insights.

As described in chapters 1, and 4, first research question aims to find the scenarios that increase the organizational ambidexterity (zone A in Figure 42), while second and third are looking for scenarios that increase one type of innovation while decreasing the other (zone B and C in Figure 42), and last scenarios that have significant negative effect on both types of innovations (zone A in Figure 49). Next, a more precise objective is formulated for each of these research questions and the simulation results that satisfied all the requirements are presented as solutions.

A. Objective is refined as, finding scenarios (initial vectors) with an expected value of 4 activated concepts (p=4/258=0.015), that lead to extremely high value of organizational ambidexterity ($0.9 \leq$ Organizational ambidexterity ≤ 1), that also prove to be robust in the face of uncertainty in the model structure (Robustness Value $_{\text{Organizational ambidexterity}} \geq 0.90$).

From the 200,000 initial vectors only 243 of them satisified the requirements for this objective in the face of simulations for 100 randomly generated adjacency matrices. That shows only very small portion (0.1%) of the explored scenarios lead to this high yield and robustness in the terms of organizational ambidexterity. These scenarios are accessible on the online shared folder[9].

A closer look into the activated concepts within these 243 scenarios, revealed that 253 concepts were present in at least one of them. But 35 concepts were shared among more than 10 scenarios as depicted in Table 8.

[9] https://drive.google.com/open?id=1FM2Eak9nRSn0CF2sWyUahxU0_K96DiQF

Table 8- Concepts that are shared among 10 or more scenarios out of 205 scenarios that extremely and robustly increased the value of organizational ambidextrous

Concept	*Frequency of presence*	*Statistical Significance (P-Value)*
Relationship learning	73	.000001
Connectedness	54	.000001
Involvement of suppliers in design activities	49	.000001
Complementary tactics	47	.000001
Leadership characteristics	43	.000001
Incentive-based payment (i.e. performance-based)	41	.000001
Intraorganizational exploitation and exploration	40	.000001
Structural characteristics	39	.000001
Multilevel approach	38	.000001
Learning synergies	27	.000001
MO [market orientation]	25	.000001
Informal coordination mechanisms	23	.000001
Compensation for knowledge sharing	20	.000001
Projects with clear goals	18	.000001
Autonomy	16	.000001
Invest in training programs	16	.000001
Effective dedicated team	15	.000001
Perceived competitive intensity positively	15	.000001
Innovative new product	15	.000001
Manage routine project modules	14	.000001
Top-down knowledge inflows	13	.000005
Outsourcing of innovation [to research institutes, government labs and universities]	13	.000005
exploitation and exploration between the organizations	12	.000047
Effective [exploration] project Management [in large construction projects]	12	.000047
Managers' entrepreneurial orientation	12	.000047
[Effective management of] projects nearing commercialization	12	.000047
Open up new markets	11	.000342
[Effective] new product development	11	.000342
Selecting the right people	10	.001
Improve yield (Performance)	10	.001
Identifying distinct role and decision makers	10	.001
Bottom-up knowledge inflows	10	.001
Separating exploring and exploiting roles	10	.001
Diversely skilled members	10	.001
PERT/CPM [techniques]	10	.001

B. Second research question aims to find the scenarios that while increase the exploitative innovation, has a negative impact on exploratory innovations. Objective is refined as, finding scenarios (initial vectors) with an expected value of 4 activated concepts (p=4/258=0.015), that extremely increase the value of Exploitative innovation (0.9 ≤ Exploitative innovation ≤ 1), that also prove to be robust in the face of uncertainty in the model structure (Robustness Value $_{\text{Exploitative innovation}}$≥ 0.90), while decrease the value of Exploratory innovation (*Exploratory innovation* <0)

From the 200,000 initial vectors, 59 of them satisfied the requirements. It is important to note that qualified scenarios are numbered because I looked for an extreme situation that exploitative innovation is absolutely increased—by over 0.9—while exploratory innovation is even decreased. With more relaxed criteria, significantly higher number of scenarios would have been qualified.

Table 9- Concepts that are shared among 10 or more scenarios out of 59 scenarios that extremely and robustly increased the value of exploitative innovation while negatively impacted exploratory innovations

Concept	*Frequency of presence*	*Statistical Significance (P-Value)*
Centralization of decision making	22	.000001
Formalization	21	.000001
High-performance work system] HPWS	16	.000001
[Linear] phased approach (i.e. waterfall models and stage-gate)	15	.000001
Top-down knowledge inflows	13	.000005
Invest in training programs	10	.001

162 of the concepts were present in at least one of these scenarios. These scenarios are accessible on the online shared folder10. Table 9- shows the concepts shared among 10 or more qualified scenarios.

C. Third research question aims to find the scenarios that while increase the exploratory innovation, has a negative impact on exploitative innovations. Objective is refined as, finding scenarios (initial vectors) with an expected value of 4 activated concepts (p=4/258=0.015), that extremely increase the value of Exploratory innovation ($0.9 \leq$ Exploratory innovation ≤ 1), that also prove to be robust in the face of uncertainty in the model structure (Robustness Value $_{\text{Exploratory innovation}} \geq 0.90$), while decrease the value of Exploitative innovation (*Exploitative innovation* <0).

From the 200,000 initial vectors, 941 of them satisfied the requirements. These scenarios are accessible on the online shared folder[11]. 256 of the concepts were present in at least one of these scenarios. Table 10 shows the top 20 concepts shared among qualified scenarios.

Table 10-Top 20 concepts shared among qualified scenarios for 3rd research question

Concept	*Freq.*	*P-Value*	*Concept*	*Freq.*	*P-Value*
Open up new markets	200	.000001	Complementary tactics	76	.000001
Managers' entrepreneurial orientation	158	.000001	Identifying distinct role and decision makers	73	.000001
Effective dedicated team	127	.000001	Explorative search beyond technological domains	73	.000001
Enter new technology fields	119	.000001	Technological volatility	72	.000001
Introduce new generation of products	116	.000001	Involvement of suppliers in design activities	71	.000001
Relationship learning	107	.000001	Multilevel approach	69	.000001
Bottom-up knowledge inflows	98	.000001	Flexible R&D management	68	.000001

[10] https://drive.google.com/open?id=1FM2Eak9nRSn0CF2sWyUahxU0_K96DiQF
[11] https://drive.google.com/open?id=1FM2Eak9nRSn0CF2sWyUahxU0_K96DiQF

Informal coordination mechanisms	94	.000001	Innovative new product	61	.000001
Structural characteristics	87	.000001	Horizontal knowledge inflows	58	.000001
[Effective management of] projects in the discovery phase of R&D	84	.000001	Inter-firm collaboration	53	.000001

D. Final research question aims to find the scenarios that are detrimental to both exploratory and exploitative types of innovation. Objective is refined as, finding scenarios (initial vectors) with an expected value of 4 activated concepts (p=4/258=0.015), that lead to significant decrease in Exploratory innovation and Exploitative innovation simultaneously (*Exploitative innovation* ≤ -0.9 and *Exploratory innovation* ≤ -0.9)

399 initial vectors satisfied these requirements. These scenarios are accessible on the online shared folder[12]. A large set of concepts, 254, were present in at least one scenario that satisfied the requirements. It was highly expected that there should be no dominant factors making up for decrease of both types of innovation, because all the concepts collected in this FCM are originated from empirical studies looking for the opposite, factors or practices that positively improve at least one of types of the innovation. But still it is interesting to note that a good portion of the random combination of these factors yielded an opposite effect.

[12] https://drive.google.com/open?id=1FM2Eak9nRSn0CF2sWyUahxU0_K96DiQF

5.6.2 What-if analysis approach- Case of managerial intervention to increase open innovation

As briefly discussed in 4.4, in addition to the approach of searching for initial vectors (scenarios) that meet the research objective requirements, this developed model of the ambidexterity can be used to test hypotheses that are proposed in the literature or explore a specific managerial intervention plan. This section constructs such a case to demonstrate the capacity of the model and provide simulation results, based on literature of open and distributed innovation as discussed in 2.5.

As mentioned in the literature review of open innovation, section 2.5, two sets of practices known as inbound and outbound open innovation practices are suggested to increase the innovation in a firm. Practices for inbound open innovation include, but are not limited to, networking and collaboration with external sources such as suppliers, competitors, users, and universities; while practices for outbound open innovation primarily include spin-offs and licensing (Busarovs 2013; Huizingh 2011; H. Chesbrough 2006).

Yet another pattern in open innovation that could be observed is that there are two sets of practices. First set of practices concentrate on collaboration with suppliers and clients (vertical cooperation), by lowering the risk of failure and giving more freedom to suppliers to take over a portion of the work. These practices as listed in V_1 seem to rely on long term relationships, lowering the risk of innovations for all the supply chains.

$$
V_1=\begin{bmatrix} V1\\ V2\\ V3\\ V4\\ V5\\ V6\\ V7\\ V8\\ V9\\ V10\\ V11\\ V12\\ V13 \end{bmatrix}=\begin{bmatrix} \textit{Cost}-\textit{plus}-\textit{fixed}-\textit{fee contracts}\\ \textit{Fixed}-\textit{price}-\textit{contracts}\\ \textit{Knowledge transfer and learning with other partner}\\ [\textit{Collaboration with}]\ \textit{suppliers}\\ \textit{Inertia in collaboration overtime}\\ \textit{Vertical alliances between suppliers}\\ \textit{Vertical cooperation}\ [\textit{supplier, client}]\\ \textit{Number of outside sourcing}\\ \textit{Upstream}\ [\textit{external}]\ \textit{linkages}\\ \textit{Exploitation alliances}\\ \textit{Non}-\textit{equity alliances}\\ \textit{Power asymmetry}\\ \textit{Contractors risks of innovation} \end{bmatrix}=\begin{bmatrix} 1\\ -1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ -1 \end{bmatrix}
$$

Figure 43-Case1-Moderate open innovation cases: knowledge sharing with established suppliers and clients

Second sets of practices are proposing a much more avant-garde approach; collaboration with outside players and rivals, collective R&D with competitors, collective research centers and co-creation and even, free revealing of proprietary innovation. See practices list at V_2.

$$
V_2=\begin{bmatrix} V1\\ V2\\ V3\\ V4\\ V5\\ V6\\ V7\\ V8\\ V9\\ V10 \end{bmatrix}=\begin{bmatrix} \textit{Collaboration with outside players}\\ \textit{Selling or licensing dormant technologies}\\ \textit{Licensing agreements}\\ [\textit{Collaboration with}]\ \textit{competitors}\\ \textit{Co}-\textit{creation}\\ \textit{Horizental alliances between rivals}\\ \textit{Collective research centres}\\ \textit{Free revealing of proprietary innovation}\\ \textit{Exploration alliances}\\ \textit{R\&D alliances} \end{bmatrix}=\begin{bmatrix} 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1\\ 1 \end{bmatrix}
$$

Figure 44-Case 2-Avant-garde open innovation practices: More knowledge sharing and collaboration with rivals

In my case study of managerial intervention, I ran two scenarios using these initial vectors to study the system behavior, and especially the impact, exploratory innovation and exploitative innovation on organizational ambidexterity.

My expectation before running the first scenario which can be labeled moderate open innovation, was to see slight increase in the exploitative innovation but no significant impact on exploratory innovation and thus organizational ambidexterity. The reason is that still insufficient knowledge sharing among supply chains would occur for breakthrough innovations when implementing such scenario in real world. Work is split between different firms and each one gets a part that they are naturally more competent at. They may get the chance to excel at their part, but it would be hard to see out-of-the-box ideas or solutions to gain traction in such set ups. Results of running the first simulation are depicted in

Figure 45 and almost perfectly matched the prior expectations: a slight increase in the average exploitative innovation value with no impact on exploratory innovation.

Determining how the second scenario, which could be called avant-garde open innovating, would impact the system was much more difficult, but overall it is the opposite of first scenario. I expected to see increase in exploratory innovation with no impact on exploitative innovation because although selling or licensing dormant technologies is considered outbound open innovation, and creates value for the firm, such tactics do not assure to increase either type of innovation. Results of running the second simulation as depicted in Figure 46 matched only half of my expectations; it showed no impact on either type of innovations. It showed there was no directly cited link or indirect connections between suggested practices and exploratory innovation exist in the model. Even if such relationship exists in the real world as speculated, the literature to this point does not explicitly provide evidence for that.

Finally, because none of these scenarios showed signs of improvement in the exploratory innovation, running both of them together—initial vector that includes all the practices of two scenarios—was not likely to lead to an ambidextrous state as well. Results of running this last scenario showed to be in line with this expectation as shown in Figure 47.

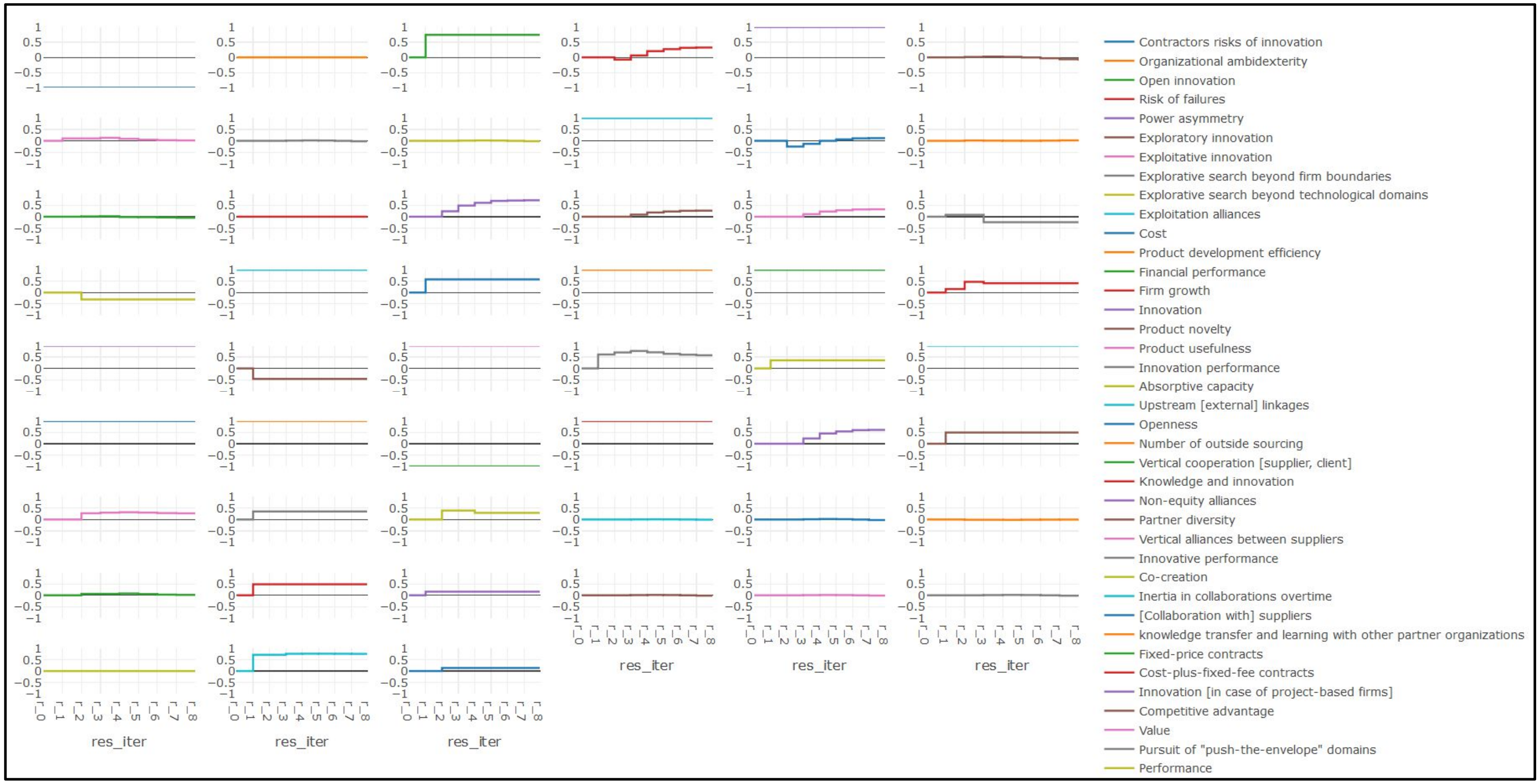

Figure 45- Case of moderate open innovation: knowledge sharing with established suppliers and clients

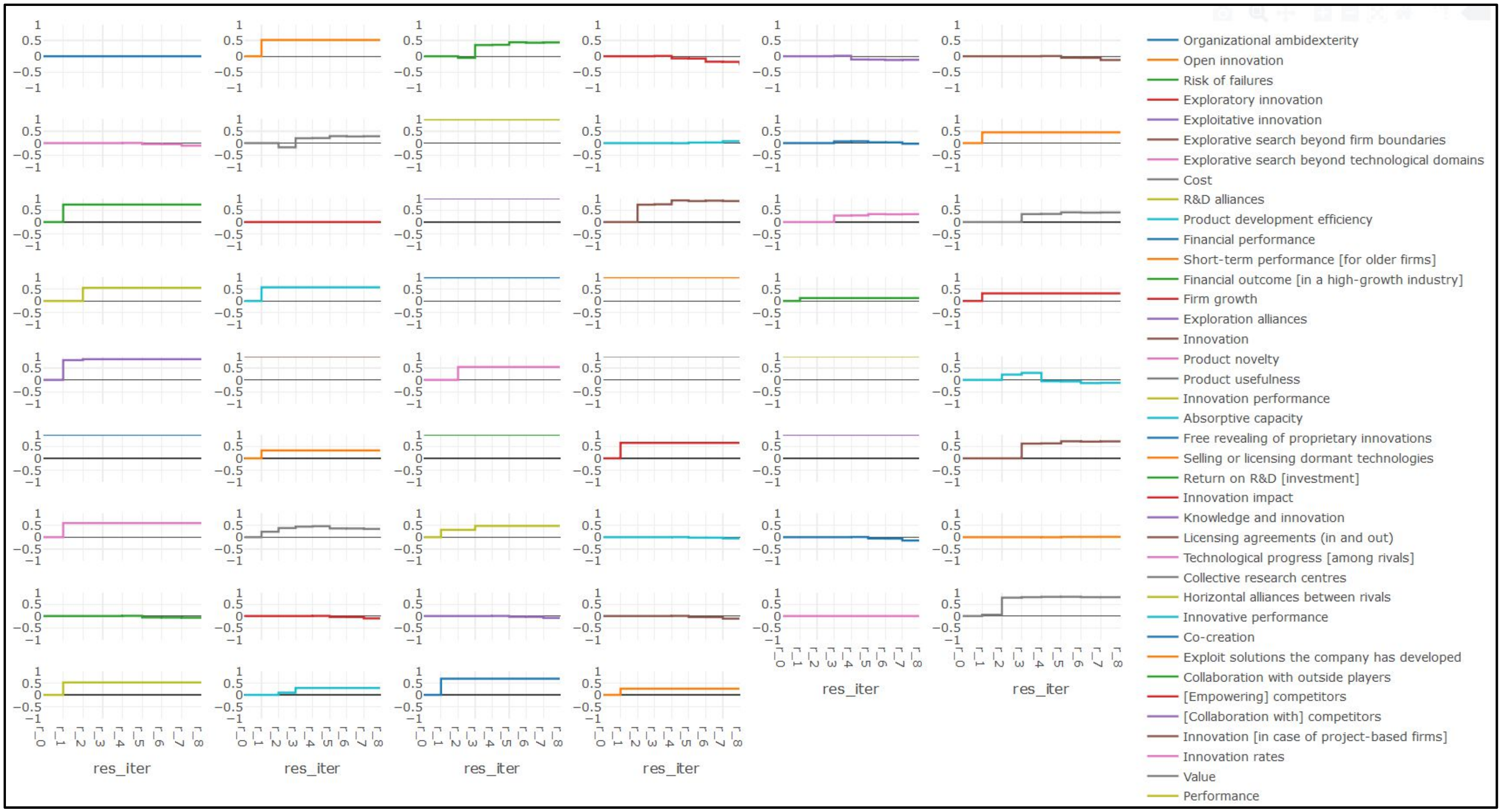

Figure 46- Case of avant-grade open innovation: Collaboration with rivals, collective R&D and free revealing of properitery innovations

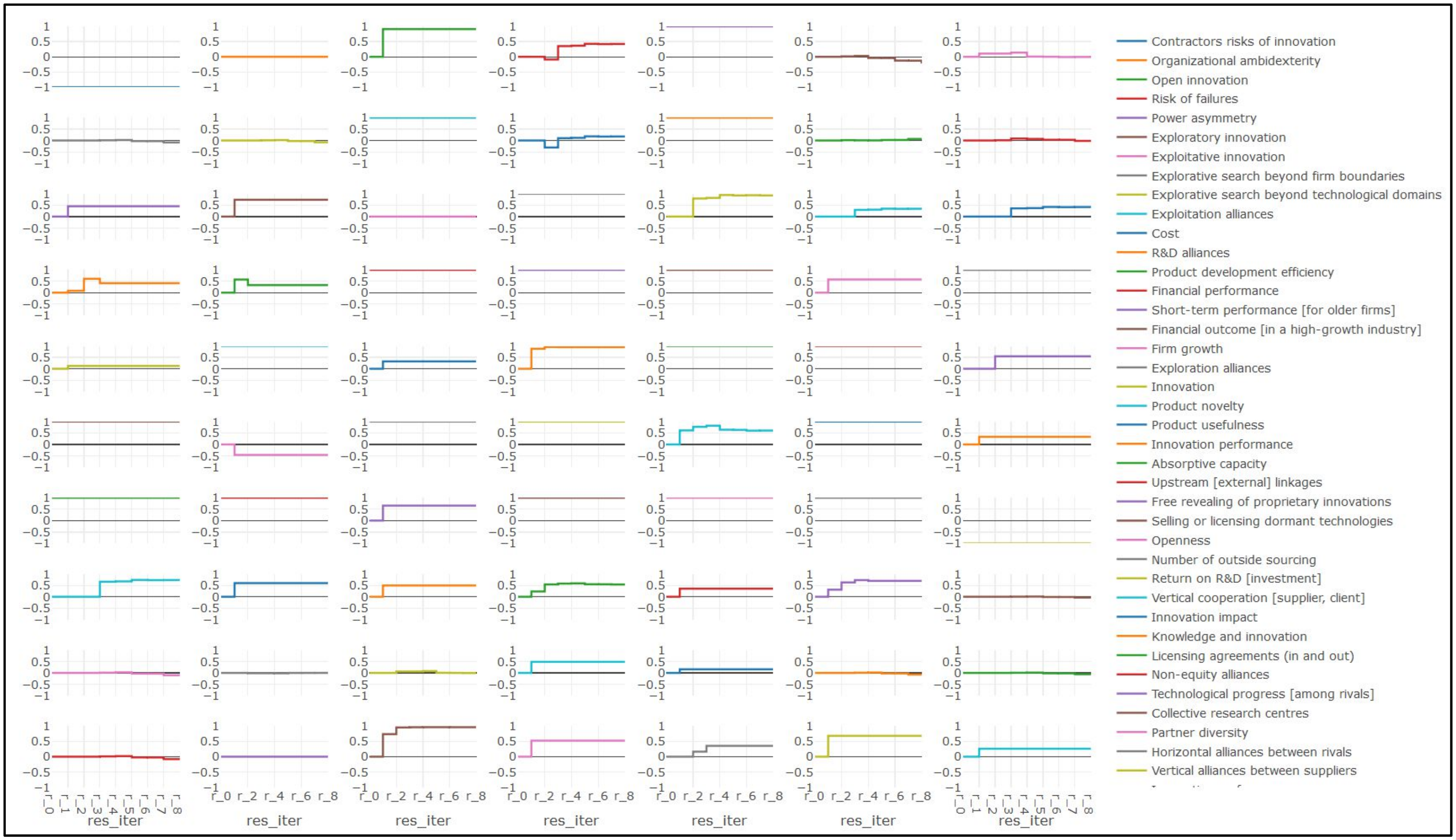

Figure 47- Case of open innovation

6. Discussion of Results

This study developed a new simulation method by employing the fuzzy cognitive map in an exploratory modeling and analysis context to examine a new path to find answers for some very complex questions. Primary questions of this research as formulated in the chapter 4, include:

1) What sets of practices lead to relatively higher exploration, exploitation, or balanced organizational ambidexterity? And, consequently, what prevents them from becoming either innovative or ambidextrous?

2) Are the practices for achieving exploration different from the practices for achieving exploitation?

In chapter 4, I found specific scenarios that impact the value of exploitative innovation, exploratory innovation or organizational ambidexterity, this analysis found patterns among concepts—practices and factors. Although finding and providing these customized scenarios to optimize the innovation, is a significant contribution to the practice of management, finding generalized patterns among practices and scenarios—combination of activated practices—would be a great advancement in innovation field and to ambidexterity theory. My findings in this regard while utilizing visualization techniques and sensitivity analysis are discussed in this chapter.

A closer look to the results of the simulations provides a great starting point. If a new layer of data to be added to the scatter plot shown in Figure 42, a new topology map like Figure

48 could be produced. Curved lines at the top corner represents 10 different elevation zones in regard to organizational ambidexterity value. Organizational ambidexterity (OA) value as defined in chapter 4, is a Gompertz function of both exploitative innovation (x_1) and exploratory innovation (x_2):

$$OA(x_1, x_2) = \begin{cases} e^{-20\, e^{-10\, x_1\, x_2}}, & where \quad x_1 \; and \; x_2 > 0 \\ 0, & where \quad x_1 or \; x_2 \leq 0 \end{cases}$$

In the topology zones in Figure 48, 10 different range of organizational ambidexterity values are depicted ranging from less than 0.1 to more than 0.9 on the right corner of the diagram along the diagonal.

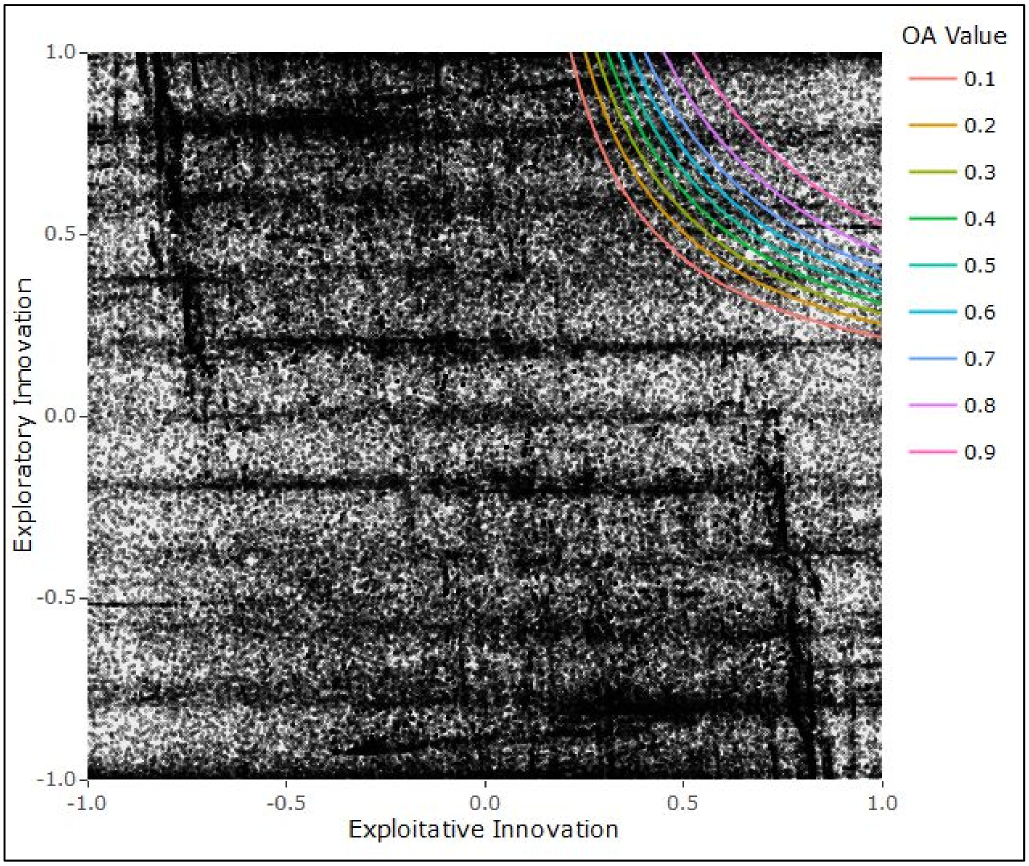

Figure 48-Topology Map: Only scenarios that extremely impacted the exploratory and exploitative innovations in positive direction—top right corner—in a highly robust way are considered the solution for increasing organizational value. Position of each scenario in on different organizational ambidexterity (OA) topology zones, reveals how much in average applying that scenario resulted in organizational ambidexterity.

Figure 48 reveals that not only a small sub-set of scenarios fall in a high OA zone at the top right, majority seems to be spread along the opposite diagonal connecting the top left of the space to the bottom left. To verify the idea, a different visualization is employed to reveal the concentration of the scenarios better.

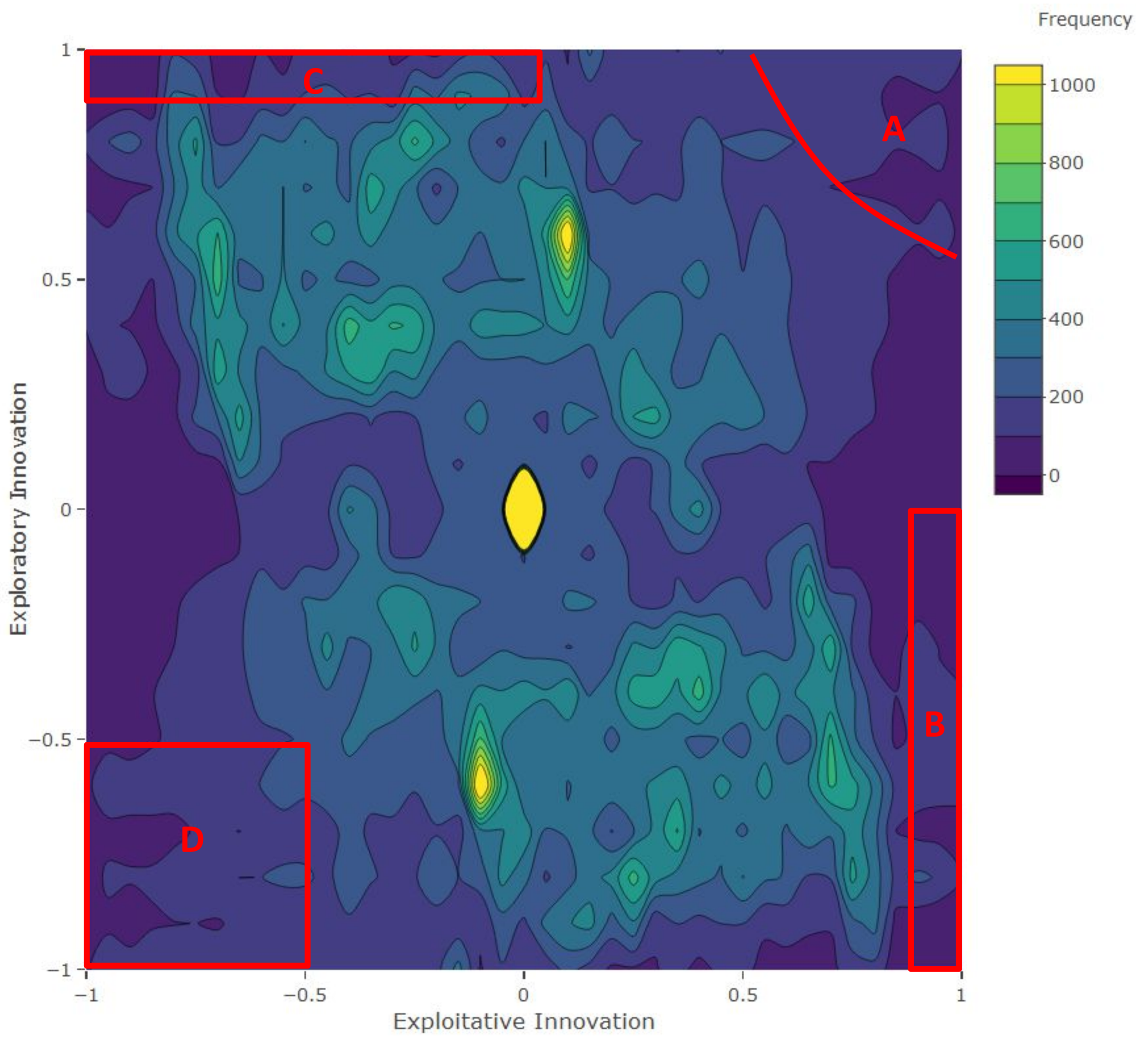

Figure 49- A heat map visualizing the concentration of the 200,000 scenarios in regard to the value they yielded for exploitative innovation and exploratory innovation. While highly concentrated clusters of scenarios are spread along the diagonal passing through second and fourth quadrants, a very small subset increase both types of innovations significantly on the top right (Zone A).

Figure 49 presents a visualization known as heat map for a better distinction of spots in the area with higher concentration of scenarios versus spots with more scarce scenarios. Zones

A, B, C and D are aligned with the requirements of research questions studied in chapter 5 that in summary increase both type of innovation, only exploitative innovation while decreasing the exploratory innovation, increase only exploratory innovation while decreasing the exploitative innovation, and negatively impacting both, respectively.

The highest concentration of the scenarios is easily recognizable around the origin suggesting that large sets of randomly generated scenarios led to zero impact on either type of innovations, as expected. However, interestingly highly concentrated clusters of scenarios are spread along the diagonal passing through second and fourth quadrant. This means that a large majority of the scenarios either increase one type of innovation in the cost of the other, or have impact on neither.

Another interesting pattern that could be observed is that clusters show some symmetry around the diagonal passing through the first and third quadrant. My explanation to partly justify such symmetry is that, mirrored scenarios in these clusters consists of similar activated concepts but in opposite direction. Meaning that if an initial vector of activated C1=+1, C2=+1, C3=-1 and C4=+1 has landed it in a cluster with high exploitative innovation and low exploratory innovation such as E, when other initial vector randomly obtain the same set of activated concepts but in the opposite direction like C1=-1, C2=-1, C3=+1 and C4=-1, that will lead to the mirrored location of the scenarios on the diagram and inside the cluster F.

6.1.Sensitivity analysis in regard to number of initial vectors

One important question would be how much the observed patterned is sensitive to the number of randomly generated initial vectors. To answer this question, I initially ran the simulations for 2000, 20000 and then 200000 initial vectors as presented earlier.

What became obvious was that as long as initial vectors are selected randomly, the number of initial vectors has no impact on the general pattern in regard to yielding different type of innovations and ultimate organizational ambidexterity. Figure 50 shows a side-by-side comparison in between results of the simulation in case of 20000 initial vectors and 200000 initial vectors.

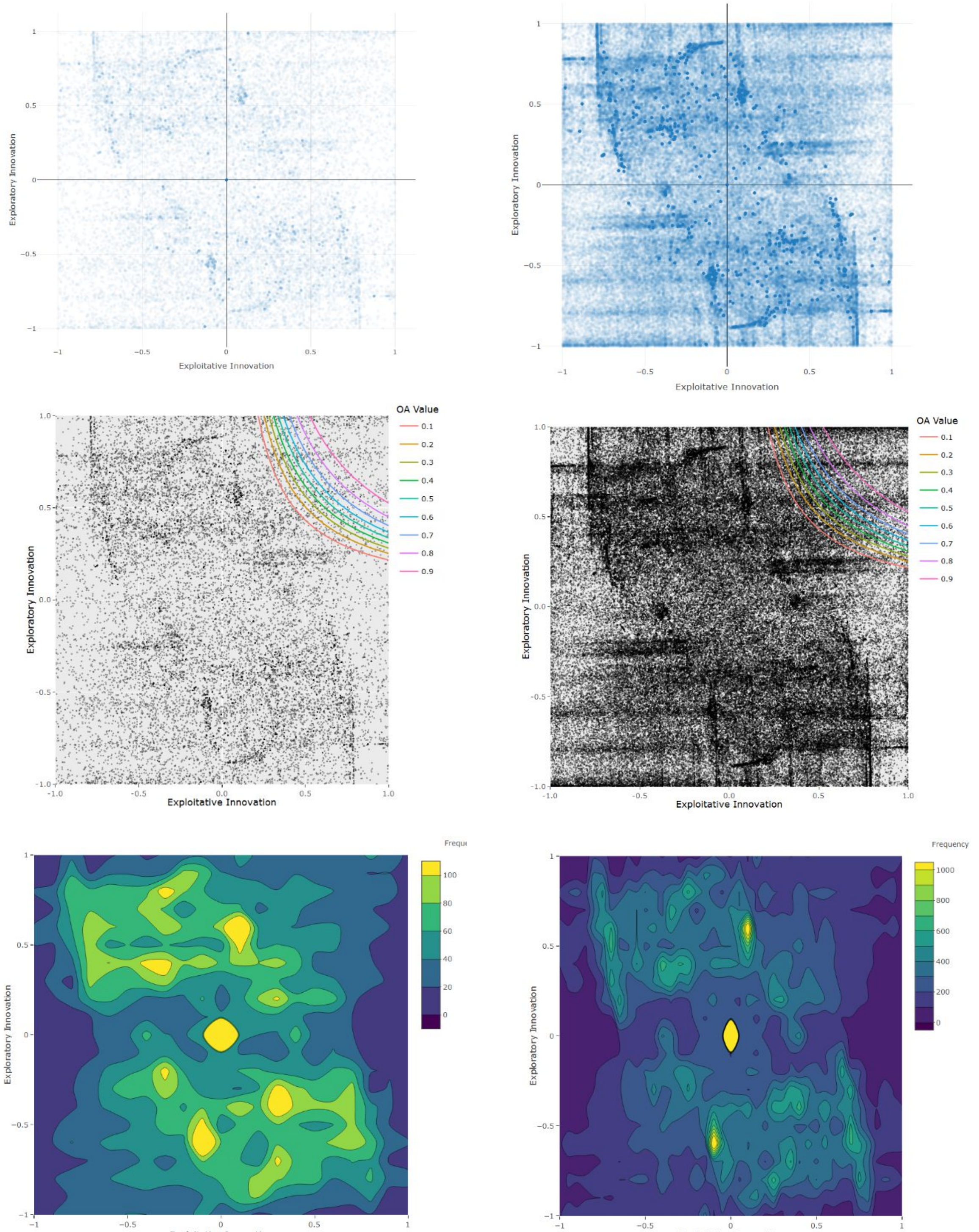

Figure 50- Concentration patterns from 20,000 initial vectors (left column) to 200,000 initial vectors (right column) shown to be consistent

6.2.Sensitivity analysis in regard to number of adjacency matrices

Another equally important concern would be the degree that number of adjacency matrices, or in other words size of the set of the model structures with random connection weights, could impact the patterns.

To answer this question a small subset of initial vectors was selected and simulation results were mapped for 100 and 1000 adjacency matrices. Comparing both simulation results, as depicted in Figure 51, shows that no visual distinction could be made between the both patterns. This means that even if the value of single concepts may vary more with higher number of model simulations, the average value of concepts remains similar.

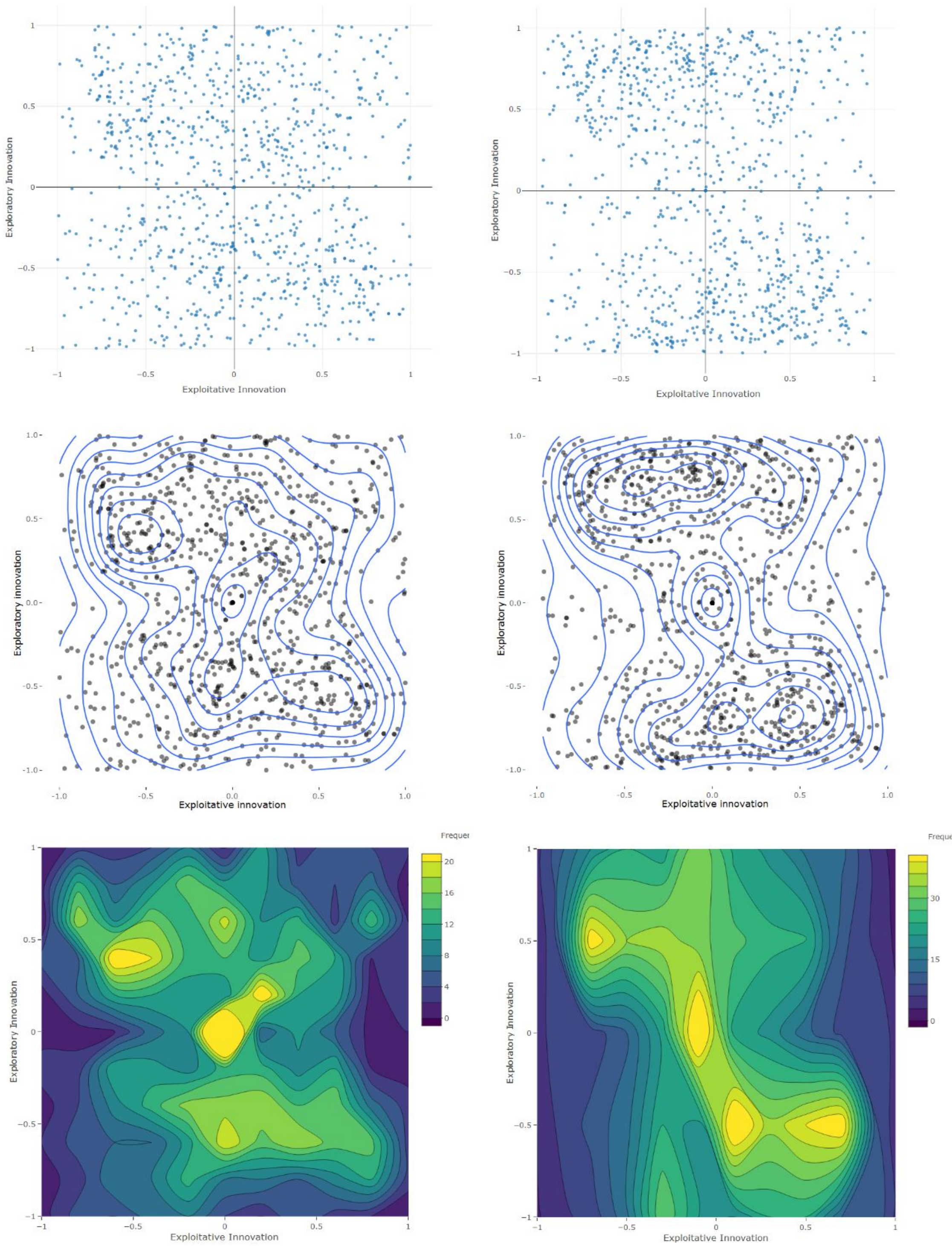

Figure 51- Sensitivity analysis on 1000 initial vectors and 10 adjacency matrices (left column) and the same initial vectors with 1000 adjacency matrices (right column)

6.3.Sensitivity analysis in regard to expected value of activated concepts in initial vectors

The final question was around the sensitivity of the results in regard to the expected value of concepts activated in initial vectors. To examine the difference results of 100 simulations for 20,000 initial vectors with the expected value of 4 activated concepts were compared with 100 simulations for 20,000 initial vectors with expected value of 6 activated concepts. As visually depicted in Figure 52, there is no distinctive change of the pattern among the two sets of simulations. The only observed difference is that as expected the simulation with higher expected value of activated concepts is more crowded.

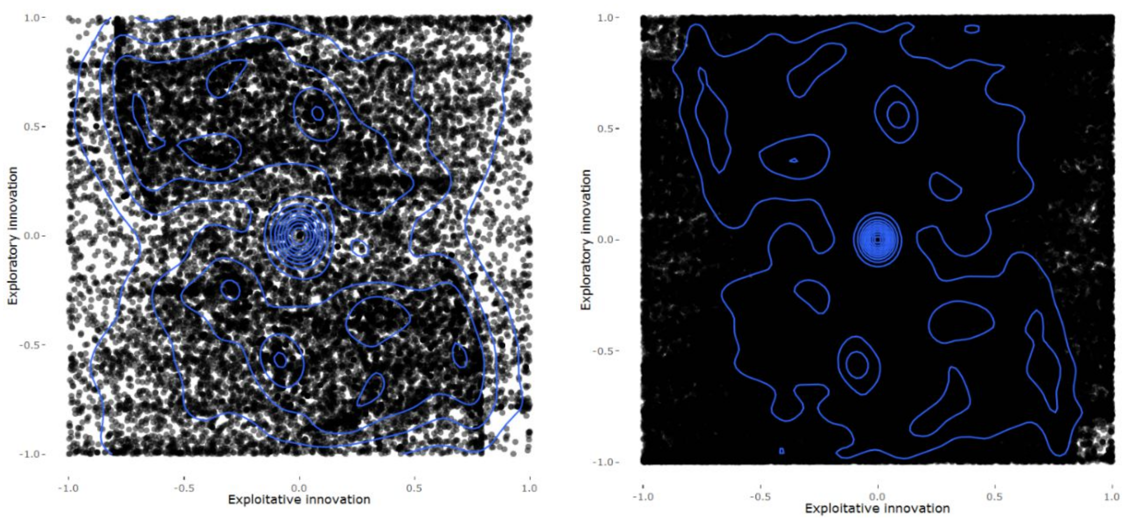

Figure 52-Cluster maps of the simulation for 100 adjacency matrix, 20000 initial vectors with expected value of 4 activated concepts (up) and 6 activated concepts (down)

6.4 Summary of results

Discussions above alongside simulation results provided in chapter 5 attempted to answer these primary research questions:

1) What sets of practices lead to relatively higher exploration, exploitation, or balanced organizational ambidexterity? And, consequently, what prevents them from becoming either innovative or ambidextrous?

2) Are the practices for achieving exploration different from the practices for achieving exploitation?

Yet, this research posed a few more side questions as well:

3) How might theory outside the literature on organizational theory* inform the challenge of reaching organizational ambidexterity? (*: product innovation theory, creativity theory, knowledge management theory, open innovation theory, human resource management theory, and project management theory)

This question was answered by developing a new framework (Figure 1) that shed lights on the gaps in the literature of organizational ambidexterity and provided a guideline on how to find practices to fill the gap from different research streams.

4) What are the factors that may directly or indirectly impact organizational ambidexterity?

After implementing the new framework and an extensive literature review, a list of 366 contributing factors were collected and then were provided in Appendix A- List of concepts in final collective FCM.

5) What is the theoretical framework for a potential decision support system for organizational ambidexterity (and innovation in general)?

This research developed a new method, exploratory fuzzy cognitive mapping, and multiple techniques to reliably capture causal information from texts. These two methods together provided one theoretical framework for an automated system, to guide managers and academic researchers to make more informed decision when it comes to organizational ambidexterity and innovation.

7. Limitations

This work has several limitations, some of which are inherent to the literature on organizational ambidexterity, while others result from the methods used in this work.

7.1 Limitations inherent to the subject matter

Literature uses terms with limited precision as noted by (C. A. O'Reilly and Tushman 2013). In my work I have taken care to work with clearly defined concepts (refer chapter on coding and intercoder reliability), yet it is possible that some of the imprecision in the underlying literature have carried over into the model. Moreover, with the exception of some studies that employ statistical techniques, there are usually no statements that would make it possible to infer the weight of a causal relationship, which is why I have employed EMA. Also, the literature does not take a system view and analyzes and discusses factors largely independent of each other. As a result, there are only few instances in which managerial strategies (i.e. combinations of actions to achieve ambidexterity) are discussed in any detail. Accordingly, it was difficult to determine meaningful input vector that represent real-world managerial approaches. I approached this limitation by running the model for randomly generated input vectors, some of which reflect strategies that no manager would really consider. Moreover, I developed two input scenarios for alternative managerial approaches to open innovation, based on my understanding of the literature and the managerial decision space. This thought experiment, however, may not be fully representative of the courses of action that managers would actually consider.

7.2 Limitations inherent to FCM/EMA

I chose an (almost) algorithmic (though manual) approach to extracting causal relationships from the literature and representing them as FCM because I wanted to lay the groundworks for a future automation of this research step. Moreover, in line with the objective of expanding ambidexterity research into neighboring research fields, I also included a diverse set of sources. The result is a very large model that contains concepts and relationships that were not used for the actual computation (see section 4.4.3), and that nevertheless is computationally so demanding that it is impossible to explore the entire space of possibilities. Moreover, the model is somewhat difficult to understand and interpret by researchers and practitioners, as the difficulties in obtaining expert weights (see Appendix IV) demonstrate. Also, because of the nature of FCM, the model cannot provide any absolute values for outcomes (e.g. the actually degree of ambidexterity) but only a degree of change. Finally, the modelling process and the data analysis was rather time consuming, which may be problematic if the approach is used in practice.

8. Future research

a) Fully automated research text mining. This research took the initial steps toward using FCM as a means for text mining in a semi-automated way. Perfecting this approach to a fully automated extraction of cause-effect relationships, will open the door for using FCM in modeling more complex phenomenon when the input from hundreds or thousands of stakeholders is available in a text format.

b) Crowd sourcing of link weights (i.e. Amazon Mechanical Turk). On top of simulating the whole range of plausible weights for each link, this study also attempted to capture the experts' judgment on the value of these weights. Process to be time consuming and challenging to weigh in even for the field experts. That raises the question of in what circumstances instead of referring to experts, crowd sourcing might provide a faster yet reliable answer to the weighting step in building an FCM. This step will be a complementary piece to earlier suggestion of fully automated text mining using FCM.

c) Usage of the model for participatory modeling in the presence of online sources. Weather in the semi-automated format implemented by current research or in a fully automated format as suggested earlier, this model could be used to create formalized and shared representation of the reality as perceived by even an extreme number of stakeholders in a participatory modeling set up in the presence of online sources.

d) Deeper exploration of ambidextrous scenarios. As part of the answer to what combinations of practices makes an organization ambidextrous, this study found 243 scenarios out of 200,000 randomly generated scenarios that in theory met the requirements. It is likely that some of these scenarios prescribing for a combination of practices that are challenging or even impossible to be implemented concurrently. A more in-depth investigation of each of these combination will be insightful in order to narrow down the scenarios to the one that offer plausible and practically possible combinations.

e) Impact of the method used by managers. Ideally a longitudinal study that investigate the impact of implementation of scenarios to achieve ambidexterity as suggested by current research on real world cases, would provide an immense amount of information on the validity of the findings in this study and our overall understanding reflected in literature of how innovation and organizational ambidexterity could be achieved.

9. Contributions

The main contributions of this work are methodological, yet there are also important theoretical and practical contributions.

9.1. Methodological Contributions

1) First-time integration of Exploratory Modeling and Analysis (EMA) with FCM.

Although exploratory modeling has been adopted in modeling techniques such as system dynamics, optimization algorithms, agent-based modeling and analysis of variance (Jan H. Kwakkel and Pruyt 2013; J. H. Kwakkel, Walker, and Marchau 2010; Agusdinata 2008), this is the first time that FCM is used with an EMA approach. Also there have been very few similar studies so far that used EMA for theory development. A study by (de Haan et al. 2016) follows the same approach.

FCM is a simple yet powerful tool to transform complex qualitative concepts to computable models and joining Exploratory Modeling and Analysis (EMA) with FCM might encourage its use in settings that currently exclusively rely on qualitative research designs. Also, FCM practice benefits from EMA when dealing with qualitative data, and consequently high uncertainty in model structure. EMA is a perfect match for FCM modeling when FCM parameters—and primarily connection weights—are hard to quantify because they rely on subjective judgement or are fuzzy in that they cover a range rather than a point.

2) Expanding FCM technique.

In order to achieve the integration of EMA and FCM, this research has made multiple contributions to FCM modeling: It developed approaches for content analysis which were published separately (Alizadeh and Jetter 2017), see Appendix 6. The methodological guideline resulting from this work describes how to extract causal relationships from a given text and represent the relationship in a fuzzy cognitive map. It covers the necessary steps for developing a raw FCM from original text, for dealing with duplications and inconsistencies, and for tuning the granularity of the map in case of parent-children concepts. Finally, two new techniques; Isolated-Graph Analysis (IGA), and Receiver-Only-Concepts Analysis (ROCA) were developed to identify and fill the gaps when finalizing an FCM.

These methodological improvements will make it easier for other researchers to develop FCM based on text, such as interviews or published research, and do so in a consistent, repeatable, and reliable manner. This should increase the appeal of FCM as technique for qualitative researchers to support analysis, hypothesis building, and learning about the system under study. For system modelers, these techniques can broaden the data sources that are used to inform models.

3) A semi-automated approach for learning from text using FCM

Doing this research, I made a strategic choice to build FCM from text in an almost algorithmic way that only minimally relies on the modelers' understanding and judgement of the underlying texts. I am estimating that such an approach reduces subjectivity, and, more importantly, provides a path for developing sophisticated automated methods for model building, that rely on big data and artificial intelligence. Such developments, which are beginning to emerge (Mueller 2015), could make it possible to create models about complex social systems based on many more sources than is commonly done today. Among others, such technologies could be used to increase stakeholder participation by extracting models from online conversations, forums, etc.

4) New, open-source software code

The methodological innovations undertaken in this research go hand-in-hand with the development of new software code. A new package called *XploratoryFCM* was developed based R language that is accessible for public use in the following address:

https://github.com/yasseralizadeh/XploratoryFCM

The package performs FCM calculations, generates unlimited number of random adjacency matrices in the case of exploratory modeling, generates all the permutations required for initial vectors, compute the FCM for all the adjacency matrices and initial vectors, compute average value and robustness of each concept and finally provides tools for filtering and visualization of the simulation results.

9.2. Theoretical Contributions

5) ***Meta review and expanded boundaries of the organizational ambidexterity theory.***

The literature on organizational ambidexterity has seen a large increase in publications but has also been criticized for applying the ambidexterity concept too broadly, while losing its focus on technology innovation and the inherent conflict of pursuing competing goals. O'Reily and Tushman identify (C. A. O'Reilly and Tushman 2013) several areas that require more research, including the role of leadership behaviors in achieving ambidexterity, the impacts of organizational culture and identity, and the influence of open innovation communities outside the incumbent firm, which they expect to increase the ability for ambidextrous innovation. None of these questions are currently considered in the literature on ambidexterity. By developing a framework that represents the core concepts of organizational ambidexterity but also bridges to related fields of study, namely knowledge management, human resource management, project management, product innovation, open innovation and distributed innovation theories, this work provides a meta review of the pertinent literature and an expansion of ambidexterity research.

6) System Model as a platform for theoretical examination of existing hypotheses as well as formulating new ones.

In the literature on organizational ambidexterity, most of which is listed in Table 1, the use statistical techniques and primarily regression analysis dominates. These techniques are used to examine and develop new or existing hypotheses. Their use is perfectly justified when a limited number of concepts and their relationships are the interest of the study but it becomes significantly challenging to apply them when interdependencies among many concepts need to be explored. In these cases, system modeling provides an unparalleled advantage and has, in fact, been used to study topics like diffusion of innovation, or adoption of technology (Maier 1998; Wu et al. 2010; Baldwin and Von Hippel 2011). However, no studies have used system modeling in the context of organizational ambidexterity

The model developed in this research provides opportunities for other researchers in the field of innovation and organizational theory to further examine and study the existing hypotheses and develop new ones. The usefulness of the model as means to explore new hypothesis was illustrated for the case of open innovation, as discussed below.

7) New insights into the role of open and distributed innovation on organizational ambidexterity

The model developed in current research could be used in order to examine the consistency of a wide range of new hypotheses with the collective knowledge as reflected in the literature of innovation and ambidexterity. This approach was used to study the effect of practicing open and distributed innovation on achieving organizational ambidexterity. This was inspired by (C. A. O'Reilly and Tushman 2013) that "further research could ……explore the impact of distributed innovation on incumbents."

Practices associated with open and distributed innovation were fed into the simulation as initial vectors and as explained in section Simulation results5.6, while an increase in the value of the exploitative innovation was observed, the value of exploratory innovation remained unchanged. Thus, based on the developed FCM model, no evidence was found that practicing open or distributed innovation could help an organization to achieve ambidexterity.

8) Estimation of the difficulty of achieving organizational ambidexterity

Although moving toward ambidexterity has been encouraged in the literature, to this date, no research gave any metric on how easy or difficult it is to achieve the true ambidexterity. However current study an insight for the first time; only 0.1% (243 scenarios out of 200,000) showed to robustly lead to a high level of ambidexterity. By definition in order to be highly ambidextrous, an organization needs to excel in both types of innovation that by finding of this research is very unlikely to happen by chance.

9) Identification of the high leverage factors for achieving ambidexterity. Finding combinations of practices that lead to higher exploratory innovation or, exploitative innovation or both, in case of ambidexterity, also was insightful in identifying practices that appear more frequently in these different scenarios. As discussed in 5.6, most frequent practices in scenarios leading ambidexterity found to be generally different than the most frequent practices leading to a single type of innovation, exploratory or exploitative.

9.3. Managerial Implications

10) Supporting managerial decision making

Although a decision support system (DSS) or similar software package was not intended to be developed as part of this research, it covers the theoretical bases for such a system in the near future. Already today, the model can be used to "test drive" different managerial strategies to see how managerial actions will impact exploration, exploitation, and both. Managers can use this to understand their organization's current ambidexterity and the resulting long-term performance, given currently existing conditions. They can also use this to identify courses of action that will improve ambidexterity and exclude those that will not have the desired impacts. Moreover, working with such a tool may also help managers to appreciate the complexity of the system they are trying to impact, thus improving their internal (mental) models of the subject matter. Leadership is likely very important in achieving the daily balancing act between exploration and exploitation and having more leaders who understand how their actions impact the system, can lead to improvements. A successful commercial DSS packages developed based on this study, should hopefully help more managers to lead their organizations toward innovation and long-term higher financial performance

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Appendix A- List of concepts in final collective FCM

Table 11- Table of concepts in collective FCM and their category based on the proposed ambidexterity framework

Concept	*Category*
Effective project evaluations	C
Establishing an evaluation and reward system based on group performance	C
Performance	C
Incentive-based payment (i.e. performance-based)	C
high-performance work system] HPWS	C
Performance management context	C
Project performance	C
Emphasize on appropriate actions	C
Cost	C
Product development efficiency	C
Exploitative learning	C
Exploratory learning	C
Team learning	C
Innovativeness	C
Financial performance	C
Short-term performance [for older firms]	C
Financial outcome [in a high-growth industry]	C
Firm growth	C
Organizational learning	C
Effective [exploration] project Management [in large construction projects]	C
OC [organic control]	C
MC [mechanistic control]	C
Simultaneous learning	C
Performance-related pay	C
Innovation performance	C
Return on R&D [investment]	C
Innovation impact	C
GERT [Graphical Evaluation & Review Technique]	C
PERT/CPM [techniques]	C

Concept	*Category*
Risk assessment techniques	C
Linear and mechanical evaluation mechanisms	C
Premature application of traditional evaluation techniques	C
Evaluating projects according to predetermined efficiency criteria	C
Loosening up of evaluation criteria	C
Focus on broad, global outcomes supported by a strong business vision	C
Micro-management	C
Evaluating methods emphasizing linearity, efficiency and control	C
Pressures on time	C
Efficiency driven management	C
Frequent milestones	C
R&D expenditure	C
Development cost [in case of radical innovations]	C
Product Superiority [In case of radical innovation]	C
Rework [in extremely uncertain projects]	C
Development time [in incremental innovation projects]	C
Development Cost [in case of incremental innovations]	C
Development time [In case of radical innovation]	C
Performance of Multitasking R&D individual	C
Costs of coordinating, controlling, and supervising employees	C
Firm quality performance	C
Originality	C
Abstractness of titles	C
Fluency	C
Novel projects	C
Innovative new product	C
Self-transcendence	H
Selecting the right people	H
Non-expert team members	H
Significant resources	H
Extrinsically motivated individuals	H
Including outsiders	H
Credibility	H
Individual R&D performance	H
Cognitive flexibility	H
Cognitive closure	H
Creative thinking skills	H

Concept	*Category*
Domain-relevant skills	H
Intrinsic motivation	H
Openness to new ideas	H
Variety [of work]	H
Expertise	H
Extrinsic motivation	H
Diversely skilled members	H
Communication while providing constructive challenge	H
Complexity	H
Feedback	H
Organizational creativity	H
Idea Generation Techniques (Idea marathon, Creative brainstorming, divergent-convergent thinking, TRIZ, idea logging, Blue Sky Projects)	H
Individual creativity	H
Creative Group Practices (help giving, help seeking, reflective reframing, and reinforcing)	H
Systems for collection of employee proposals	H
Planned job rotation	H
Firm-internal [training]	H
Firm-external training	H
Invest in training programs	H
Compensation for knowledge sharing	H
Staffing premium workers	H
Performance appraisal	H
Openness	H
Seniority-based [management]	H
Self directed responsibility and freedom	H
Project leaders	H
teams of specialists assemble [and] share knowledge	H
knowledge transfer and learning within the company	H
Intrinsically motivated individuals	H
KM Practices including HR and IT focused on organizational learning and knowledge management)	H
KM Practices including IT focused on technological advancements)	H
IT focused on quality and productivity	H
KM Practices (HRM focused on product and process innovation)	H
Entrepreneurial individuals	H
Tacit accumulated knowledge incarnated in individuals	H
inter-firm personnel inflow	H

Concept	*Category*
Local personnel inflow	H
Practice of rotating R&D personnel	H
Diversity of background	H
Diverse resource allocation	H
[Effective management of] projects in the discovery phase of R&D	H
Managers' entrepreneurial orientation	H
Emergence of new ideas	H
Manage routine project modules	H
Learning synergies	H
Contingency rewards	H
Explicit accumulated knowledge	H
Socialization and externalization	H
Combination and internalization [of knowledge]	H
Self-organizing project teams	O
Multilearning	O
Built-in instability [culture]	O
Organizational transfer of learning	O
Speed and flexibility	O
Autonomy	O
Cross-fertilization	O
Managing the differences in rhythm throughout the development process	O
Tolerating and anticipating mistakes	O
Creating an open work environment	O
Senior management commitment	O
Project team approach	O
[Successful] stage-gate approach	O
Concurrent Engineering (CE)	O
Iterative and dynamic process of trial and error.	O
Flexibility [in novel projects]	O
Structural characteristics	O
Leadership characteristics	O
Alignment	O
Adaptability	O
Social context	O
Organizational context	O
Contextual ambidexterity	O
Punctuated equilibrium	O

Concept	*Category*
Internal rivalry	O
Stretch	O
Discipline	O
Support	O
Trust	O
Risk of failures	O
Ambidextrous organizational culture (i.e. diversity and shared vision)	O
Leadercenteric teams	O
Interactions between the team leader and team members	O
Interactions among team members [advocates of the existing product and the innovation]	O
Centralization of decision making	O
[Collective] decision making	O
Teamcenteric teams	O
Structural differentiation	O
Formalization	O
Connectedness	O
Informal coordination mechanisms	O
Information-processing efficiency	O
Top-down knowledge inflows	O
Communication	O
Rules and procedures	O
Agile development	O
Bottom-up knowledge inflows	O
Horizontal knowledge inflows	O
Effective dedicated team	O
Risk taking	O
Separating exploring and exploiting roles	O
Organizational slack	O
Firm size	O
Technological competence	O
Multitasking	O
Specialization	O
Coordination	O
Perceived competitive intensity positively	O
Horizontal inflows of knowledge	O
Interpersonal trust	O
Commitment to the work	O

Concept	*Category*
Interdisciplinary workgroup	O
Quality circles	O
Delegation of responsibility	O
Integration of functions	O
Knowledge management capacity	O
Absorptive capacity	O
Opportunities of participation	O
Single unit [structure]	O
Interdisciplinary design and integration	O
Heavyweight project leaders	O
Linear approach [imposed by] stage-gate models	O
Centralization of authority	O
Organic approaches including informal communication	O
Organic approaches including free flow of knowledge within projects	O
Organic approaches including organisation by mutual adjustment	O
Organic approaches including establishing loose authority relations	O
Organic approaches including making extensive use of matrix structures and boundary spanners	O
Project based [organization]	O
Multidisciplinary teams	O
Senior management support	O
Parallel trials	O
Project-based firms	O
Specialized teams	O
Strategic direction and a vision	O
Empowering project managers to reassess the situation repeatedly	O
Bottom-up communication	O
High dependency on top management [for decision making]	O
Coordinate individuals	O
Top-down communication mode	O
Middle-up-down communication	O
Self organizing	O
Hierarchical organization	O
Flexible R&D management	O
Complementary tactics (Such as integration or differentiation)	O
Cross-functional interfaces	O
Senior team social integration	O

Concept	*Category*
Multilevel approach	O
[Risk taking culture]	O
Communication [in extremely uncertain projects]	O
Integration [in extremely uncertain projects]	O
Integration	O
Resistance to premature closure	O
Voluntary new product development	O
Early shutting down of [innovation] projects	O
Innovation cycle time	O
Structure [in uncertain and turbulence situation]	O
Collaboration	O
Manage highly uncertain project	O
[project management] PM success	O
Decisions by top management	O
Overlapping development phases	P
Under-resourced execution	P
A lack of market orientation	P
Inadequate market assessment	P
Proper allocation of development resources	P
A visible road map	P
Explorative innovation strategies	P
Exploitative innovation strategies	P
Improve Existing product quality	P
Improve production cost	P
Improve yield (Performance)	P
Introduce new generation of products	P
Extend Product Range	P
Open up new markets	P
Enter new technology fields	P
Identifying distinct role and decision makers	P
Explorative search beyond firm boundaries	P
Explorative search beyond technological domains	P
Incremental new product	P
Duration of a temporal overlap between an exploitation process and an exploration process	P
Experimentation and ad hoc problem solving efforts	P
Learning achievement goal	P
Performance achievement goal	P
Product novelty	P

Concept	*Category*
Product usefulness	P
Exploit solutions the company has developed	P
redundancy and slack	P
Flexibility of time	P
[Project management] planning	P
Emphasis on complete system definition before entering development	P
[Linear] phased approach (i.e. waterfall models and stage-gate)	P
Design iteration	P
Flexible planning	P
Initially hypothesized and the evolving [plan] details	P
Diagnose the uncertainty profile of the project	P
Standard phased approach	P
Recursive [approach]	P
Evolving [approach]	P
Selectionism [approach]	P
Linear [project management approach i.e. Stage-gate]	P
Significant improvement products	P
Pursuit of push-the-envelope domains	P
Product innovation	P
Process innovation	P
High-quality decisions [In Leadercenteric team]	P
Problem solving ideas	P
Stimulating growth	P
Projects with clear goals	P
Contractors risks of innovation	X
Encouraging suppliers to become self organizing	X
Encouraging engineers to go out into the field and listen to what customers and dealers have to say	X
R&D spending intensity	X
Involvement of suppliers in design activities	X
Open innovation	X
Cooperative procurement procedures (including joint specification, partner selection based on multiple criteria, incentive-based payment, and collaborative tools)	X
Collaborative tools (i.e. developing joint objectives, performing teambuilding activities, joint IT-tools, joint risk management)	X
Intraorganizational exploitation and exploration	X

Concept	Category
Relationship learning	X
Power asymmetry	X
Inter-firm collaboration	X
Technological volatility	X
exploitation and exploration between the organizations	X
Exploitation alliances	X
Interaction effect between contextual ambidexterity and external rivalry	X
Financial distress	X
R&D alliances	X
Science intensity	X
External resource access	X
Exploration alliances	X
Number of equitybased exploration alliances	X
Number of nonequitybased exploration alliances	X
MO [market orientation]	X
Interaction effect between contextual ambidexterity and internal rivalry	X
Outsourcing research	X
External linkage of firms	X
Upstream [external] linkages	X
Free revealing of proprietary innovations	X
Patent protection	X
Selling or licensing dormant technologies	X
Number of outside sourcing	X
Vertical cooperation [supplier, client]	X
licensing agreements (in and out)	X
Non-equity alliances	X
Technological progress [among rivals]	X
Collective research centres	X
Knowledge spillovers	X
Partner diversity	X
Alliance or network approach	X
Geographic [proximity]	X
Horizontal alliances between rivals	X
Vertical alliances between suppliers	X
Co-creation	X
Alliance and the construction of networks	X
Acquiring	X

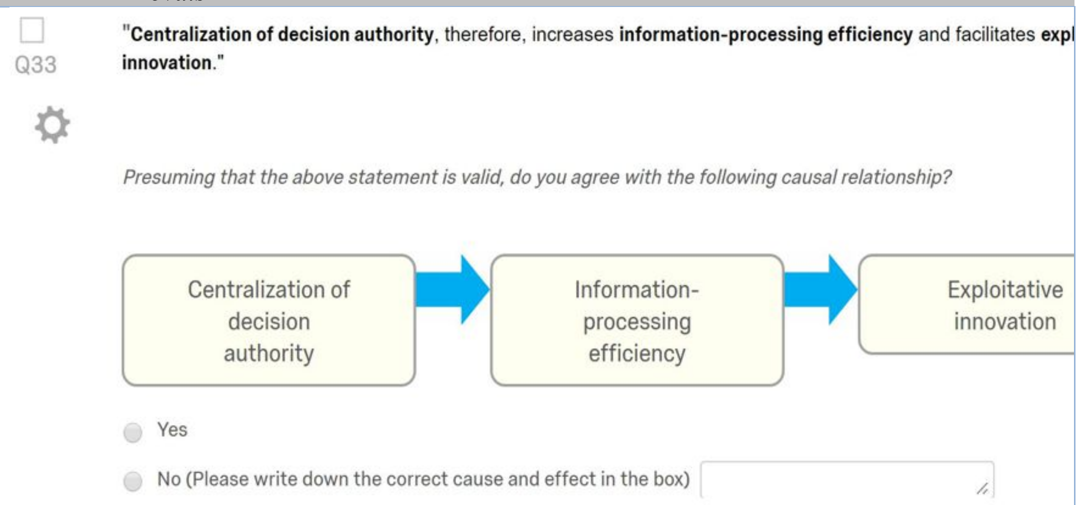
Concept	Category
Collaboration with outside players	X
Inertia in collaborations overtime	X
[Empowering] competitors	X
Distance of the outside technology to the company's knowledge domain [when acquiring]	X
[Collaboration with] suppliers	X
[Collaboration with] customers or users	X
Intellectual property (i.e. publications, patents, donations)	X
[Collaboration with] competitors	X
[Collaboration with] universities	X
Outsourcing of innovation [to research institutes, government labs and universities]	X
knowledge transfer and learning with other partner organizations	X
Fixed-price contracts	X
Cost-plus-fixed-fee contracts	X
Cross-boarder personnel inflow	X
Ease of learnings from spill overs	X
Competitive advantage	X
Number of alliances	X
Product innovation intensity	X
Stability and predictability	X
Net gain in private profit for the innovator	X
Organizational ambidexterity	N/A
Exploratory Innovation	N/A
Exploitative innovations	N/A
Innovation	N/A
Knowledge and innovation	N/A
Innovative performance	N/A
Firm retention	N/A
Innovation [in case of project-based firms]	N/A
Innovation rates	N/A
[Effective management of] projects nearing commercialization	
Interactive effect of exploitative learning and exploratory learning	N/A
[Effective] new product development	N/A
Financial performance [in dynamic environments]	N/A
Strategic performance	N/A
Firm efficiency [for defenders at high level of competitive intensity]	N/A

Concept	Category
Firm efficiency [for prospectors at high level of competitive intensity]	N/A
Short-term performance [for younger firms]	N/A
Financial outcome [in a low-growth industry]	N/A
Organizational longevity	N/A
Firm performance [for prospectors]	N/A
Firm performance [for defenders]	N/A
Ambidexterity [in SMEs]	N/A
Firm valuation	N/A
New product innovation outcomes	N/A
Exploitation	N/A
Exploration	N/A
Value	N/A
Accelerate development [of technology at industry level]	N/A
Innovation [in uncertain and turbulence situation]	N/A
Performance of innovation projects [in case of project-based firms]	N/A
Performance of innovation projects [in case of non project-based firms]	N/A

Appendix B- Inter-coder reliability survey results

Table 12- Inter-coder reliability survey results

Q	*Number of Approvals vs Disapprovals*	*Reviewer's reasoning for disagreement*	*Action taken by the researcher*


Q33

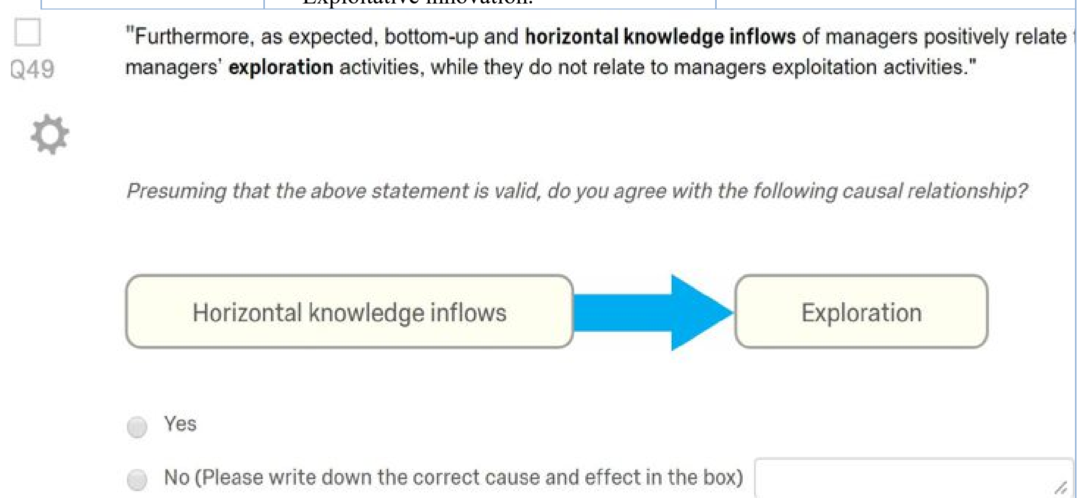
"**Centralization of decision authority**, therefore, increases **information-processing efficiency** and facilitates **expl** **innovation**."

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

33	1 Y, 1 No	Centralization of decision authority & gt; Information-processing efficiency & centralization of decision authority & gt; Exploitative innovation.	Despite one agreement and one disagreement, I moved forward with accepting this.


Q49

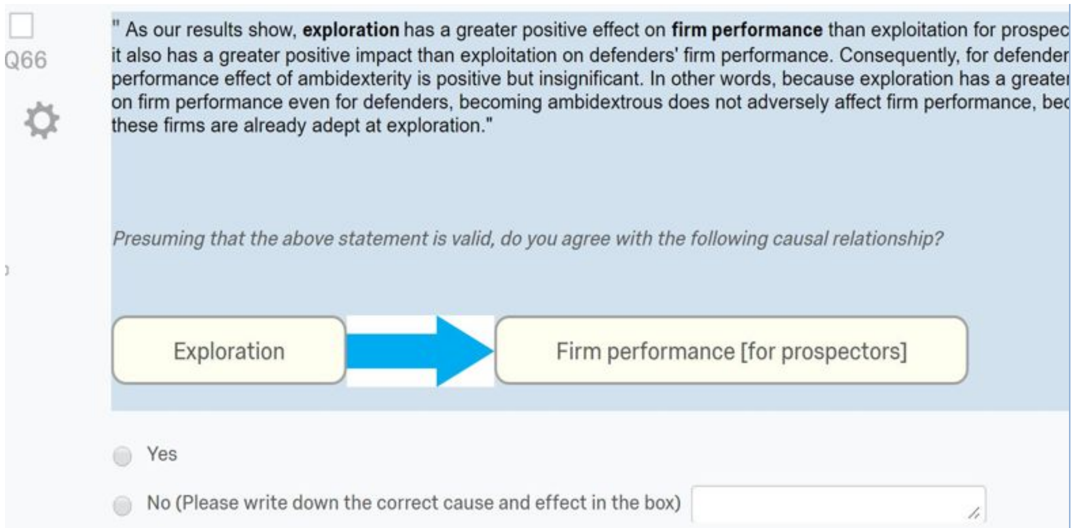
"Furthermore, as expected, bottom-up and **horizontal knowledge inflows** of managers positively relate managers' **exploration** activities, while they do not relate to managers exploitation activities."

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

49	1 Y, 1 No	It is mentioned "relate to these managers' exploration activities'. It is not clear what is the direction of causation. This relation might be in the opposite direction meaning: Exploration --> Horizontal K	Although the comment is acceptable, based on researcher's judgment this direction of the causality is proposed to be included in the test


Q66

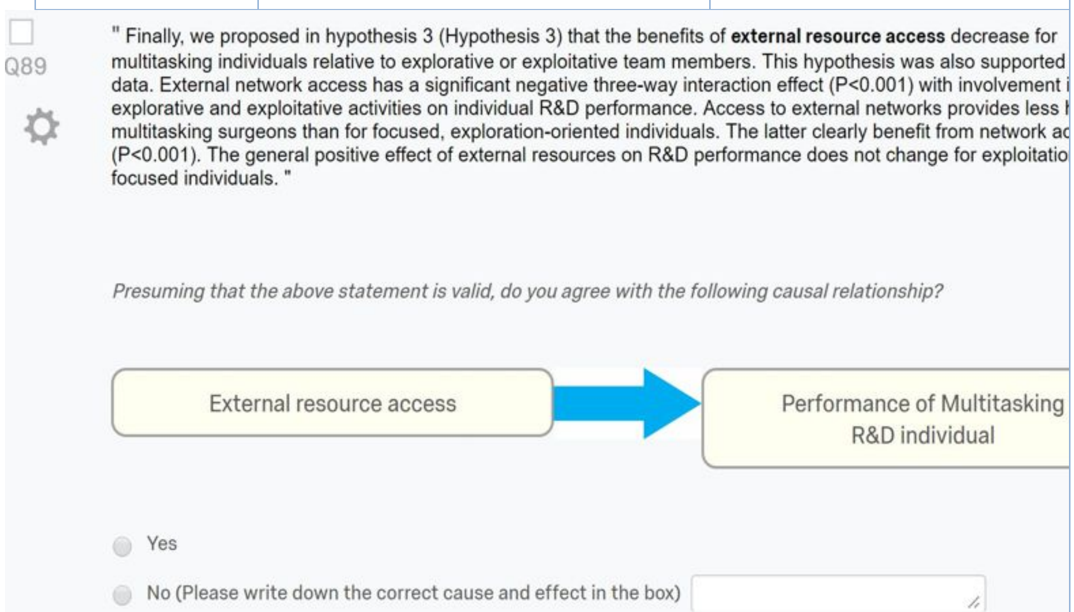
" As our results show, **exploration** has a greater positive effect on **firm performance** than exploitation for prospec
it also has a greater positive impact than exploitation on defenders' firm performance. Consequently, for defender
performance effect of ambidexterity is positive but insignificant. In other words, because exploration has a greate
on firm performance even for defenders, becoming ambidextrous does not adversely affect firm performance, bec
these firms are already adept at exploration."

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

6	1 No	Maybe not really connected.	Objection is not acceptable. Researcher moves forward with the suggested assumption


Q89

" Finally, we proposed in hypothesis 3 (Hypothesis 3) that the benefits of **external resource access** decrease for
multitasking individuals relative to explorative or exploitative team members. This hypothesis was also supported
data. External network access has a significant negative three-way interaction effect (P<0.001) with involvement i
explorative and exploitative activities on individual R&D performance. Access to external networks provides less l
multitasking surgeons than for focused, exploration-oriented individuals. The latter clearly benefit from network ac
(P<0.001). The general positive effect of external resources on R&D performance does not change for exploitatio
focused individuals. "

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

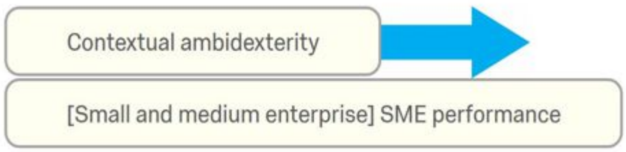
No (Please write down the correct cause and effect in the box)

8	1 No	There is an inverted negative correlation for sure, but if the relationship is spurious, there is no causation.	Despite the objection, based on the text researcher still moves forward with the proposed causality

Q126

" Model 2 showed no significant relationship between **contextual ambidexterity** and **[small and medium enterpri performance."**

Presuming that the above statement is valid, do you agree with the following causal relationship?



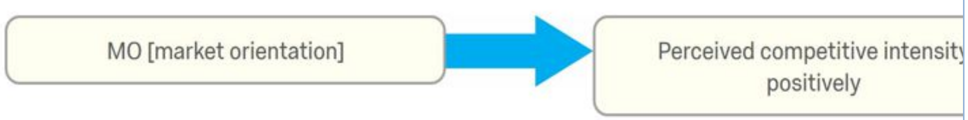
- Yes
- No (Please write down the correct cause and effect in the box)

126	1 Y, 1 No	The statement does not imply a (positive or negative) causality.	Objection is accepted

Q134

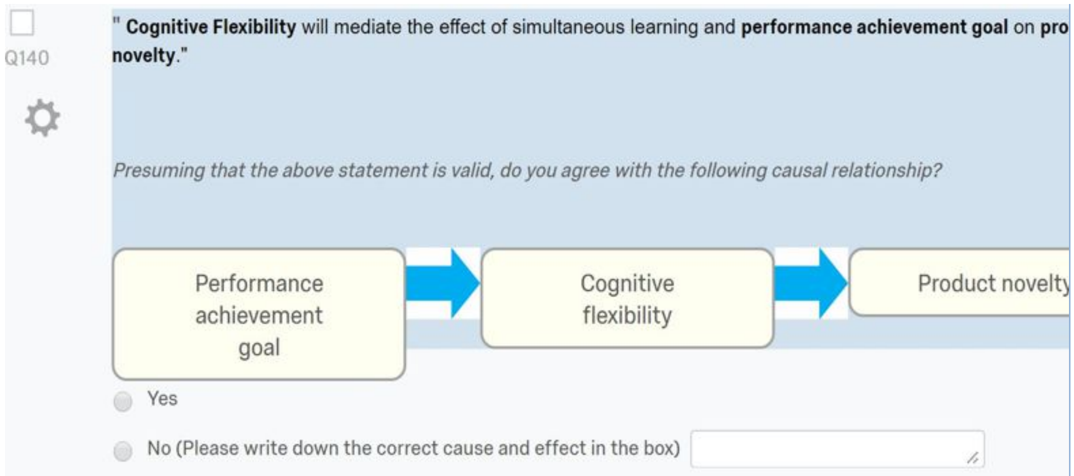
" H3a proposes that **perceived competitive intensity positively** moderates the relationship between **MO [market orientation]** and degree of exploitation activities in SMEs. The result of moderated regression analysis in Table 3 (3) shows a statistically significant but negative regression coefficient (B=−0.32, Pb0.05)."

Presuming that the above statement is valid, do you agree with the following causal relationship?



- Yes
- No (Please write down the correct cause and effect in the box)

134	1 No	I think the direction of arrow should be reversed.	Comment is valid since the text does not explicitly expressed the direction of causality, but researcher based on context moves forward with proposed direction


Q140

" **Cognitive Flexibility** will mediate the effect of simultaneous learning and **performance achievement goal** on **pro**
novelty."

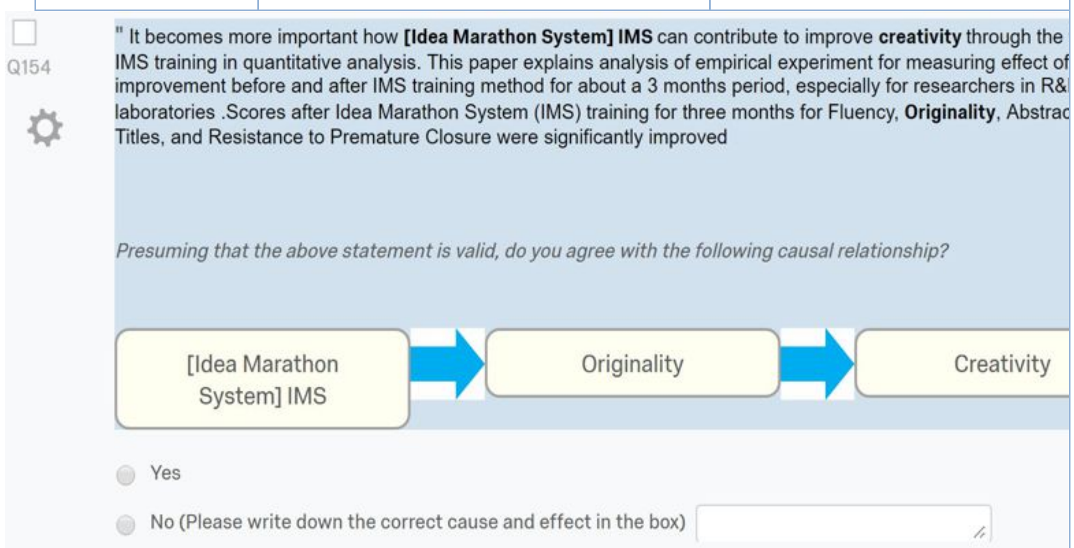
Presuming that the above statement is valid, do you agree with the following causal relationship?

Performance achievement goal → Cognitive flexibility → Product novelty

Yes

No (Please write down the correct cause and effect in the box)

1	1 Y, 1 No	Cognitive flexibility --& gt; performance achievement goal (on product novelty)	1 objection is not acceptable


Q154

" It becomes more important how **[Idea Marathon System] IMS** can contribute to improve **creativity** through the IMS training in quantitative analysis. This paper explains analysis of empirical experiment for measuring effect of improvement before and after IMS training method for about a 3 months period, especially for researchers in R&
laboratories .Scores after Idea Marathon System (IMS) training for three months for Fluency, **Originality**, Abstrac
Titles, and Resistance to Premature Closure were significantly improved

Presuming that the above statement is valid, do you agree with the following causal relationship?

[Idea Marathon System] IMS → Originality → Creativity

Yes

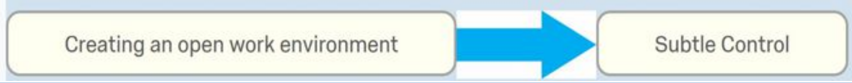
No (Please write down the correct cause and effect in the box)

1	1 No	IMS-> Creativity-> Originality	Objection is partially accepted. Relationship will be revised to IMS causes creativity and that changes originality as a something that could be measured to indicate the change in creativity

Q179

Subtle control is exercised in the new product development process in seven ways:
1) Selecting the right people for the project team while monitoring shifts in group dynamics and adding or dropping members when necessary. We would add an older and more conservative member to the team should the balance shift too much toward radicalism, said a Honda executive. "We carefully pick the project members after long deliberation. We analyze the different personalities to see if they would get along. Most people do get along, thanks to our common set o values."
2) **Creating an open work environment**, as in the case of Fuji-Xerox.
3) Encouraging engineers to go out into the field and listen to what customers and dealers have to say. A design engineer may be tempted to take the easy way out at times, but may reflect on what the customer had to say and try t find some way of meeting that requirement," noted an engineer from Fuji-Xerox.
4) Establishing an evaluation and reward system based on group performance. Canon, for example, applied for patents for products from the PC-10 project on a group basis.
5) Managing the differences in rhythm throughout the development process. As mentioned earlier, the rhythm is most vigorous in the early phases and tapers off toward the end.
6) Tolerating and anticipating mistakes. Engineers at Honda are fond of saying that a 1% success rate is supported by mistakes made 99% of the time."A Brother executive in charge of R&D said, "It's natural for young engineers to make a lot of mistakes. The key lies in finding the mistakes early and taking steps to correct them immediately. We've taken steps to expedite the trial production cycle for that reason." A 3M executive noted, "I believe we learn more from mistakes than from successes. That's not to say we should make mistakes easily. But if we do make mistakes, we ough to make them creatively."
7) Encouraging suppliers to become self-organizing. Involving them early during design is a step in the right direction. But the project team should refrain from telling suppliers what to do. As Xerox recently found out, suppliers produce better results when they have the problem explained to them and are allowed to decide how to furnish the parts. "

Presuming that the above statement is valid, do you agree with the following causal relationship?



129	1 Y, 1 No	It is just mentioned Subtle Control is exercised in 'Creating an open work environment'. There is no relation.	Objection is accepted, the FCM would be changed to consider the creating an open work environment as child of Subtle control

Q180

" Subtle control is exercised in the new product development process in seven ways:
1) Selecting the right people for the project team while monitoring shifts in group dynamics and adding or droppi members when necessary. We would add an older and more conservative member to the team should the balan too much toward radicalism,"" said a Honda executive. ""We carefully pick the project members after long delibe We analyze the different personalities to see if they would get along. Most people do get along, thanks to our co of values.
2) Creating an open work environment, as in the case of Fuji-Xerox.
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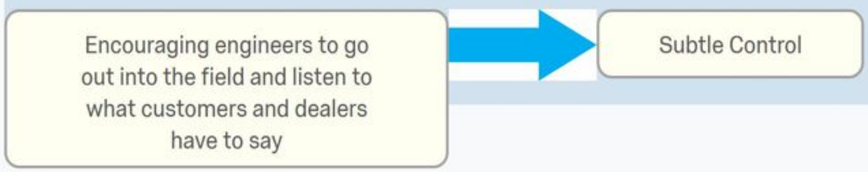
Presuming that the above statement is valid, do you agree with the following causal relationship?



Yes

No (Please write down the correct cause and effect in the box)

I	1 Y, 1 No	No relation.	Objection is accepted, the FCM would be changed to consider the "Encouraging engineers' as child of Subtle control

Q204

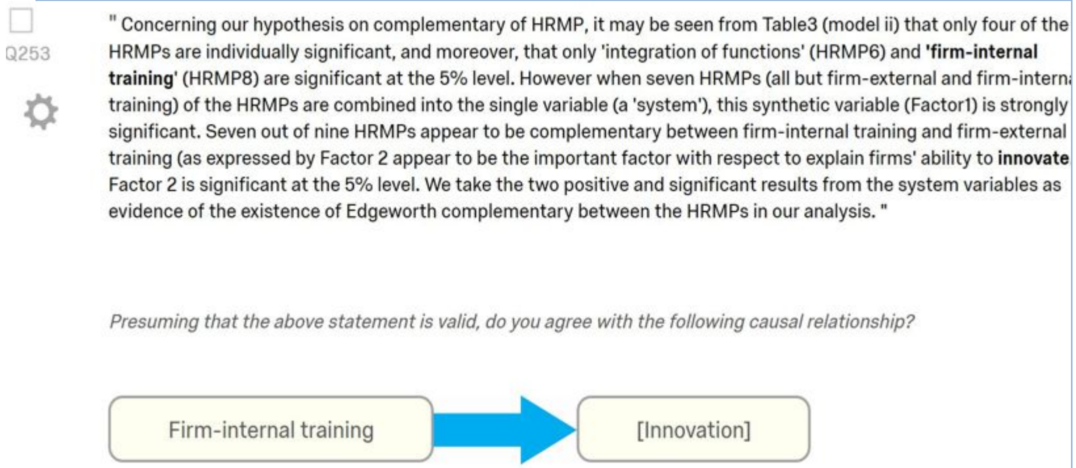
"These results are in line with the most supported trend of studies on this topic and reinforce the idea that **[conc engineering] CE** has serious limitations in conditions of extreme uncertainty. In accordance with the arguments s in such research, in situations where changes are neither predictable nor can be kept under control, concurrence generate large problems of communication, integration and **rework**. These inevitably lead to considerable reproc to a greater probability of errors, to chaos in management and, in short, to inefficiency, which ends up converting positive results derived from CE into negative results or penalties, rendering its use inappropriate. "

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

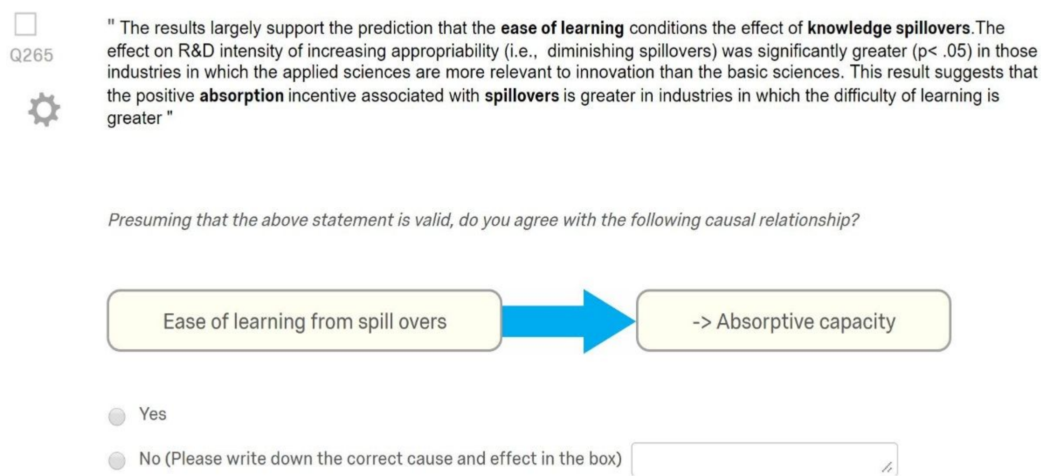
2	Blank		No argument is provided for acceptance or rejection, therefore researcher moves forward with the provided causality


Q253

" Concerning our hypothesis on complementary of HRMP, it may be seen from Table3 (model ii) that only four of the HRMPs are individually significant, and moreover, that only 'integration of functions' (HRMP6) and **'firm-internal training'** (HRMP8) are significant at the 5% level. However when seven HRMPs (all but firm-external and firm-intern training) of the HRMPs are combined into the single variable (a 'system'), this synthetic variable (Factor1) is strongly significant. Seven out of nine HRMPs appear to be complementary between firm-internal training and firm-external training (as expressed by Factor 2 appear to be the important factor with respect to explain firms' ability to **innovate** Factor 2 is significant at the 5% level. We take the two positive and significant results from the system variables as evidence of the existence of Edgeworth complementary between the HRMPs in our analysis. "

Presuming that the above statement is valid, do you agree with the following causal relationship?

2	Blank		No argument is provided for acceptance or rejection, therefore researcher moves forward with the provided causality


Q265

" The results largely support the prediction that the **ease of learning** conditions the effect of **knowledge spillovers**.The effect on R&D intensity of increasing appropriability (i.e., diminishing spillovers) was significantly greater (p< .05) in those industries in which the applied sciences are more relevant to innovation than the basic sciences. This result suggests that the positive **absorption** incentive associated with **spillovers** is greater in industries in which the difficulty of learning is greater "

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

2	1 No	I think the text convey positive relation between these two. And also the strength of this positive relation will be higher in case of industries with higher difficulty of learning.	Objection, is acceptable, direction of causality remain the same but the sign will be corrected

Q276

" We carried out interviews in a financial services firm to investigate the management of innovation projects and the context within which they are carried out. This illustration also points to attempts to control the **innovation** process by imposing **linear and mechanical evaluation mechanisms**, but one that has proven less successful, resulting in the org management of innovation by stealth.

Presuming that the above statement is valid, do you agree with the following causal relationship?

Yes

No (Please write down the correct cause and effect in the box)

276	1 No	Not sure	No argument is provided for acceptance or rejection, therefore researcher moves forward with the provided causality

Q327

" Second, starting in 1963, the [department of defense] DoD switched from **cost-plus-fixed-fee** to fixed-price contracts that increased the contractors' responsibility in achieving project objectives. This decision was rather controversial as it greatly increased the paperwork and legal disputes around contract definition. Moreover, it shifted the **risks associated with innovation to the contractors**, which further discouraged the **pursuit of "push-the-envelope" domains**. It helped to cement the McNamara Revolution, which emphasized project plannability and control, and centralized decision making. "

Presuming that the above statement is valid, do you agree with the following causal relationship?

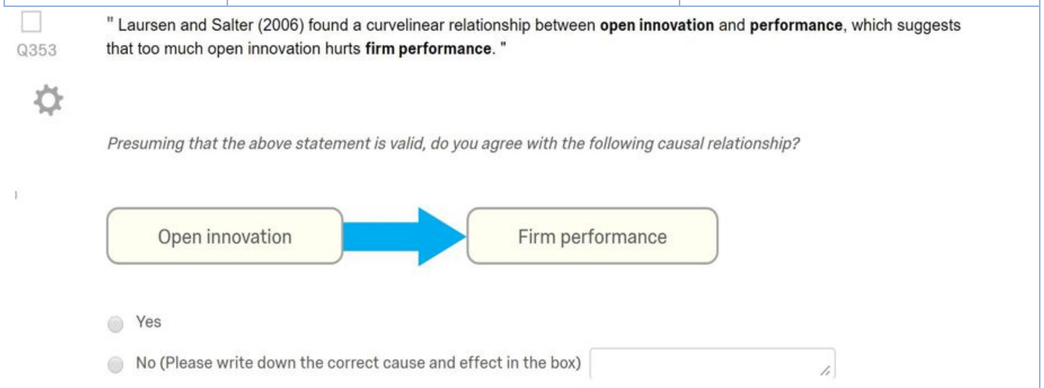
327	Blank		Although researcher agrees that no explicit causality is expressed in the text, based on the context researcher moves forward with the proposed causality

Q327

" Second, starting in 1963, the [department of defense] DoD switched from **cost-plus-fixed-fee** to fixed-price contracts that increased the contractors' responsibility in achieving project objectives. This decision was rather controversial as it greatly increased the paperwork and legal disputes around contract definition. Moreover, it shifted the **risks associated with innovation to the contractors**, which further discouraged the **pursuit of "push-the-envelope" domains**. It helped to cement the McNamara Revolution, which emphasized project plannability and control, and centralized decision making. "

Presuming that the above statement is valid, do you agree with the following causal relationship?

3	1 No	Maybe innovation-related performance is only one kind of innovation for firms.	Objection is not acceptable. Researcher moves forward with the suggested assumption



3	1 Y, 1 No	Alliance and the construction of networks is a specific type of "Incorporating external knowledge"	Objection is accepted, the FCM would be changed to consider the "Alliance and the .." as child of incorporating external knowledge

Appendix C- Content Analysis using Fuzzy Cognitive Map (FCM)

Content Analysis using Fuzzy Cognitive Map (FCM)

A Guide to Capturing Causal Relationships from Secondary Sources of Data

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[1] Dept. of Engineering and Technology Management, Portland State University, Portland, Oregon, USA

***Abstract*—Cognitive mapping was introduced as a method to model complex systems that reflects how experts or stakeholders understand cause-and-effect relationships. Later, fuzzy cognitive mapping (FCM) combined cognitive mapping with artificial neural networks (ANN), resulting in the unique capacity to capture and use qualitative data to perform quantitative analysis and study system behavior in response to changes of system elements. However, when it comes to building FCM models from qualitative data, particularly from secondary data sources, guidance for modelers is scarce. This article introduces a step by step guideline for building FCM that not only deals with causal relationships but also offers techniques to adjust the inconsistencies, and tune the granularities through parent-child relationships. It also proposes two techniques, isolated graph analysis, and receiver-only-concept analysis to investigate the completeness of the final FCM and hypothesize new connections to fill the gaps.**

Introduction to Fuzzy Cognitive Map (FCM)

Fuzzy cognitive mapping (FCM) is a method to model complex causal-effect systems utilizing cognitive maps and fuzzy logic (Kosko 1986). It provides a means to represent complex human cognition in a computable format. It can deal with linguistic ambiguities, complex causalities – including loops and feedbacks – and dynamic changes in the system. It also has been praised for its ease of use, understandable end-results – even for a non-technical audience – and relatively low computational time (Papageorgiou, Salmeron, and others 2013; van Vliet, Kok, and Veldkamp 2010; Antonie J. Jetter 2006).

In the past decade, FCM has been widely used as a tool for collective decision making (Khan and Quaddus 2004), exploring complex behavioral systems and scenario building (Muhammad Amer, Antonie Jetter, and Tugrul Daim 2011; A. Jetter and Schweinfort 2011; Salmeron, Vidal, and Mena 2012), and the study of stakeholder conflicts (R. C. Sperry 2014; A. J. Jetter and Sperry 2013; Kafetzis, McRoberts, and Mouratiadou 2010) in different fields, including medical (Papageorgiou et al. 2003; Georgopoulos, Malandraki, and Stylios 2003; Papageorgiou, Stylios, and Groumpos 2006; Stylios et al. 2008; Iakovidis and Papageorgiou 2011), robotics (Motlagh 2011; Motlagh et al. 2012), and social and environmental research (Madlener, Kowalski, and Stagl 2007; Ozesmi and Ozesmi 2003; Kontogianni, Papageorgiou, and Tourkolias 2012).

In the following section I, an overview of the fundamentals of fuzzy cognitive mapping (FCM), including a brief discussion of FCM calculation, is provided. This overview starts with two basic building blocks for FCM: cognitive maps, and fuzzy sets. It subsequently discusses temporal characteristics of FCMs and augmented FCMs. Section II discusses, how FCM models are commonly built from qualitative data. Section III proposes a guideline to extract causal relationships from texts (e.g. articles, interview transcripts, research notes) in a methodic and reliable fashion, as the main contribution of this article.

Cognitive maps; basis of FCM

The political scientist Robert Axelrod (Axelrod 1976) first introduced cognitive mapping in order to represent political elites' social knowledge. Cognitive maps are directed graph structures, which represent experts' knowledge or perception of a complex causal system. Systems are modeled via variables (concepts) and causal connections (edges) in between them. Concepts can have positive or negative impacts on each other.

A positive causality between concept C_1 and concept C_2 means that by increasing or decreasing concept C_1, concept C_2 would be increased or decreased respectively if no other concepts or edges exist in the system. For example, Figure 53 depicts a casual cognitive map in which concept C_1 impacts positively on both concept C_2 and C_3, while concept C_3 itself has a negative impact on concept C_2. Therefore, by increasing concept C_1, concept C_2 may increase or decrease based on the strength of the impacts.

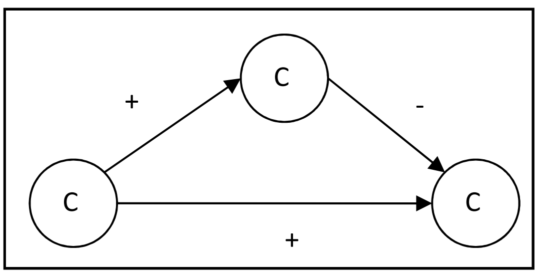

Figure 53- A simple casual cognitive map

In the early introduction of the cognitive maps by Axelrod (Axelrod 1976), the strength of the connections was not taken into account. In other words, all edges were considered to carry equal impact, but in negative or positive directions. An adjacency matrix is used to show these associations in between concepts where -1, 0 and 1 represent negative impact, no impact, and positive impact, respectively. Therefore, an adjacency matrix (M) would be a square n by n matrix where n is the number of concepts. An element of the matrix (m_{ij}) is a value function of the corresponding concepts: $m_{ij}= f(C_i, C_j)$. If C_i causally increases C_j, $m_{ij}= +1$, if Ci decreases Cj, $m_{ij}=-1$ and if there is no causality, then $m_{ij}=0$. The adjacency matrix of Figure 53 would be as follows:

$$\begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 0 \\ 0 & -1 & 0 \end{bmatrix}$$

Adjacency matrices are not necessarily symmetric and would have values other than zero on the main diagonal only if a concept directly impacts itself, also known as a self-loop.

Fuzzy set theory

In contrast to the classic theory of sets, where an object is either a member of a set or not, according to fuzzy set theory, a theory introduced by Zadeh in 1965 (Zadeh 1965), the object can be a member of a class with different degrees of membership, ranging between zero and one. Fuzzy theory is a response to the fact that in many cases in the real world there are no clear criteria that include or exclude objects from a class. "Class of tall men,", "class of young women", and "class of numbers much greater than 10" are a few examples to show the degree of ambiguity involved in human reasoning and linguistics in everyday life, which is very difficult or impossible to express with the classic theory of sets (Zadeh 1965).

To reflect this ambiguity, Zadeh defined "linguistic variables" as an alternative to numerical variables. The linguistic variable "age", for example, consists of overlapping sub-sets, such as be young, middle aged, very young, old, not very old and so forth. A person's age of 25, for example, may have a membership of 0.7 in the class of "young", whereas an age of 35 might only have a degree of membership of 0.2. Fuzzy sets and their application to the concept of linguistic variables have thus provided a means of approximate characterization of phenomena which are too complex or too ill-defined to describe (Zadeh 1975).

Kosko in 1986 (Kosko 1986) added fuzzy logic to cognitive maps and introduced fuzzy cognitive maps (FCM). In an FCM, nodes not only accept values of 0, 1 and -1 but also all other real numbers in between them. Also, edges accept a weight that determines what fraction of the activation from the proceeding node will be transferred to the

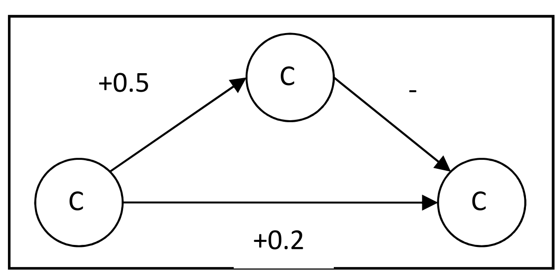

Figure 54 - A simple casual cognitive map with fuzzy connections

succeeding node. Figure 54 illustrates the FCM model of the cognitive map shown earlier.

Respectively, the adjacency matrix of the map would be as follows:

$$\begin{bmatrix} 0 & .2 & .5 \\ 0 & 0 & 0 \\ 0 & -.6 & 0 \end{bmatrix}$$

In this example, if concept C_1 increases from 0 to 1 (iteration 1), then concept C_2 would increase by 0.2 immediately (iteration 2). But it also increases concept C_3 by 0.5. Since concept C_3 has a negative impact on concept C_2 (-0.6), in the next iteration concept C_3 would be dropped to -0.3.

Different values of the concepts in each iteration could be shown as a vector matrix as follows:

Iteration 1, $[1 \quad 0 \quad 0]$
Iteration 2, $[0 \quad 0.2 \quad 0.5]$
Iteration 3, $[0 \quad -0.3 \quad 0]$
Iteration 4, $[0 \quad 0 \quad 0]$

In general, the value of each concept is calculated based on the value of influencing concepts and the strength of the influence as follows:

$$C_i^{(k)} = C_i^{(k-1)} + \sum_{All\, j \neq i} C_j^{(k-1)} \; W_{ji}$$

Where W_{ji} is the value of an edge from concept C_j to concept C_i at iteration k.

For illustration purposes, this example omits the use of squashing functions, that normalize iteration results into the interval of [-1;1] or [0:1] after each iteration. However, they are commonly used.

Temporal characteristics of FCM

While using FCM, time units of edges in between the nodes need to be similar to be able to use a connection matrix that updates all the concept values in each and every iteration. For instance, when modeling a quadruped walking (Motlagh et al. 2012) with concepts defined as legs, all the interactions between concepts take place in a fraction of a second, whereas in an FCM of the adoption of solar energy technologies (A. Jetter and Schweinfort 2011), the time scale for all the effects is months or years. Since in both of these applications time scales are consistent, there would be no problem using FCM.

In case that an FCM includes inconsistent temporal associations, then a method proposed by Park and Kim (Park and Kim 1995) can be used that uses discrete values representing the time unit of each edge and how long it takes before the effect transfers to the destination node. Experts could be asked about the time units, and responses could be fitted into two or three categories such as “normal,” “long,” and “very long.” Then for long and very long edges, one or two dummy concepts would be used respectively between the two concepts to delay the effect until the second or third iteration. For any m>1 delay units, between nodes i and j, m-1 dummy concepts need to be added between nodes i and j to imply the time lags.

Another attempt to embody the time unit differences into the FCM is by (Tsadiras, Margaritis, and Mertzios 1995), in which a memory capability or a decay mechanism is also added to the concepts traits. The state of a concept is not only determined by the magnitude of signals from causal concepts, but also by its tendency to keep the previous iteration's value. The lower the memory decay rate, the longer it takes for the concept to change based on the input from other concepts. In an extreme form, a concept with a memory decay of zero can be held or clamped to its initial value. This technique has been used frequently in modeling systems with different time units as well as systems in which initial inputs are held at a specific level, regardless of the dynamics of the system representing an exogenous factor.

Collective or augmented FCMs

Although cognitive maps were initially intended to visualize the perception and cognition of an individual – an expert in a domain or a stakeholder –the literature soon took the natural step of augmenting several FCMs into one integrated collective fuzzy cognitive map of multiple sources. This is aligned with the main goal of many FCM projects: to explore and study complex phenomena that, in many cases, no single expert has all relevant knowledge about. The collective FCM instead integrates FCMs of different experts, not only to assure the phenomenon is observed from multiple perspectives but also to reduce the error by triangulation of overlapping concepts. The triangulation process, in general, takes advantage of multiple perceptions to clarify the meaning of concepts and to verify the repeatability of an observation or interpretation (Stake 2000).

Augmentation needs to be performed on two levels: on the first level, augmented FCM includes all of the concepts and connections of two or more input FCMs. Then duplicate concepts and connections are merged into single concepts and causal relationships, respectively. On the 2nd level augmentation, information about the magnitude of relationships (i.e. the weight of links) from different FCM models need be also consolidated. This level of the augmentation is often more challenging. However, a simple mathematical average of the values of a connection as proposed by experts in input FCMs is often sufficient (Dickerson and Kosko 1993).

Another approach in integrating multiple FCMs is encouraging experts to work as a group to find the shared concepts and common connections and later to find a consensus on the weight of the new augmented FCM.

CONTENT ANALYSIS USING FCM

In the past decade, FCM has been widely used as a tool for collective decision making (Khan and Quaddus 2004), exploring complex behavioral systems and scenario building (Muhammad Amer, Antonie Jetter, and Tugrul Daim 2011; A. Jetter and Schweinfort 2011; Salmeron, Vidal, and Mena 2012), in different fields, including medical (Papageorgiou et al. 2003; Georgopoulos, Malandraki, and Stylios 2003; Papageorgiou, Stylios, and Groumpos 2006; Stylios et al. 2008; Iakovidis and Papageorgiou 2011), robotics (Motlagh 2011; Motlagh et al. 2012), social and environmental research (Madlener, Kowalski, and Stagl 2007; Ozesmi and Ozesmi 2003; Kontogianni, Papageorgiou, and Tourkolias 2012). Most of these FCM studies build on data from interviews and workshops with experts and stakeholders that are specifically created for the purpose of the modeling study. Nevertheless, it is often challenging to synthesize and model the information from these primary data sources. Researchers frequently have to check back with study participants (stakeholders, subject matter experts, etc.) to ensure the validity of the FCM.

Recently, there is growing interest in using content analysis of secondary data, such as publications, reports, and online discussions, for modeling complex causal systems as FCM (R. C. Sperry 2014; A. J. Jetter and Sperry 2013; Kafetzis, McRoberts, and Mouratiadou 2010). Checking the internal validity of the final FCM in these cases is even more challenging since there is virtually no way of validating the model by referring to the experts or stakeholders, who have authored the documents under study. (Internal validity also known as reliability is defined as the capacity in which other researchers could draw the same conclusions if they followed the same process and used the same sets of data (Closer 2001; Churchill and Wertz 2001).)

The following section suggests systematic and transparent approaches for analyzing qualitative content for the purpose of FCM modeling in order to improve reliability. The proposed steps and techniques are applicable to the analysis of both, primary and secondary data, however, they will likely bring the greatest improvements to the latter category of research projects.

PROPOSED GUIDE TO CAPTURE CAUSAL-EFFECT RELATIONSHIPS FROM CONTENT

The purpose of this guideline is to help researchers identify and model, as FCM, the causal relationships explicitly or implicitly conveyed in a text. This guideline falls into two categories of *knowledge capturing* and *model adjustment* as explained by (Antonie J. Jetter 2006), in the large scheme of fuzzy cognitive modeling. *Identifying objectives*, *knowledge elicitation*, *knowledge capture*, *model adjustment*, *calibration of the model* and *running the FCM along with interpretation of the results* are suggested as the overall steps for modeling and simulations using FCM (Antonie J. Jetter and Kok 2014; Antonie J. Jetter 2006).

The steps and techniques proposed in this article are illustrated with data from a study of the contributing factors to two types of innovation – so-called exploratory and exploitative innovation. Both types of innovation are extensively discussed in three streams of the research literature, namely organizational (ambidexterity) theory, new product development theory, and human resource management. In the following, we introduce processes for extracting causal relations from texts and for evolving them into an FCM. The approach is illustrated with examples that result from fuzzy cognitive mapping and modeling the insights from above streams of the literature.

Step 1: Draw the raw FCM based on the original text terminology

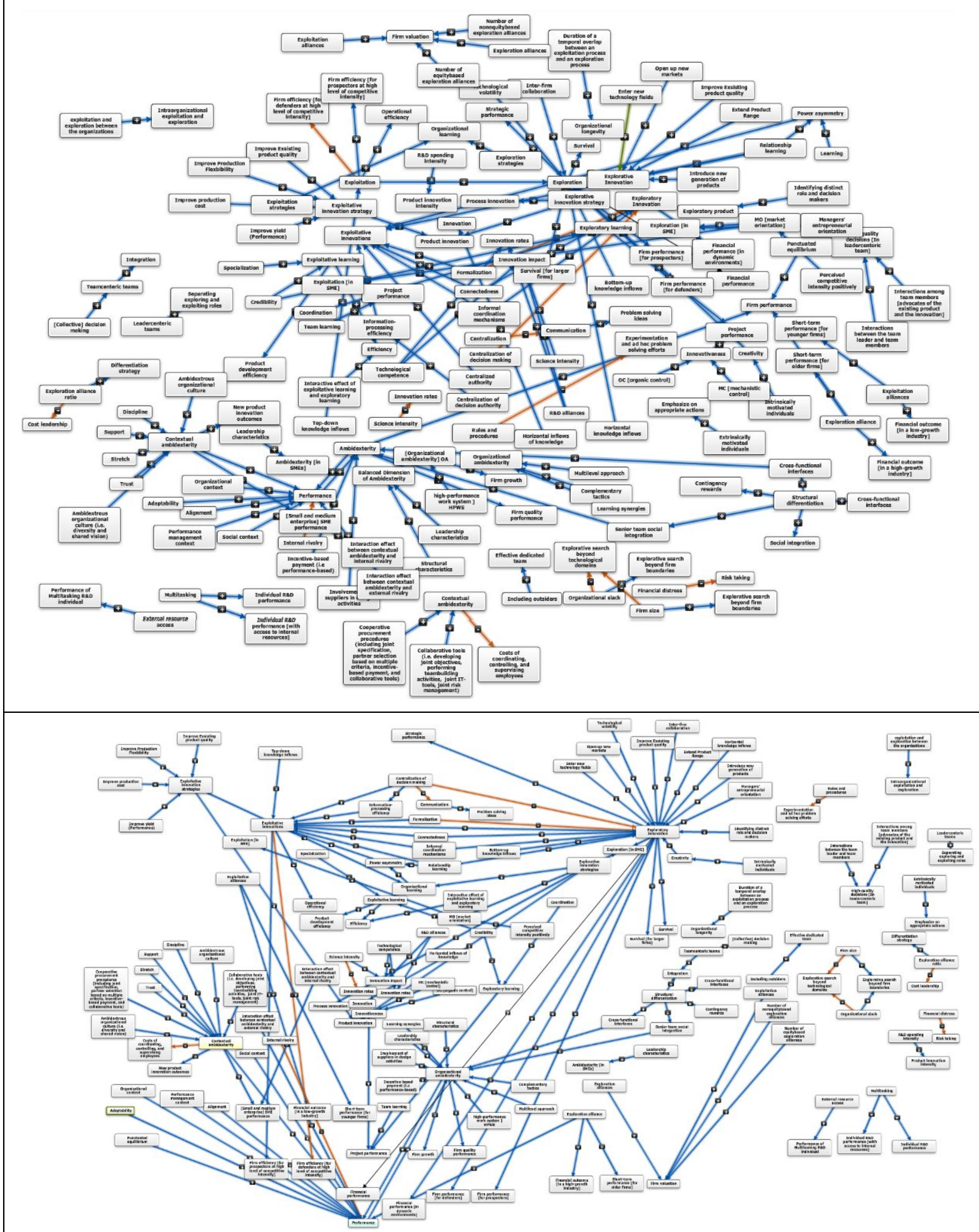

Figure 55-Raw FCM of exploitative and exploratory innovations as found in organizational theory (up) and reduced FCM after consolidating essentially identical concepts (down)

The raw FCM contains every causal connection between concepts that are mentioned in the texts under study, using the terminology of the texts' authors. For instance

Figure 55 shows a raw FCM of exploitative and exploratory innovations, as they are described in 69 selected publications on organizational theory. This raw map, which consists of 173 concepts and 145 connections, was drawn using the *MentalModeler* software. In this step, concept names should match the terms used in the original text as closely as possible or even literally, to make it possible to trace back the concept's original meaning and context. For example, the following is a quote from article (Li and Huang 2013) that states a connection between *"specialization"* and *"exploitative learning*", which resulted in the inclusion of all bold terms in the raw FCM above:

"H1a and H1b predict that there is a positive relationship

between ***specialization*** *and both* ***exploitative*** *and exploratory* ***learning****. H1a is supported (b = 0.19, p < 0.05); however, H1b is not supported."*(Li and Huang 2013)

To distinguish between concepts that are taken verbatim from the text versus concept names that are assigned by the researchers, it is good practice to put researcher-assigned terminology in brackets.

Step 2: Consolidate the identical concepts

In this step, the researcher consolidates concepts with different labels but essentially identical meaning after considering the context of the sources. A common method to address the issue has been referring to a domain-specific thesaurus as explained in detail at (Antonie J. Jetter 2006). The outcome of any modification through this process will be recorded in a *codebook* as a complimentary piece to the FCM. For instance, the concept *Exploration* and the concept *Exploratory Innovation* in

Figure 55 have the same meaning but are captured as different concepts since they originated from different sources or sections of text. They are therefore merged into the term *Exploratory Innovation*, which was chosen as the final concept label because it was the more specific term of the two. This can be recorded in a *codebook* as follows:

Exploration:=Explortory innovation[13]

Similar concepts; *Explorative innovation* and *Exploratory product* are also consolidated into *Exploratory innovation* and captured in the Codebook as following:

Explorative innovation:= Exploratory innovation
Exploratory product:= Exploratory innovation

Other modifications to consolidate all the essentially identical concepts found in FCM in

Figure 55 are found and recorded in the codebook as follows:

Exploitation:=Exploitative innovation
Merge: Contextual ambidexterity
Performance:=Firm Performance
Ambidexterity:=Organizational Ambidexterity
[Organizational ambidexterity]:= Organizational Ambidexterity

[13] Read this as; *exploratory innovation* label is assigned to *exploration* concept.

Balanced dimension of ambidexterity:= Organizational Ambidexterity
Social integration:=Integration
Merge: Project Performance
Exploitation strategies:= Exploitative innovation strategies
Exploitative innovation strategy:= Exploitative innovation strategies
Exploration strategies:= Explorative innovation strategies
Explorative innovation strategy:= Explorative innovation strategies
Centralization:= Centralization of decision making
Centralized authority:= Centralization of decision making
Centralization of decision authority:= Centralization of decision making
Merge: Science intensity
Learning:=Organizational Learning
Merge: Explorative search beyond firm boundaries

After applying these consolidations FCM shown in

Figure 55 (top) is reduced to FCM shown in

Figure 55 (bottom) with 154 concepts and 144 connections.

Step 3: Adopt consistent terminologies for conceptually similar concepts

When phenomena within an FCM are conceptually similar and have the same units of measurement, they should be documented in a consistent manner, even if the concepts are not identical. For instance, in the new product development FCM, shown in Figure 56 (left), the concepts *reduction time* and *development time* are both temporal concepts (i.e. they are measured in weeks, months, or years) and pertain to how long it takes to develop a product. Time reduction is therefore replaced by the concept Development Time.

Time reduction [in incremental innovation proejcts]:= Development time [in incremental innovation proejcts]

Note that in this case, the sign of the relationship needs to be reversed in order to preserve the original meaning of the causal relation after the above modification.

Similar cases are the two concepts of *development cost [in the case of radical innovation]* and *cost [in the case of incremental innovation]*. Although two different concepts, the units of measurement for both are the same –i.e. money or dollars. To increase the congruency of the FCM as shown in Figure 56 (right) one could be relabeled to become consistent with the other

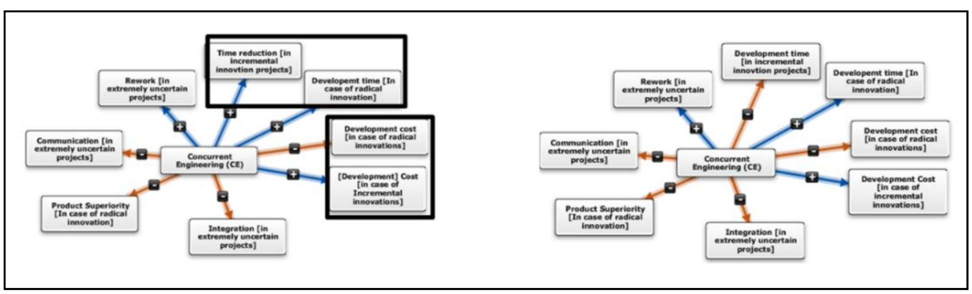

Figure 56- Part of new product development FCM with incosistant concepts (left) and modified version (right)

as follows

[Development] Cost [in case of Incremental innovations]:=
Development Cost [in case of incremental innovations]

Another example for this step could be imagined through the context of the research conducted by (Antonie J. Jetter 2006). In the context of that research, two concepts of "*right-wing political party*" and *Republicans*[14] are found to be interchangeably usable, therefore in the presence of both, they need to be presented as one identical concept as suggested by step 2. But imagine a case that two concepts namely "*right-wing political party*" and *Democrats* shown on the FCM. These are not interchangeably usable but both have a similar "unit" of measurement. Both of them would be referring to political parties, although different ones. Therefore, either "*right-wing political party"* needs to be relabeled as "*Republicans*" to be consistent with *Democrats* concept or, *Democrats* need to be relabeled as "*Left-wing political party*" in order to adopt a consistent terminology across the FCM.

Step 4- Tune the granularity for concepts and sub-concepts

FCMs sometimes contain concepts that are rather detailed and limited in scope because they are sub-concepts to a broader, more general concept. The broad concept may already exist elsewhere in the model or not yet be mentioned in the FCM at all. For researchers and modelers, this poses an important question: Should they create a granular model that contains only the detailed sub-concepts and omit the broader concept? Or should they collapse the detailed concepts into a broader category?

Preserving the higher resolution and eliminating the parent concept makes sense when the sub-concepts, taken together, fully describe the parent concept. Moreover, the sub-concepts should be free of overlaps and each must contribute to a unique aspect of the broader parent concept. Also, if the parent concept, that is to be replaced by its sub-concepts, was included in the original FCM model, its relationships with other concepts need to be broken into multiple connections on the children level. With this first path of keeping the children concepts, FCM calculations would be more impacted by that phenomenon. If other phenomena are studied at the same level of granularity or if this specific phenomenon is a matter of interest, this would be the right approach.

In contrary, by collapsing some detailed concepts into a broader parent concept, FCM would include a more simplified and lower granularity portrayal of the phenomenon. If applied to all the parent-child concepts present in the FCM, this path would increase the consistency. The drawback of this approach, naturally, is the loss of some of higher resolution insights. By simplifying to parent concepts and removing the children, obviously, some of the detailed connections will be lost or consolidated into fewer connections in between parent concepts and with less impact in overall FCM calculations. Therefore lowering the granularity is not the suggested path if a detailed analysis may benefit from higher resolution insights, later in the project.

In both paths, when faced with missing connections researcher is required to reinvestigate the content or experts to find –or propose –connections that fill the gap and fit the new granularity level.

As an example, in the FCM of human resource management-depicted in Figure 57, *upstream [external linkages]* represents a sub-concept of *external linkages of firms*.

Also, strategic human resource (HR) practices include *opportunities of participation*, *performance appraisal*, *communication for knowledge sharing*, *invest in training programs*, and *staffing premium workers* based on the context. Finally, *knowledge acquisition*, *knowledge sharing,* and *knowledge application* are sub-concepts of a broader concept called *knowledge management capacity* based on the original context. In Figure 57, thick rectangles group these concepts to depict the parent-child relationships. From here researcher could choose one of the two opposite paths as explained earlier. First, increase the granularity by keeping the sub-concepts of a concept—assuming that they are all mutually exclusive and collectively

[14] A conservative right-wing party in the united states

exhaustive,—and eliminate the parent concept. The second path would be keeping only the parent concept and removing the children (members) from the FCM.

But selecting any of these approaches has important implications. For example in of case of human resource FCM as depicted by Figure 57 by choosing the first path of lowering granularity, we would be implying that all the *strategic human resource practices* and not only the *compensation for knowledge sharing* and *invest in training programs* –as suggested by one study—are connected to *exploration* and *exploitation*.

Isolated-graphs analysis

Isolated graph analysis is as simple as identifying graphs that are not connected to other parts of the FCM model: In the FCM Figure 58, 14 isolated graphs are recognized, which can potentially be connected to another concept. Connecting isolated graphs is a learning process: The researchers need to investigate if the literature or other data sources have already established the existence of connections between graphs. If nothing can be found, researchers need to suggest plausible connections and intermediary concepts bridge the gap in between these graphs. Investigating

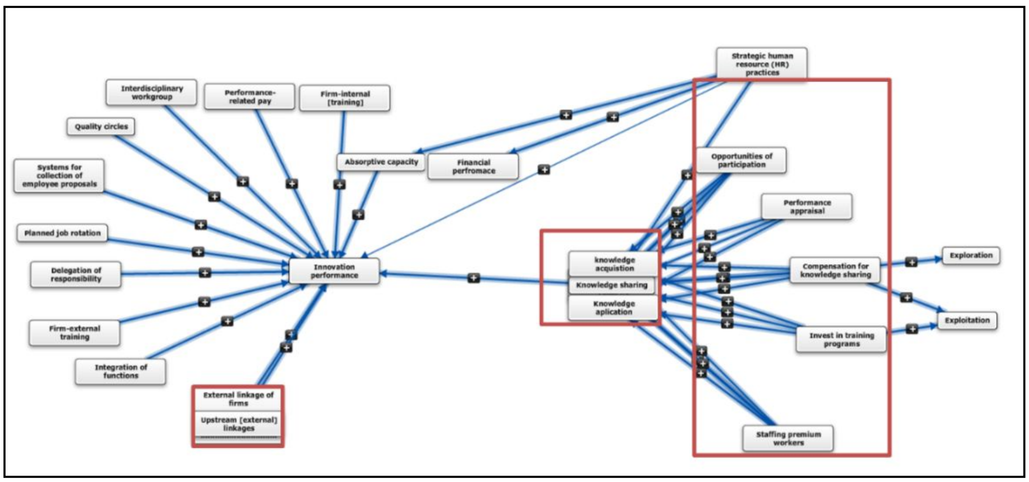

Figure 57- Parent-childeren concepts as found in the human resource management FCM

Step 5-Identify and close the gaps

The processes described above build an FCM mode from texts in an inductive fashion. The resulting model sometimes consists of "islands' of closely connected concepts, which often stem from the same body of literature, with few or no connections to other islands. One reason fo such insular groups of concepts can be the structure of research articles, which are typically focused on details and make "bigger picture' connections almost in passing, in the introduction or conclusion & outlook. In other cases, the literature may not yet have established any links between insular concepts, leaving it up to the researchers to propose hypotheses about causal relationships. In either case, analyzing the gaps provides important opportunities for improving research results. Accordingly, two techniques are proposed for investigating possible gaps in the final FCM.

those hypotheses would add to the knowledge of researcher about the phenomena under study by itself and may shed light on some overlooked aspects.

For the Ambidexterity FCM depicted in Figure 58 following modifications have been hypothesized to fill the gap and connect all the isolated graphs to form a single whole FCM:

Add a positive connection from *Experimentation and ad hoc problem-solving efforts* to *Exploratory learning.*

Add a positive connection from *Short-term performance [for older firms]to Firm valuation*

Add a positive connection from *Financial outcome [in a high-growth industry] to Firm valuation*

Add a positive connection from *Firm growth to Firm valuation*

Add a positive connection from *Financial performance to Firm valuation*

Add a positive connection from *Risk taking to Exploratory Innovation*

Delete *Innovation* and connect its only transmitter - *Horizontal inflows of knowledge-* to *Innovativeness*

Add a positive connection from *Explorative search beyond technological domains* to *Exploratory Innovation and vice versa*

Delete *Exploration alliance ratio, Differentiation strategy and Cost leadership.*

Add a positive connection from *Separating exploring and exploiting roles to Structural differentiation*

Add a positive connection from *External resource access* to *Individual R&D performance.*

In the same manner, an additional 9 missing connections were identified and added to the model leading to formation of a connected FCM as represented in Figure 59.

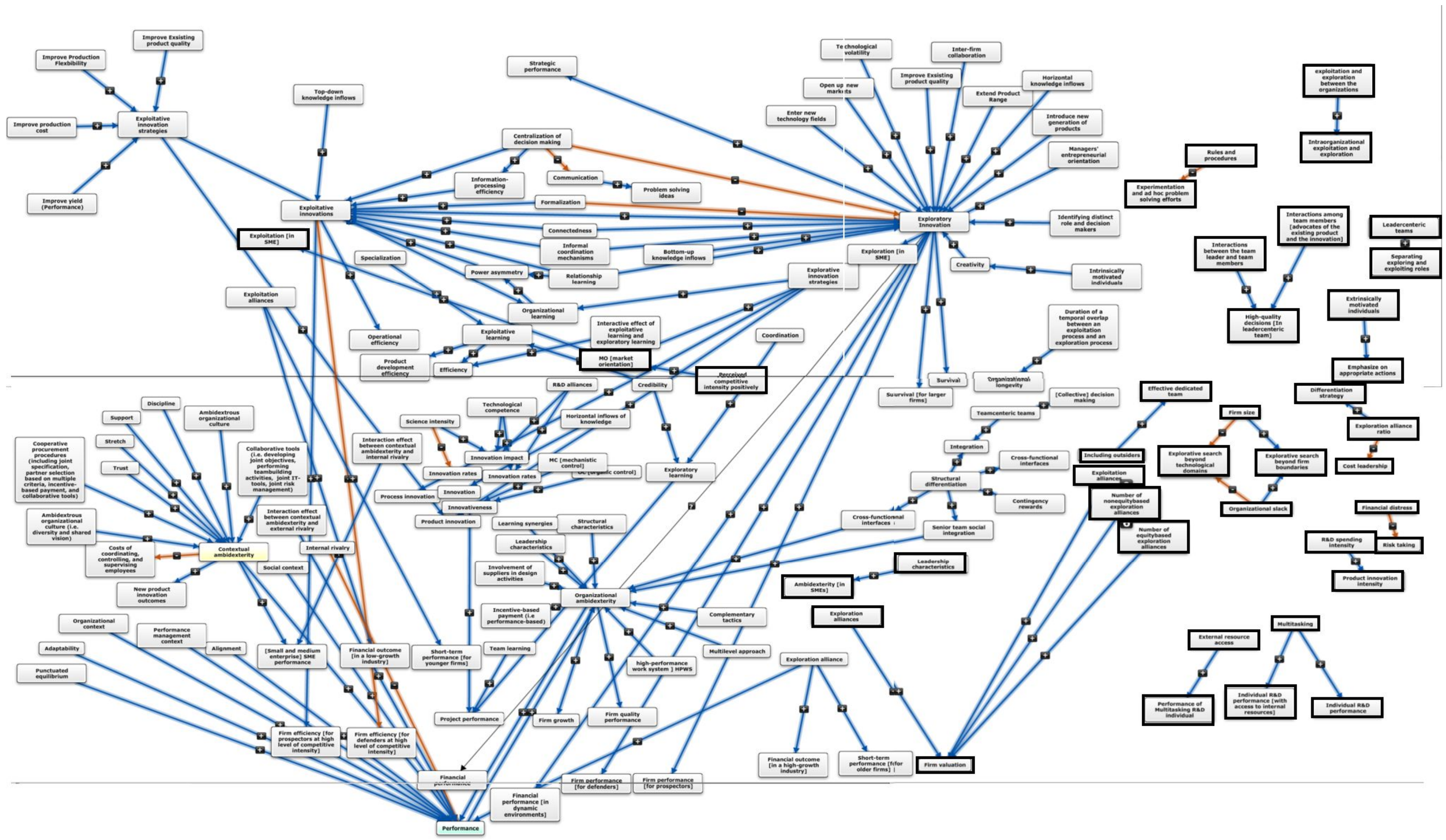

Figure 58- Isolated graph analysis as performed on ambidexterity FCM (isolated graphs from the main FCM are represented by bold concpt lines)

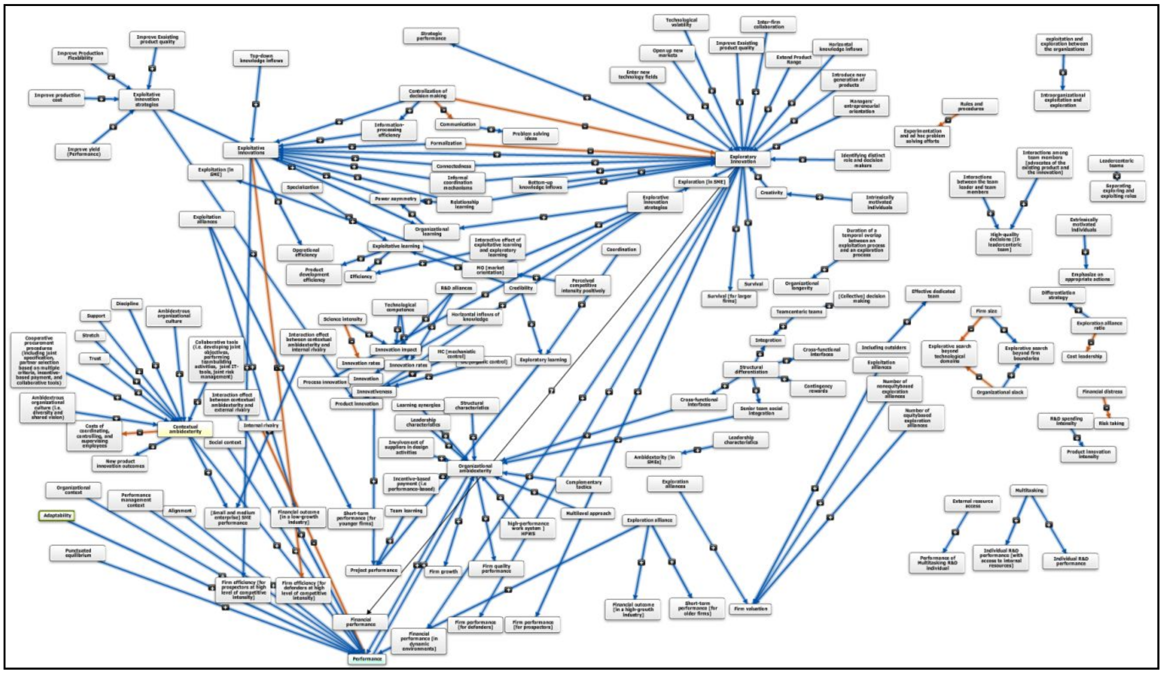

Figure 59- Only one connected FCM is recognizable on Ambidexterity FCM after isolated graphs analysis

Receiver-only-concepts analysis

The other technique to investigate potential gaps is to look for receiver-only concepts with no outbound relationships that are not the objective of the study.

For instance in the human resource FCM shown in Figure 60, four receiver-only concepts are highlighted; *innovation performance*, *financial performance*, *exploitation,* and *exploration*. Not all of these "dead end" concepts are the study objectives per se and although realized in the FCM they would have no impact on any other concepts.

One approach to solving the problem is to realizing the missing connections between such receiver-only-concepts and objective concepts. *Exploration* and *exploitation*, for example, are associated with *innovation performance*, according to key definitions of innovation reviewed for this study, even though the literature on human resources does not make an explicit link. Thus adding direct connections between *exploration* and *exploitation* to *innovation performance* would be one approach to addressing the issue.

The problem could also be resolved by considering *exploration* and *exploitation* as sub-concepts of innovations –or innovation performance—as explained in step 4. A connection is also added from *innovation performance* to *financial performance*, based on prior studies of ambidexterity literature, in order to fully address the issue of receiver-only concepts. As a result, modified FCM depicted in Figure 61 has no more than one receiver-only concept which represents the ultimate interest of the study; *financial performance.*

All such interferences in FCM need to be clearly documented in order to allow for tracing back to the original FCM extracted from the original text when needed.

Conclusion

This paper, for the first time, proposes a methodic guideline on how to extract the causal relationship from a given text and encode them using fuzzy cognitive map. This method consists of following steps; *1) draw the raw FCM based on original text terminology*, *2) consolidate identical* *concepts, 3) adapt consistent terminologies for conceptually similar concepts, 4) tune the granularity for parent-child concepts, 5) identify and close the gaps using isolated-*

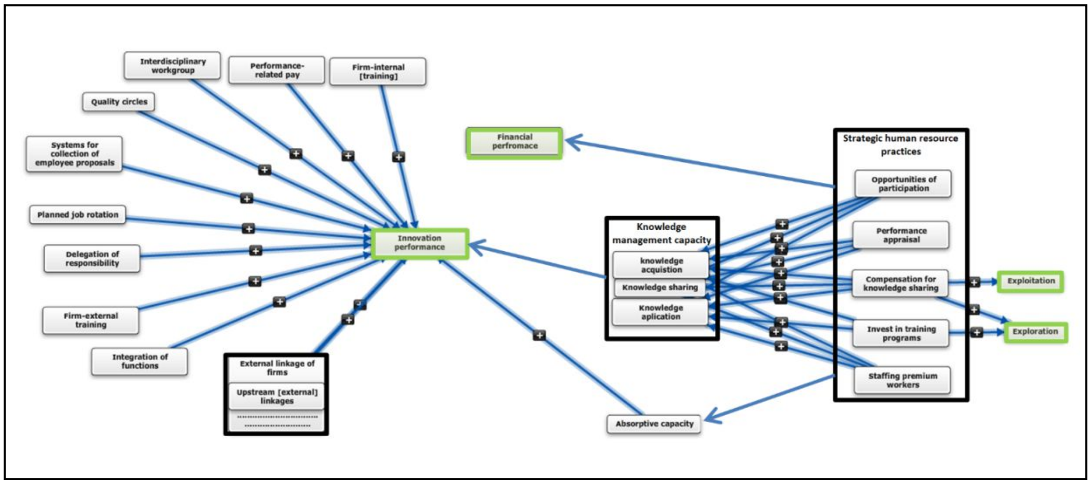

Figure 60-Receiver-only-concept analsyis on human resource management FCM

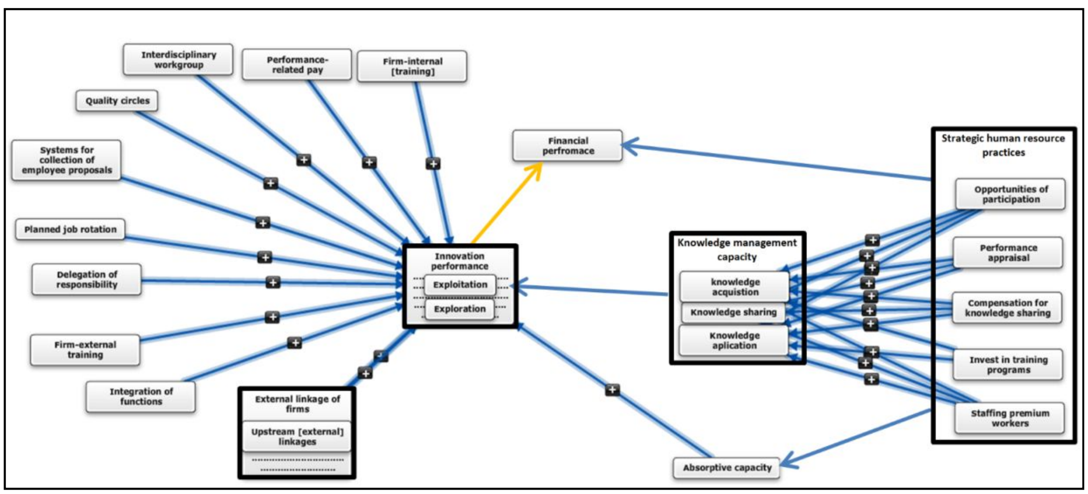

Figure 61-Modified human resource management FCM based on received-only-concept analysis

graph analysis, and receiver-only-concepts analysis.

Many of the steps above include novel techniques that enhance the consistency, repeatability, and reliability of content analysis performed by qualitative researchers. They are expected to increases the appeal of fuzzy cognitive mapping as a technique not only to decode the qualitative data but also to investigate, hypothesize and learn while encoding the data back to a fuzzy cognitive map.

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Appendix D- Expert panel and connection weight survey

A panel of experts consisting of scholars in innovation, organizational behavior, and management as well as practicing executives and managers will be asked to provide estimates of the weights of the connections. Although in rare cases existing empirical studies may have suggested a correlation coefficient for a causal relationship presents in the collective maps. Still the expert panel will be the only data source for two reasons. First, the scarcity of such data still dictates using a complementary method such as expert panel to fill the gaps, which will introduce the risk of inconsistency to the input data. This inconsistency rises not only because different studies have reported the causality in different forms and with different level of confidence, but also the outcome of an expert panel assessment will be categorical – i.e., Likert scale – and subjective. Second, even in the case of available data and similar research designs, assessing the parameters via an expert panel has been preferred in some studies, since the "degree of confidence or belief" could also be measured in parallel (Nadkarni and Shenoy 2004). How much the expert is confident about any given evaluation could be used as an extra piece of information for building the plausible models for the purpose of exploratory modeling.

These weights were added to the collective cognitive map to complete the fuzzy cognitive map of the ambidexterity. Each causal relation (link) will be evaluated by two or more experts (Pfaff, Jill L. Drury, and Klein 2015) who are asked to assign a number between [0,1] for a positive link and [-1, 0] for a negative link.

When the two or more experts assign different weights for each link, the highest and lowest assigned weight will provide the range of plausible weights. For instance, if one expert evaluates the weight of a link as -0.5 and another assigns a weight of 0.7, a range that covers both [-0.5, 0.7] will be the input to the analysis in compliance with the exploratory modeling requirements (Jan H. Kwakkel and Pruyt 2013). The simulation process described below will run multiple scenarios that will use randomly generated values in the plausible range of [-.5, .7] as an input. Probability distribution functions that will be used to generate a random value within this range will be discussed later. DESIM, a software package developed by MITRE Corporation, can be used to facilitate this step (Pfaff, Jill L. Drury, and Klein 2015).

In order to transform the emerged collective cognitive map to a collective FCM, the weight of all connections was needed to be added to the network. All causal relations were sent to an expert panel to capture the highest and lowest thresholds of a plausible range as explained in 4.2.3. *Matrix A* below represents a set of thousands of adjacency matrices required for exploratory analysis of the final collective FCM.

$$10.\ A=\begin{bmatrix} A11 & \cdots & A1i \\ \vdots & \ddots & \vdots \\ Ai1 & \cdots & Aii \end{bmatrix}$$

Where A_{ij} = [L, U] and L and U are the lower and upper level of the plausible range of values of concept A_{ij}. Where $L, U \in \mathbb{R}$ and $-1 < L < +1, \ -1 < U < +1$

In order to determine the value of L and U for each connection, collective FCM was broken into smaller FCMs and were sent to an expert panel to weigh the links in a survey format. Figure 62 shows a sample sub-FCM and its questionnaire sent to the expert panel for weighing the causal-effect relationships.

The expert panel was formed from 191 authors of the peer reviewed articles that informed this study about at least one causal-effect relationship and eventually constructing the FCM model. Contact information was collected from email addresses provided in the articles as well as extensive search through the web.

However, survey emails were not delivered to 27% of the recipients due to outdated contact information—due to changing the affiliation, retirements and so on. After 12 weeks and in average 3 times follow up with the recipients, while 12% responded to the request one way or another, only 6% completely answered the survey. This was short of 10%; the minimum expected survey completion required to collect at least one data point for each link weight.

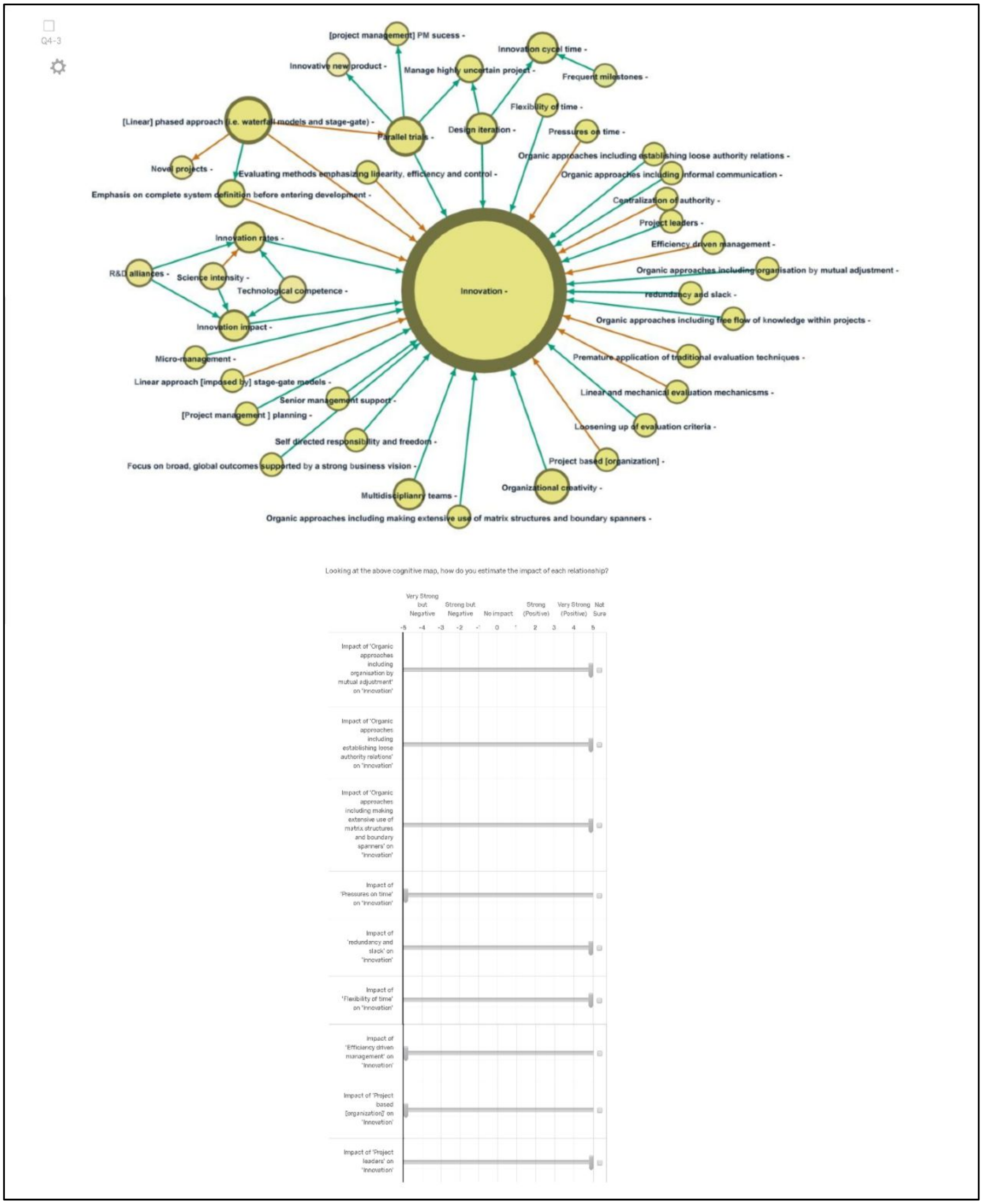

Figure 62- A sample sub-FCM and its questionnaire sent to the expert panel for weighing the causal-effect relationship

Appendix E- Domain and collective cognitive maps memo

Organizational Theory Map

To construct the domain cognitive maps, steps 1 through 4 as follows, were implememnted if applicable. Last step of tIdentifying and closing the gaps was done, at the collective level when all the domain cognitve maps were augmented.*Step 1: Draw the raw FCM based on the original text terminology*
Step 2: Consolidate the identical concepts
Step 3: Adopt consistent terminologies for conceptually similar concepts
Step 4- Tune the granularity for concepts and sub-concepts
Step 5-Identify and close the gaps

Step 1- Draw the raw FCM based on the original text terminology

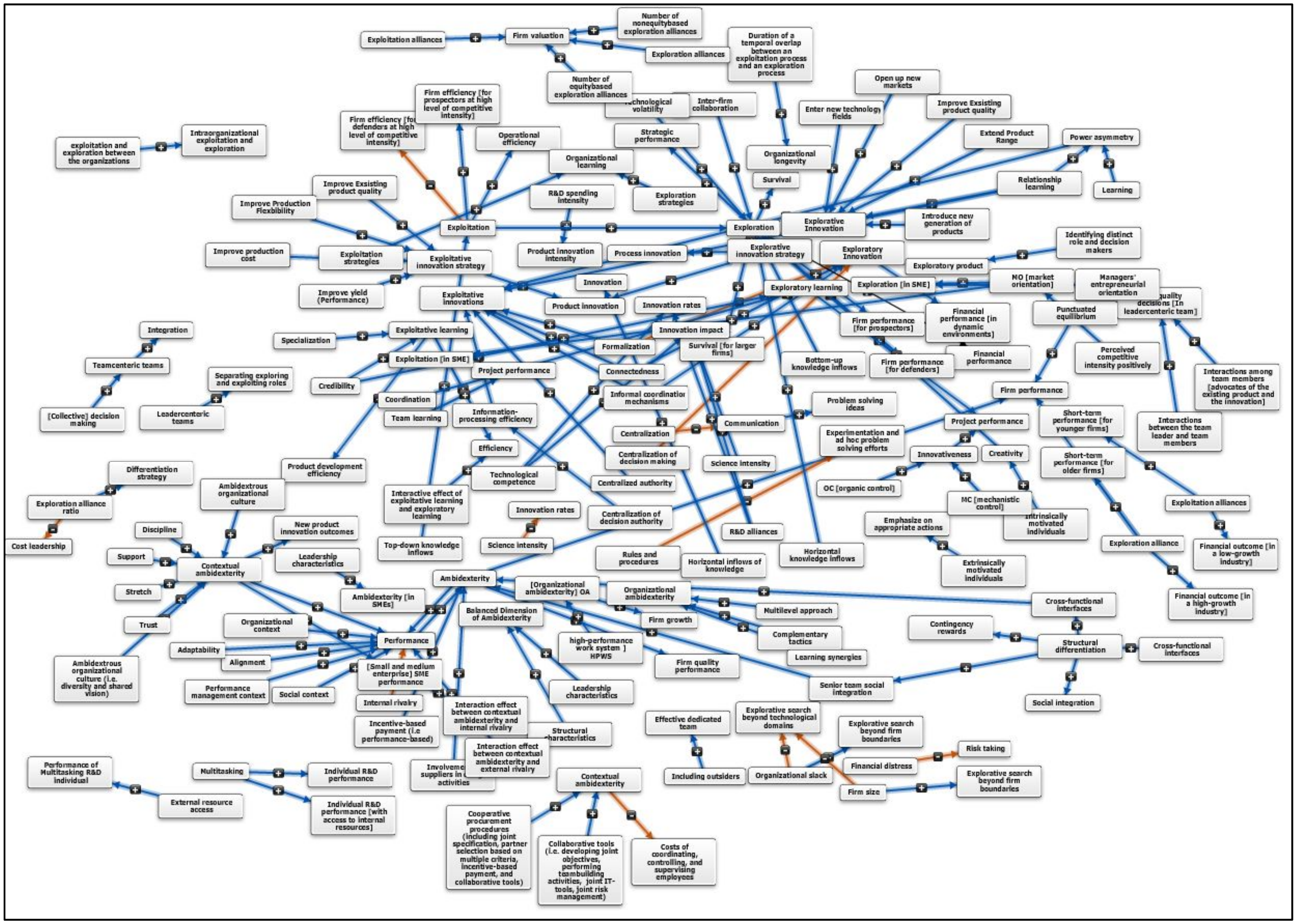

Figure 63- Raw Organizational Theory Map as extracted from the text

Step 2: Consolidate the identical concepts (color coded)

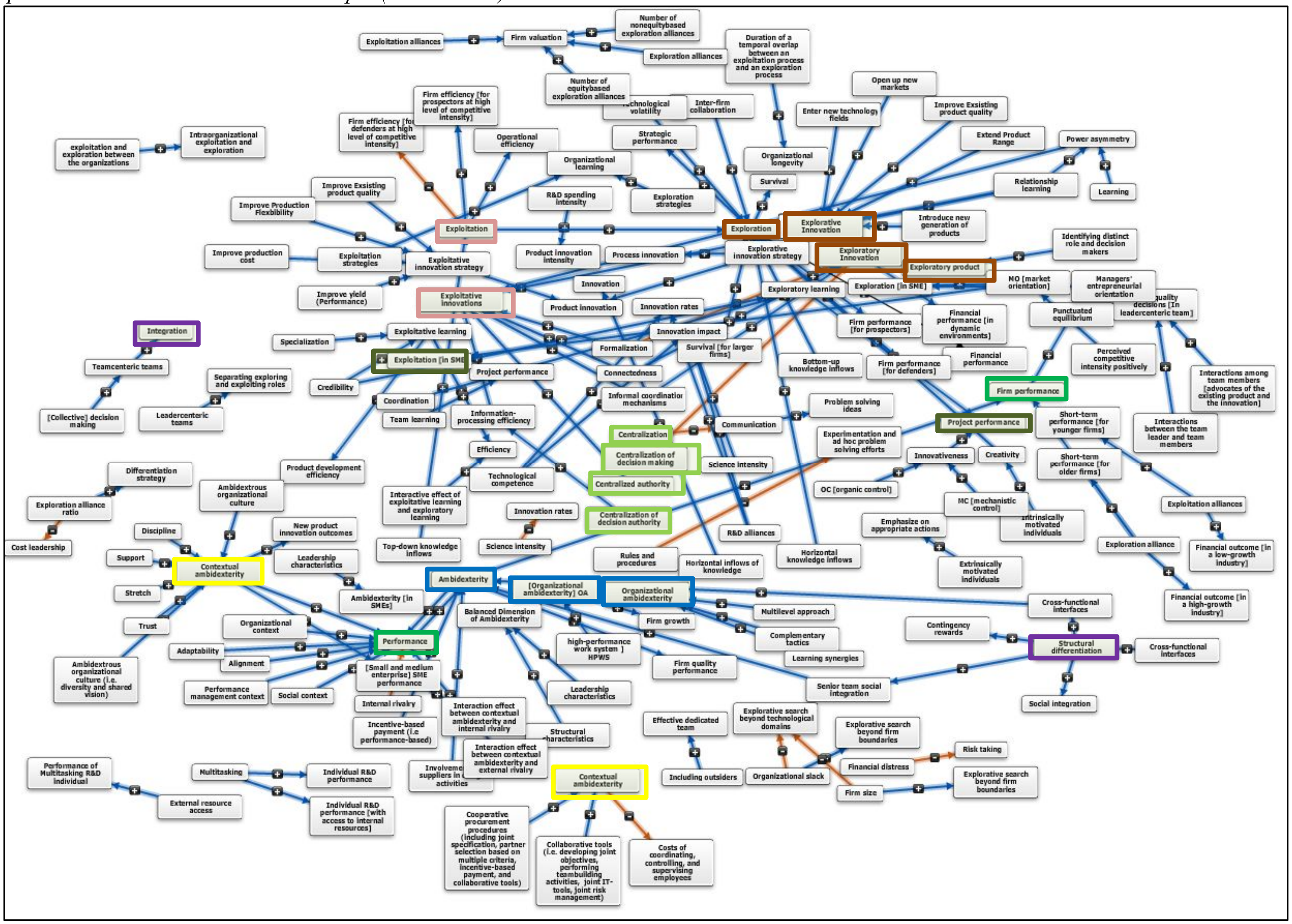

Figure 64- Organizational Theory Map, with identical concepts identified- Number of total components 173, Number of total connections 145

1. Exploration:=Explortory innovation
2. Explorative innovation:= Explortory innovation
3. Explortory product:= Explortory innovation {Rev00-11}
4. Exploitation:=Exploitative innovation {Rev00-12}
5. Merge: Contextual ambidexterity { Rev00-13}
6. Performance:=Firm Performance { Rev00-14}
7. Ambidexterity:=Organizational Ambidexterity
8. [Organizational ambidexterity]:= Organizational Ambidexterity { Rev00-15}
9. Balanced dimension of ambidexterity:= Organizational Ambidexterity
10. Social integration:=Integration {I am surpirised that structural differentiation is positively associated with integration according to this research!} { Rev00-16}
11. Merge: Project Performance { Rev00-17}
12. Exploitation startegies:= Exploitative innovation strategies
13. Exploitative innovation strategy:= Exploitative innovation strategies { Rev00-17}
14. Exploration strategies:= Explortive innovation strategies
15. Explortive innovation strategy:= Explortive innovation strategies
16. Centralization:= Centralization of decision making
17. Centralized authority:= Centralization of decision making { Rev00-19}
18. Centralization of decision authority:= Centralization of decision making
19. Merge: Scinece intensity
20. Learning:=Organizational Learning { Rev00-20}
21. Merge: Explorative search beyond firm boundaries
22. Merge: Improve Exsisting product quality (is not applied yet) & Merge Innovation rates

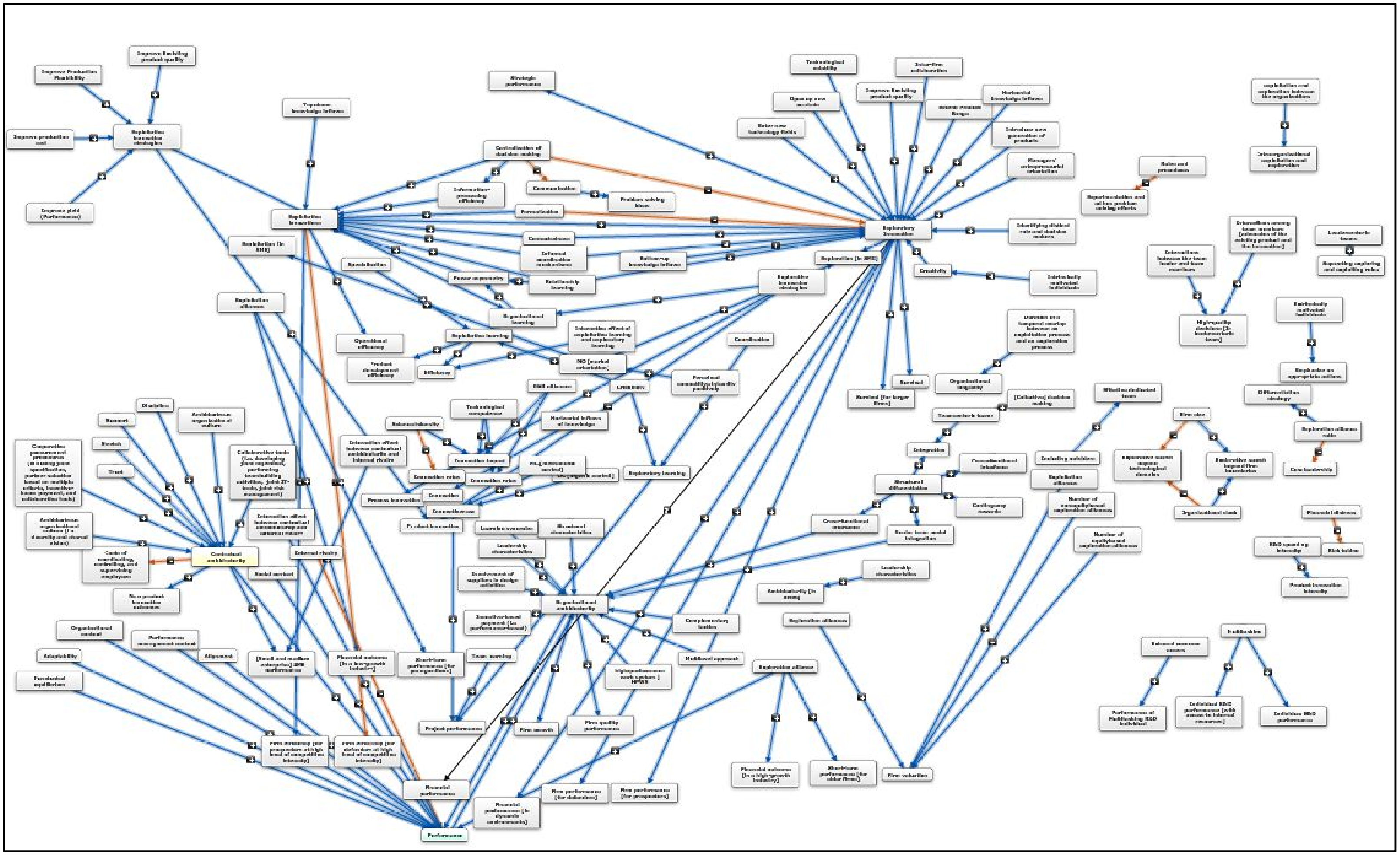

Figure 65- Organizational Theory Map, after consolidating identical concepts, Number of total components 155, Number of total connections 144

Step 3: Adopt consistent terminologies for conceptually similar concepts

Merge: Organizational longevity into Survival

Step 4- Tune the granularity for concepts and sub-concepts

Not applicable.

Step 5-Identify and close the gaps, Isolated graphs analysis (IGA)

This could be done partly by inspecting the connectedness (density) of the cognitive map. When there are isolated groups of concepts, it suggests that there are either missing relations or concepts or both. Reason could be the inability of the researcher to find and extract the relevant pieces from the literature review or the lack of explicit mention of such pieces in the given stream of research. Looking at the ambidexterity FCM, 13 isolated graphs is recognized.

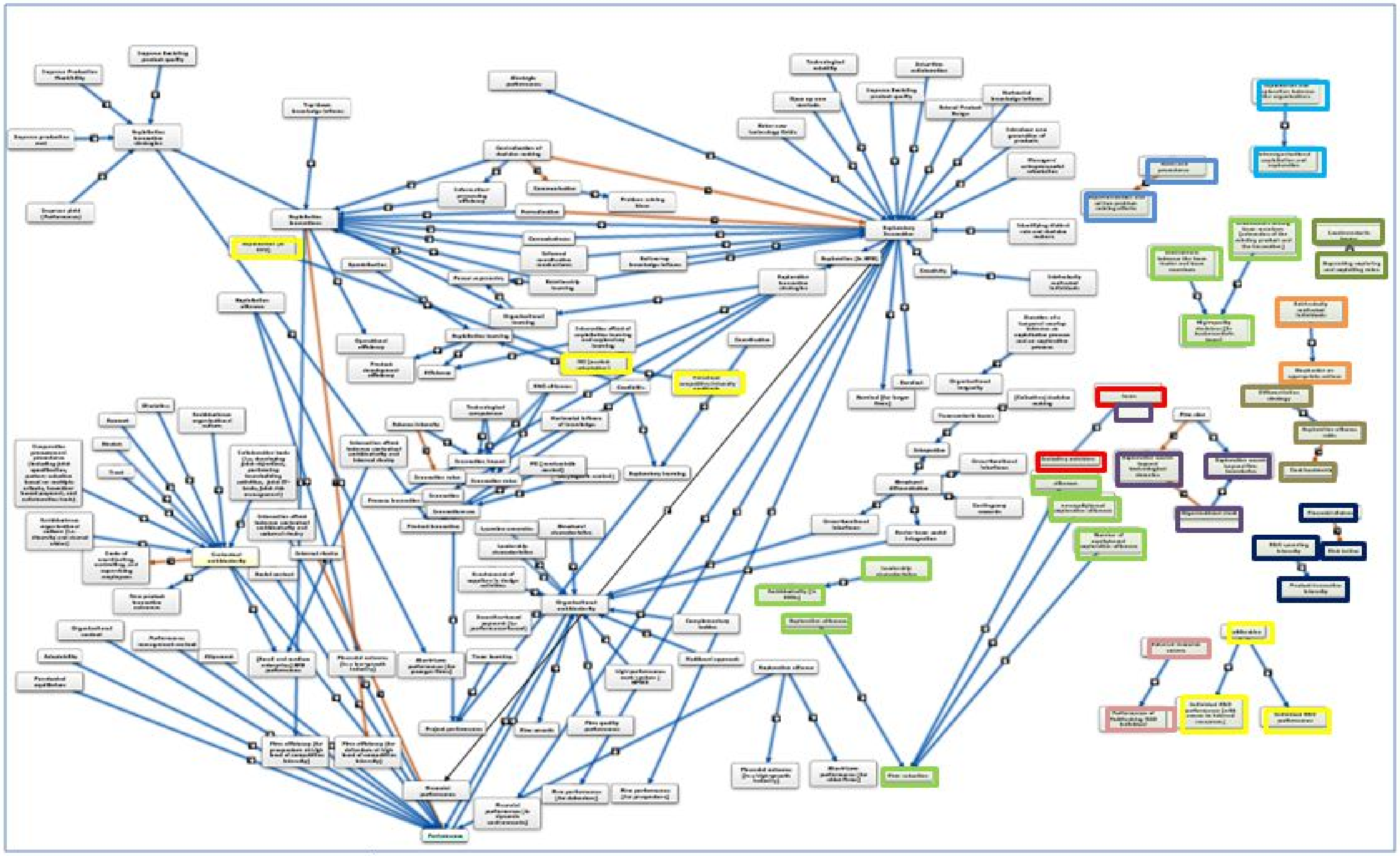

Figure 66- Organizational Theory Map, with isolated graph identified

In following cases positive conection were added:

1. From *Experimentation and ad hoc problem solving efforts* to *Exploratory learning.*
2. *From Short-term performance [for older firms]to Firm valuation*
3. *From Financial outcome [in a high-growth industry] to Firm valuation*
4. *From Firm growth to Firm valuation*
5. *From Financial performance to Firm valuation*
6. *From Risk taking to Exploratory Innovation*
7. *From Explorative search beyond technological domains to Exploratory Innovation and vice versa (correlation, definition)*
8. *From Explorative search beyond firm boundaries to Exploratory Innovation and vice versa (correlation, definition)*
9. *From Separating exploring and exploiting roles to Structural differentiation*
10. *From Emphasize on appropriate actions to Exploitative innovations*
11. *From Intraorganizational exploitation and exploration to Exploratory Innovation and Exploitative innovations*
12. *High-quality decisions [In leadercenteric team] to Centralization of decision making*
13. *Delete Innovation and connect its only transmitter - Horizontal inflows of knowledge- to Innovativeness*
14. *From Effective dedicated team to Exploratory Innovation*
15. *Deleted Exploration alliance ratio, Differentiation strategy and Cost leadership*
16. *From R&D spending intensity to Product innovation (in fact merge of Product innovation intensity to R&D spending intensity): Consiatnt terminology*
17. *Deleted Individual R&D performance [with access to internal resources]*
18. *From Individual R&D performance to Innovativeness*
19. *From Project performance to Performance*
20. *From External resource access to Individual R&D performance*

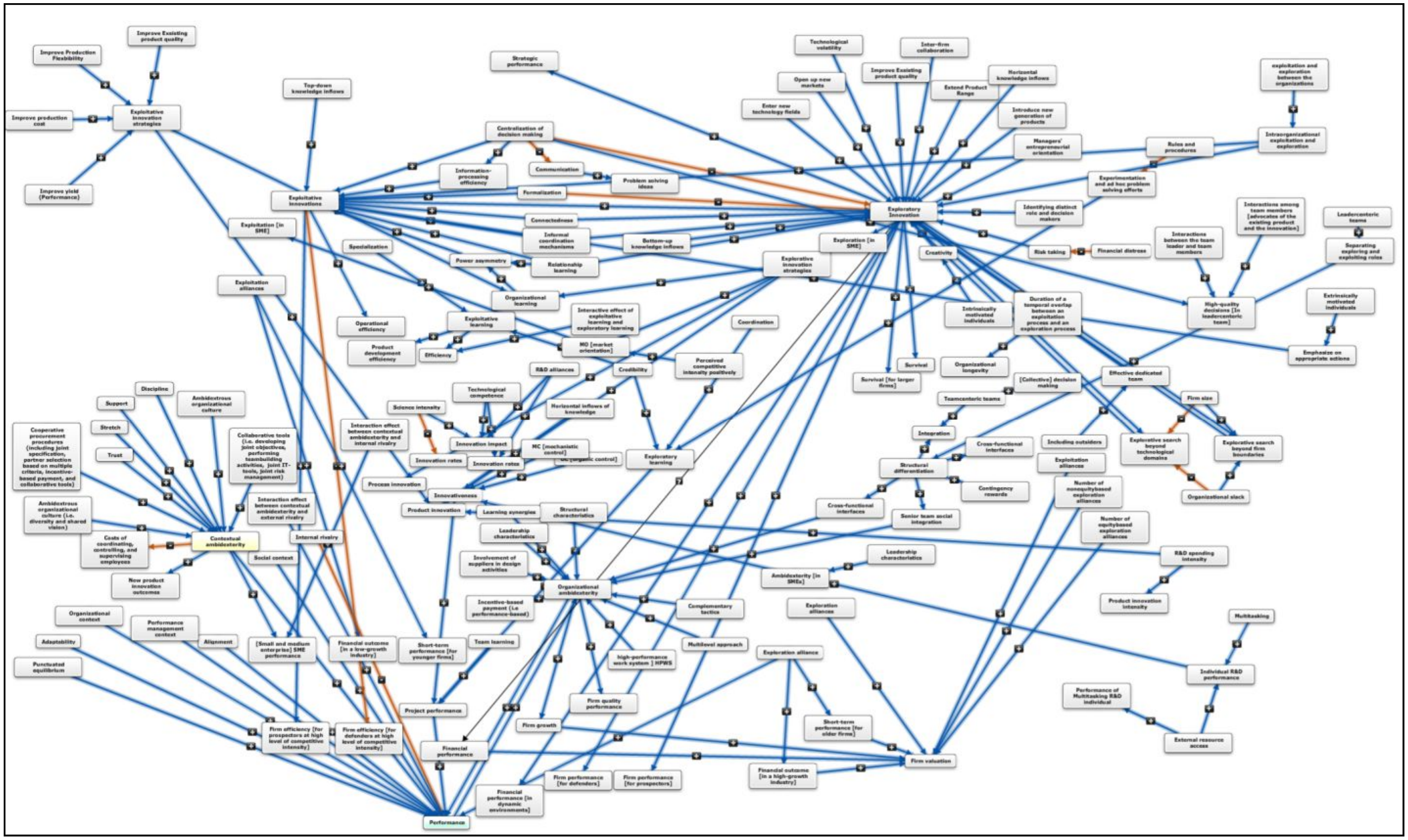

Figure 67- Organizational Theory Map, after IGA analysis

Creativity Theory Map

Step 1: Draw the raw FCM based on the original text terminology

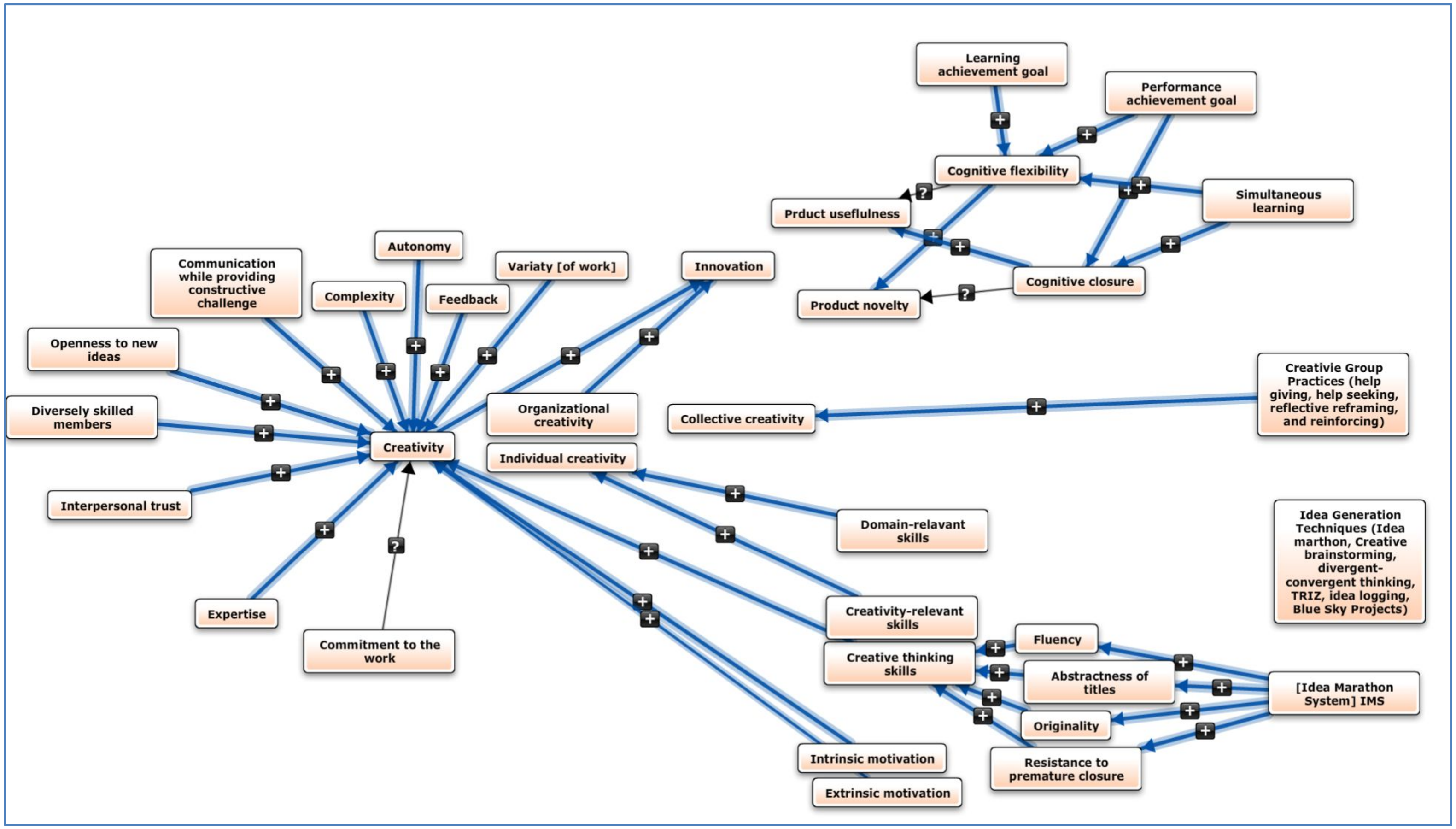

Figure 68- Raw Creativity Theory Map as extracted from the text

Step 2: Consolidate the identical concepts (color coded)

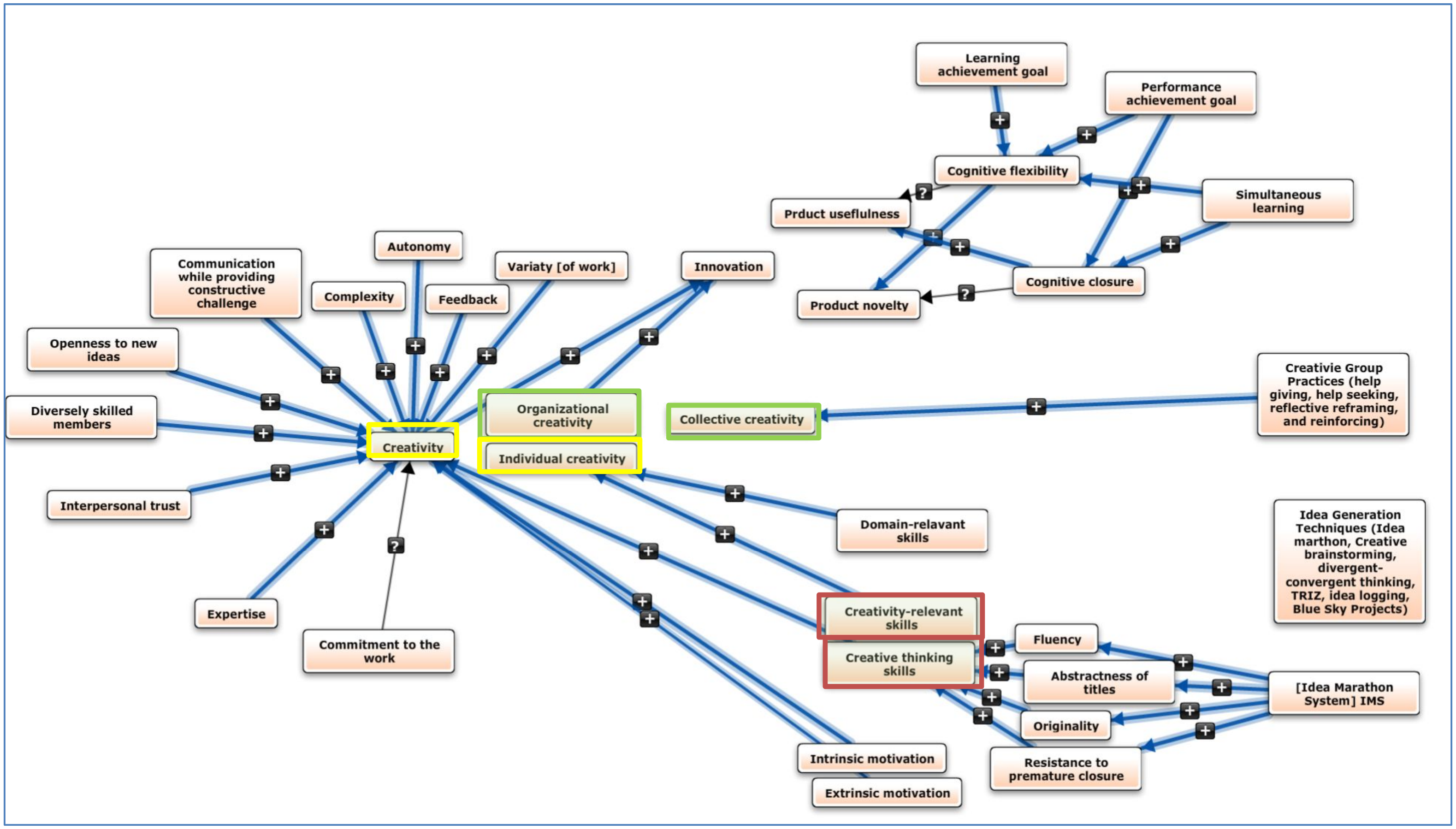

Figure 69- Creativity Theory Map, with identical concepts identified

1. Collective creativity:= Organizational creativity

2. Creativity-relevant skills:= Creativity-thinking skills { Rev0-1}
3. Creativity:= Individual creativity

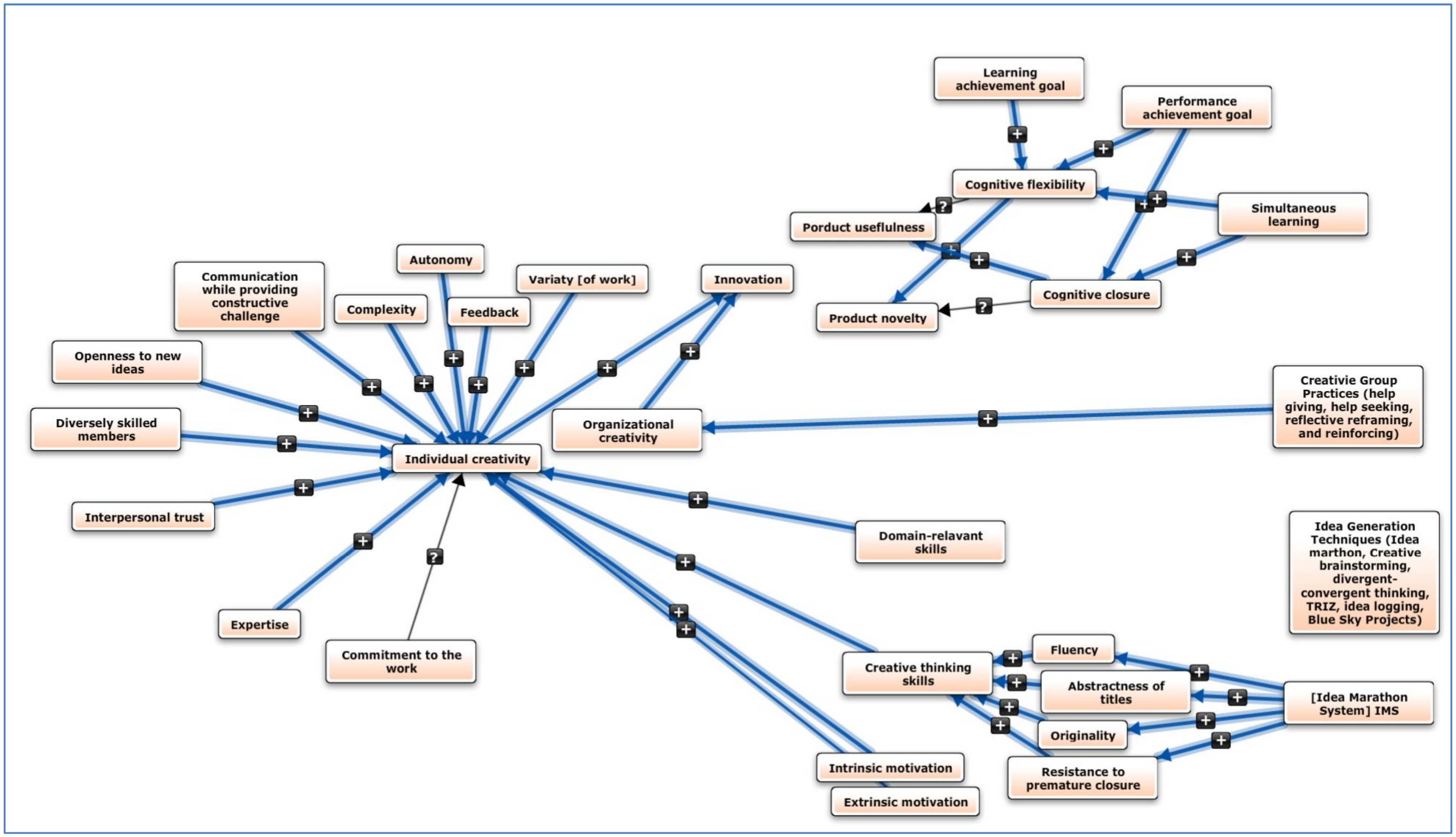

Figure 70- Creativity theory map, after consolidating identical concepts

Step 3: Adopt consistent terminologies for conceptually similar concepts

Not applicable.

Step 4- Tune the granularity for concepts and sub-concepts

Two apporach could be taken; increasing the granularity by keeping all the sub-sets or decreasing the granuarity (simplifcation) by keeping only *Creativity*. For our objective and since we have all the conncentions at the sub-set level, keeping the granularity high would be the choice. But as for Motivation, there is no basis to belive any direct conncetion between interinsic and exterinsic conncetion need to exist, since such relation is not found in the literature high granularity at this concept is retained with no additive relationship.

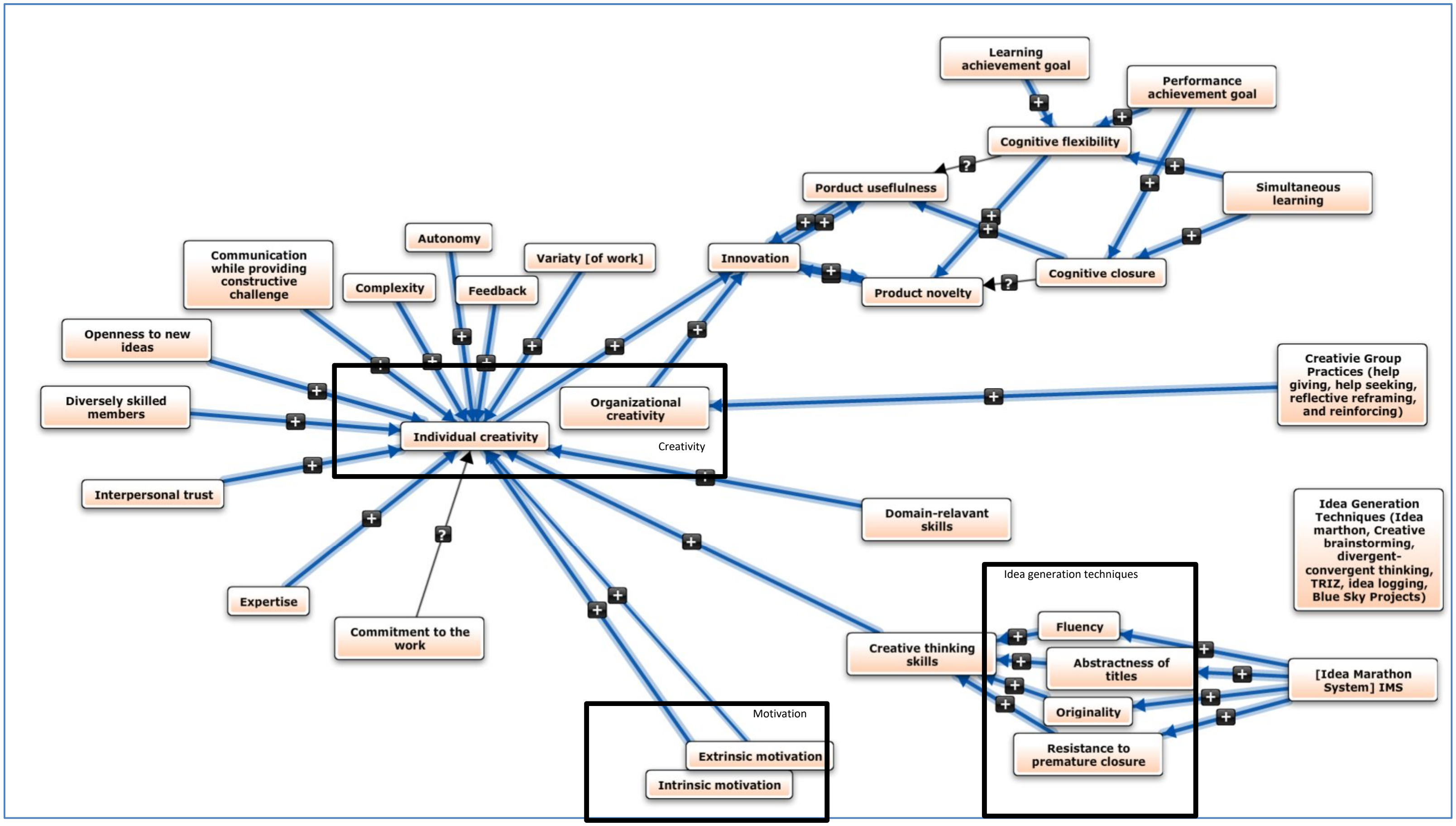

Figure 71- Creativity Theory Map granularity analyzed

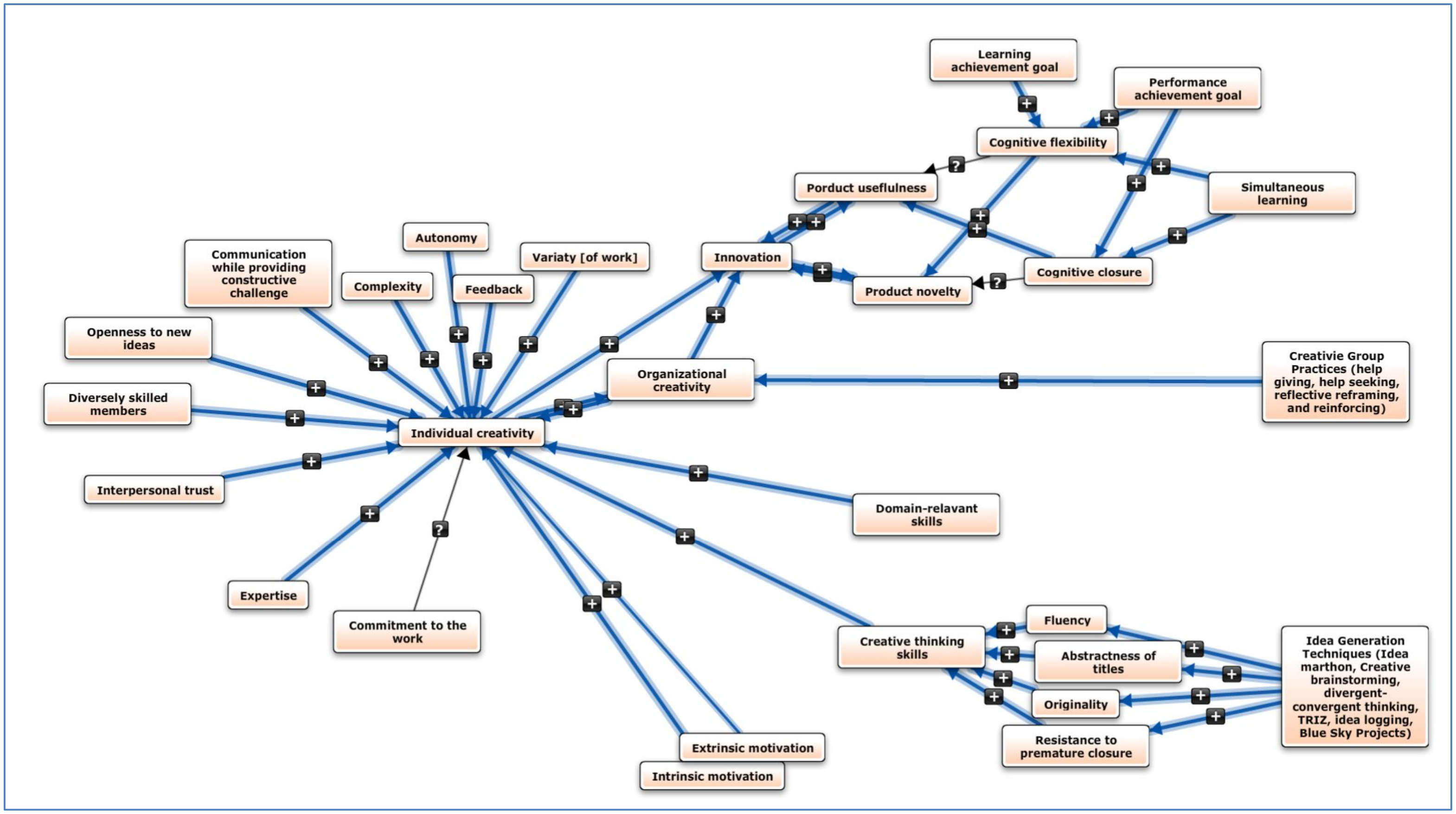

Figure 72- Creativity Theory Map, after tuning the granularity

Note: Later on from intercoder relaibility check it was realized that Idea geration… is directly increasing the Creative thinking skills but that is measured with Fluency and so on so they are not mediators but were effect of Creative thiking. CollectiveFCM Rev3 refelct the changes.

Product Innovation (NPD) Map

Step 1: Draw the raw FCM based on the original text terminology

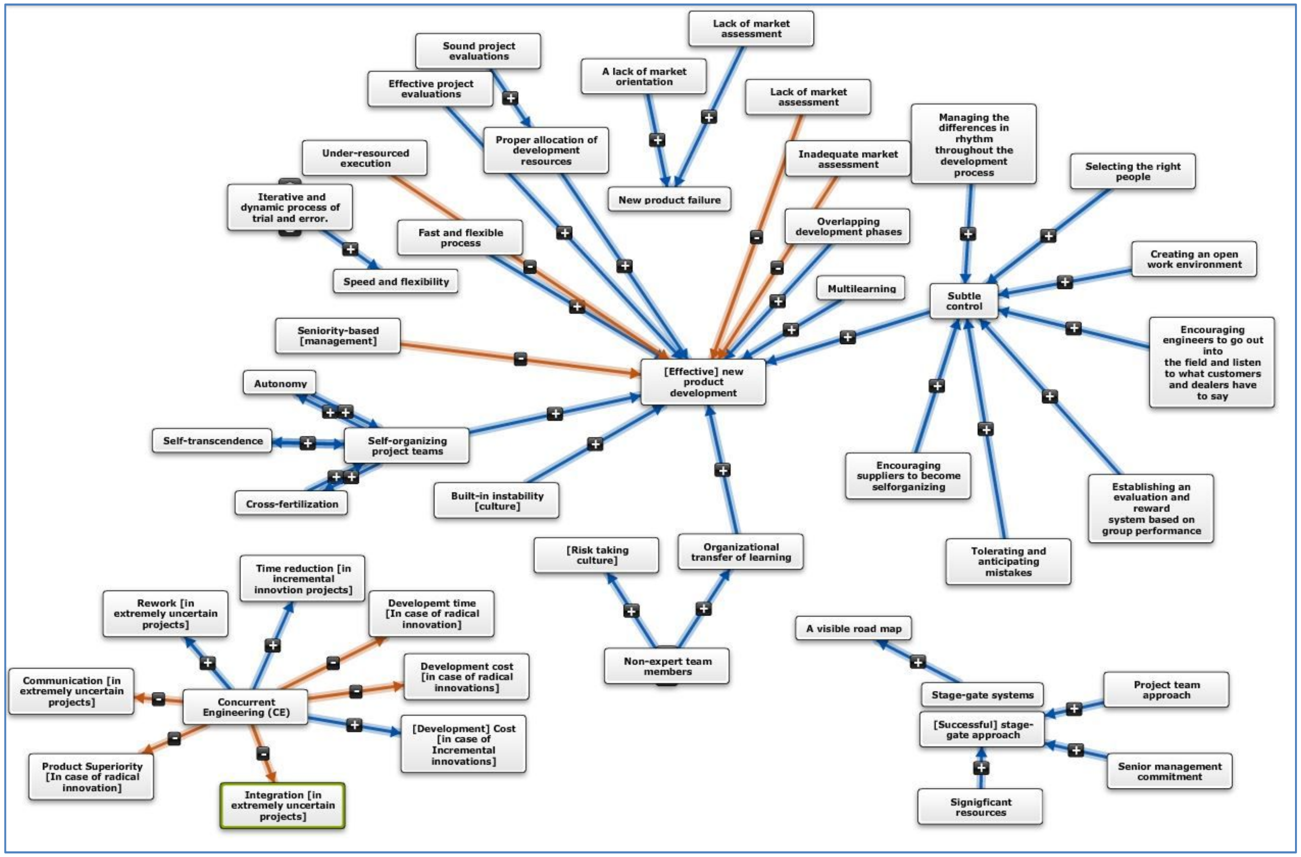

Figure 73- Raw Product Innovation & NPD map as extracted from the text

Step 2: Consolidate the identical concepts

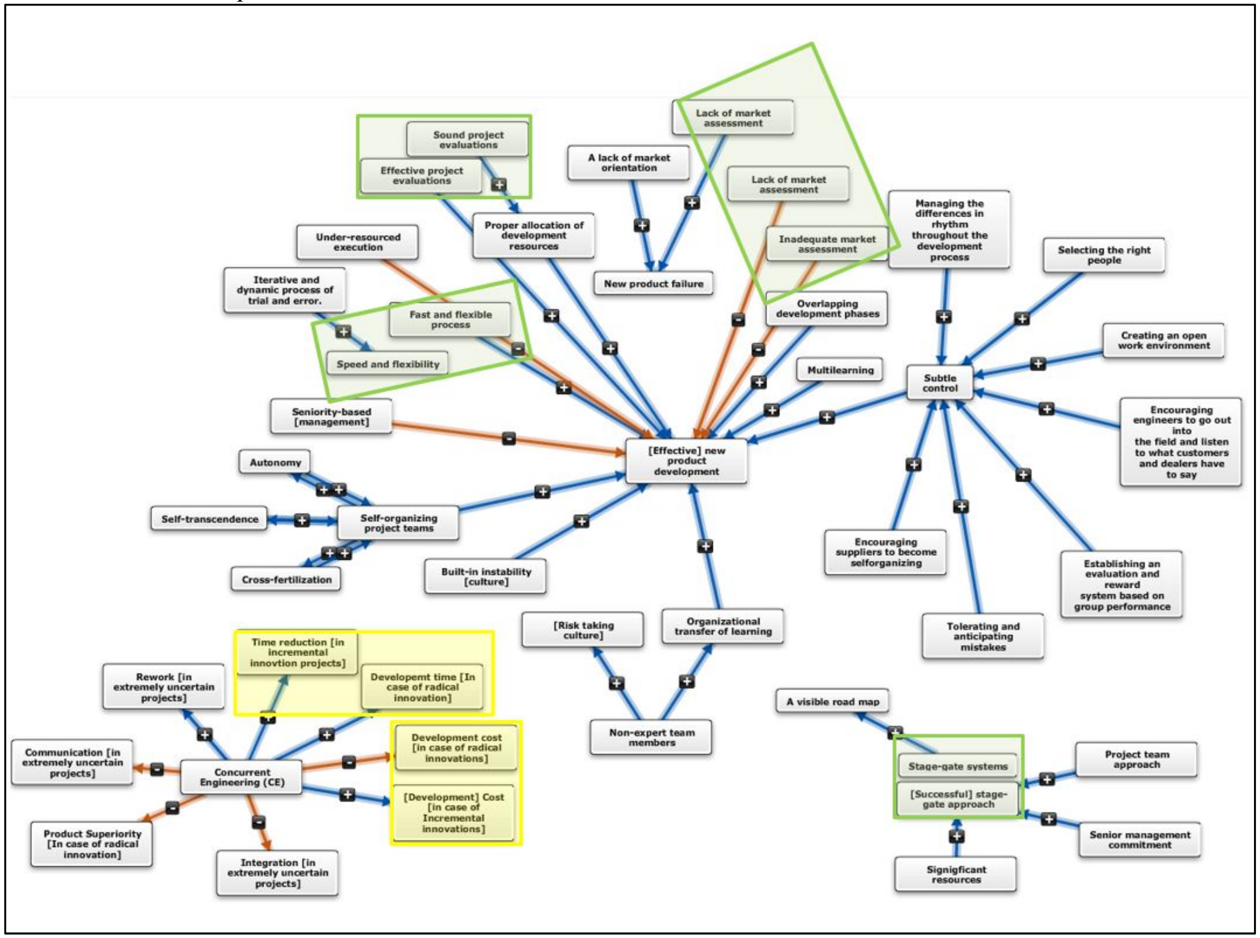

Figure 74- Product Innovation & NPD map with identical concepts identified

1. Lack of market assessment:= Inadequate market assessment
2. Sound project evaluation:= Effective project evaluation
3. Consolidating lack of market assessment to inadequate market assessment requires that :
4. New product failure get replaced with [effective] new product development with the inverse relationship
5. Fast and flexible process:= Speed and flexibility
6. Stage-gate systems:= [Successful] stage-gate approach

Step 3: Adopt consistent terminologies for conceptually similar concepts

1. Time reduction [in incremental innovation proejcts]:= Development time [in incremental innovation proejcts] and reversed the relationship
2. [Development] Cost [in case of Incremental innovations]:= Development Cost [in case of incremental innovations]

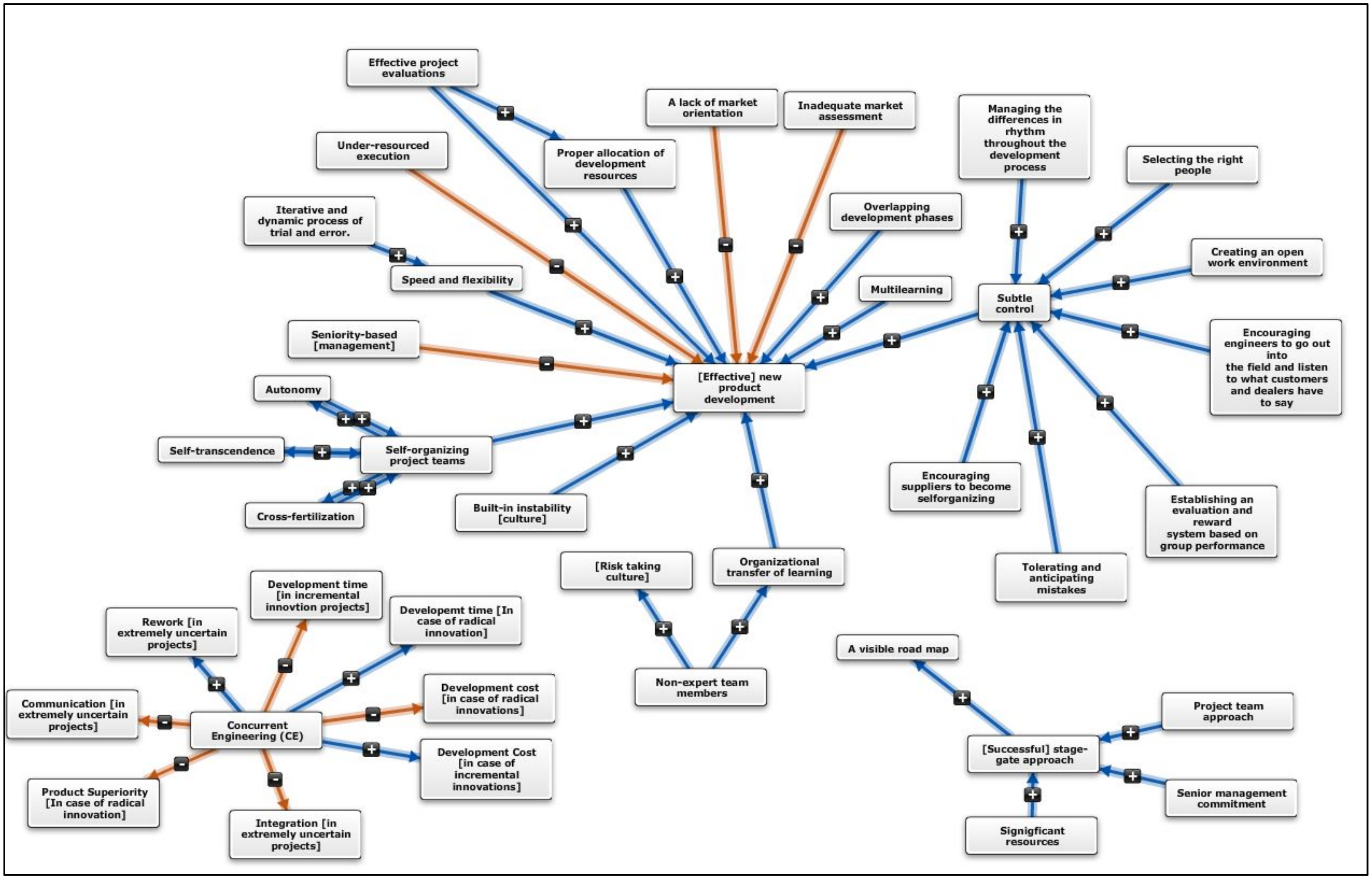

Figure 75- Product innovation and NPD cognitive map after consolidating identical concepts and adopting consistent terminologies

Step 4- Tune the granularity for concepts and sub-concepts and Step 5-Identify and close the gaps, Receiver-Only Concepts Analysis (ROCA)

Looking at the new product development FCM, three isolated graphs is recognized. While new product development has been treated as one generic type in some studies, other have either recognized two types of new product development efforts – incremental and radical- or focused in one type of new product development process-like stage gate approach. In order to mesh the disconnected network together, this distinction of two types of the innovation need to be followed consistently across the map. New product development needs to be broken into exploratory and exploitative innovations. The other technique is to look for the receiver-only concepts; those with no outbound relationships. If not the object of the study themselves, then obviously they have no input to the state of the new product development process as the object of the study.

1. A new connection is added from "A visible road map" to "[Effective] new product development".
2. Subtle Control is the parent of followings (Note: This was added based on inter-coder reliability input)

a. Encouraging suppliers to become self-organize
b. Creating an open work environment
c. Selecting the right people
d. Managing the differences in rhythm throughout the development process
e. Tolerating and anticipating mistakes
f. Establishing an evaluation and reward system based on group performance
g. Encouraging engineers to go out into the field and listen to what customer's and dealers have to say

Therefore, subtle control is eliminated and all the children are persevered. Since based on literature review a causal relationship from Subtle control to [Effective] New product development is identified all other children inherits the same relationship.

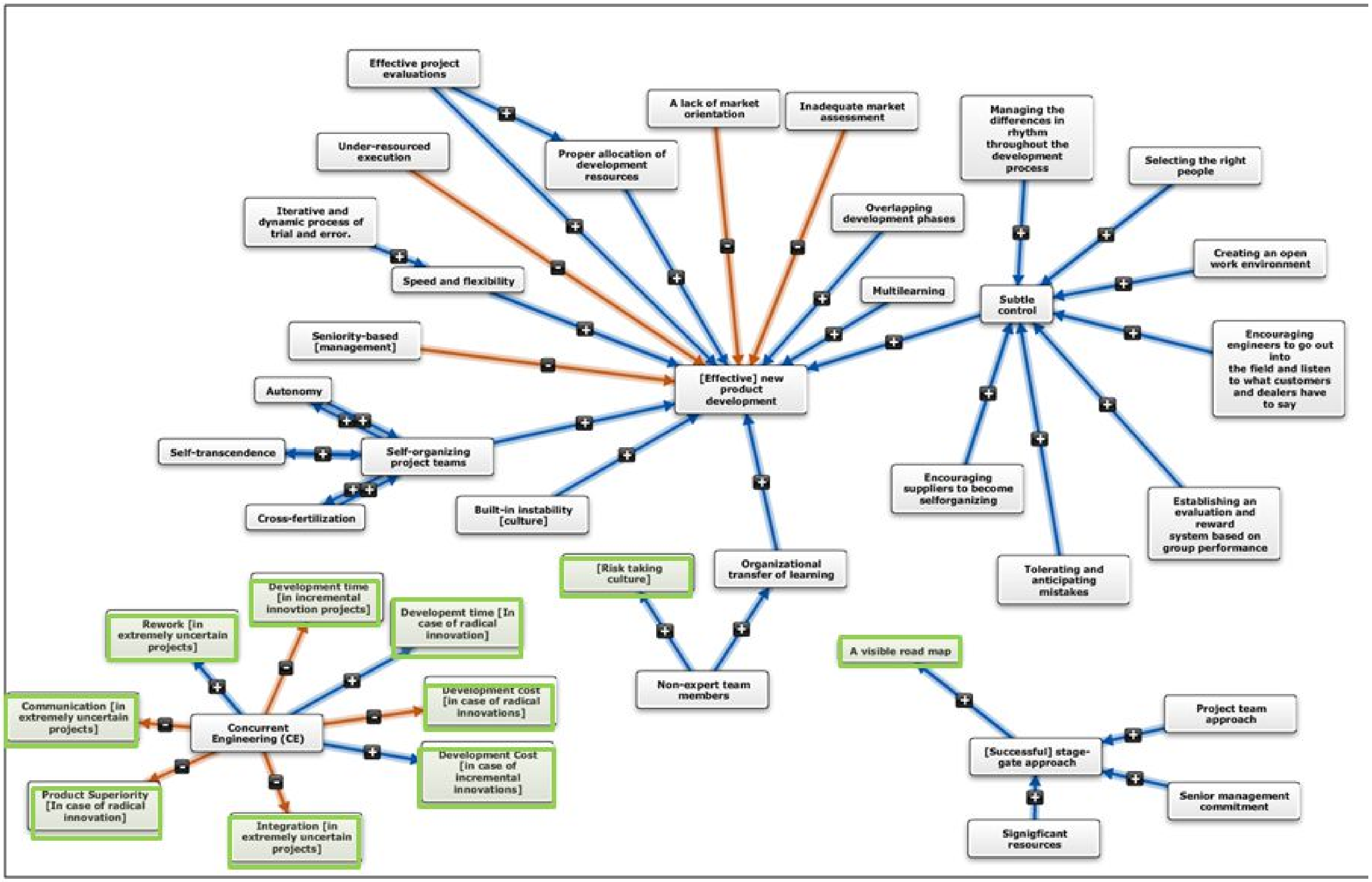

Figure 76- Product innovation and NPD cognitive with receiver-only concept identified

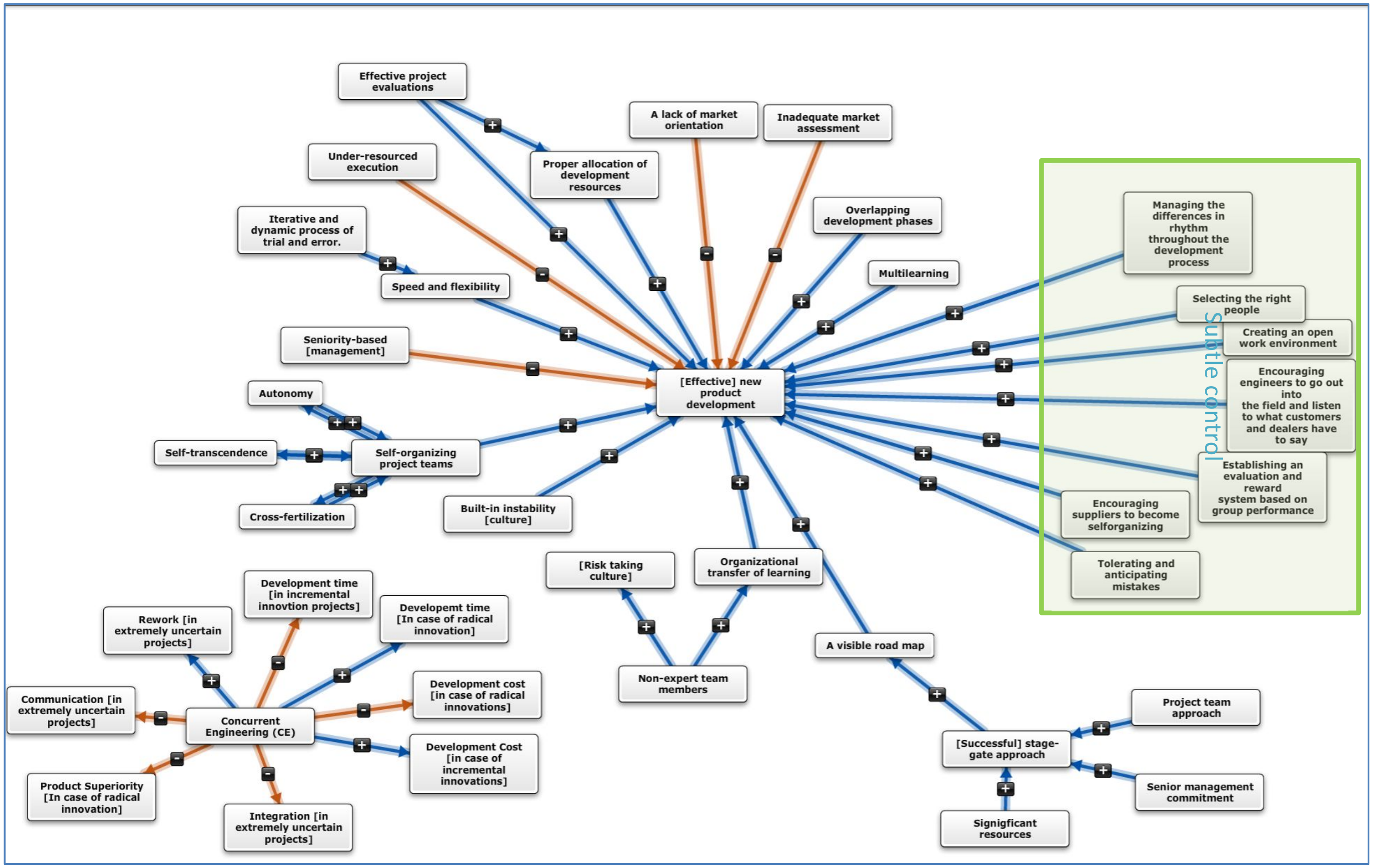

Figure 77- Product innovation and NPD cognitive after granularity tuning and receiver-only concept identified

Knowledge Management Theory Map

Step 1: Draw the raw FCM based on the original text terminology

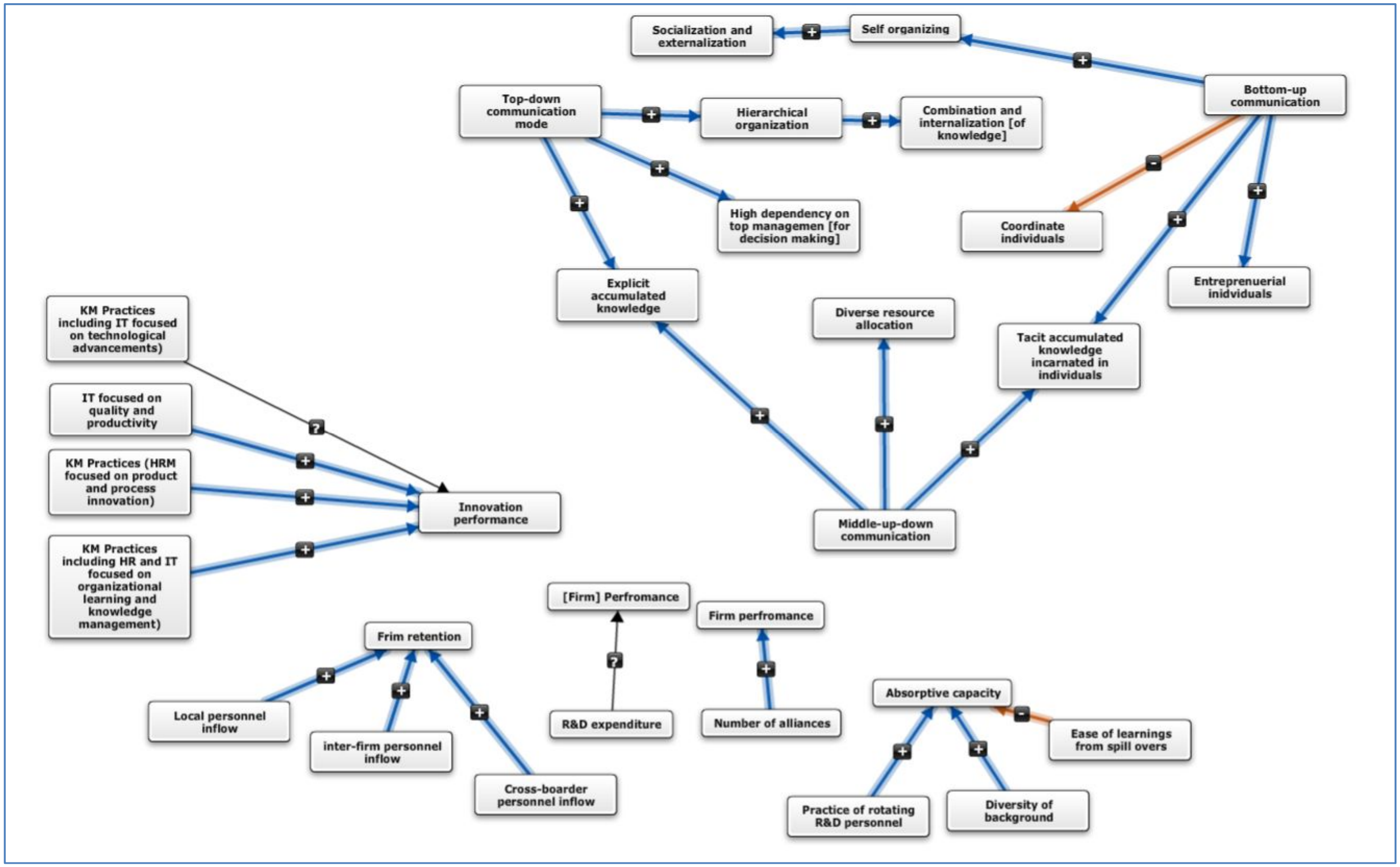

Figure 78- Raw Knowledge Management map as extracted from the text

Step 2: Consolidate the identical concepts

1. [Firm] Performance:= Firm performance
2. Add negative link from “High dependency on top management [for decision making]” to “Innovation performance”
3. Add positive link from “Tacit accumulated knowledge incarnated in individuals” to “Innovation performance”
4. Add positive link from “Diverse resource allocation” to “Diversity of background”
5. Add positive link from “Absorptive capacity” to “Innovation performance”
6. Add positive link from “Entrepreneurial individuals to “Innovation performance”
7. Add positive link from “Innovation performance” to “Firm performance”
8. Add link from “Firm retention” to “Innovation performance”
9. Add link from “Firm retention” to “Firm performance”
10. Add negative link from “Coordinate individuals” to “Innovation performance”

Step 3: Adopt consistent terminologies for conceptually similar concepts

Not applicable.

Step 4- Tune the granularity for concepts and sub-concepts

Not applicable.

Human Resource Management

Step 1: Draw the raw FCM based on the original text terminology

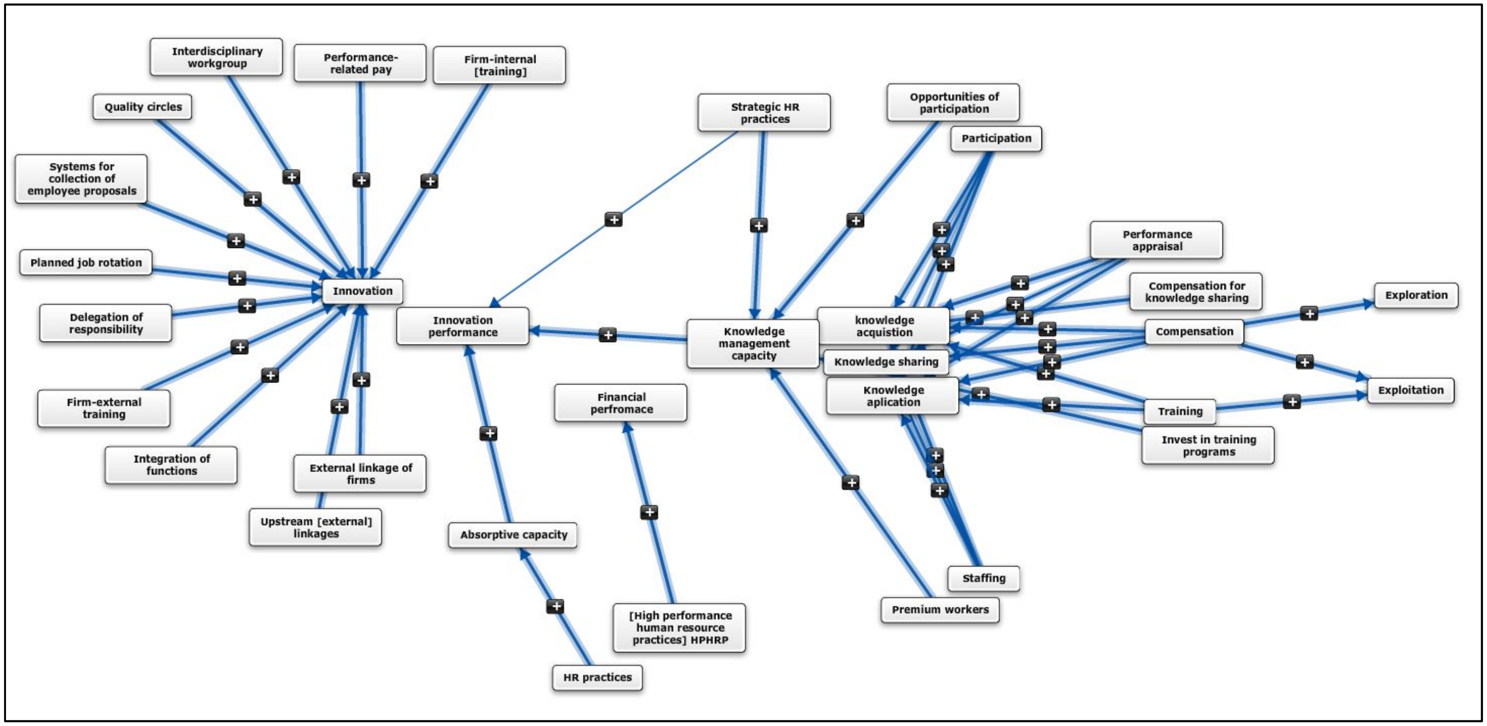

Figure 79- Raw Human Resource Management map as extracted from the text

Step 2: Consolidate the identical concepts

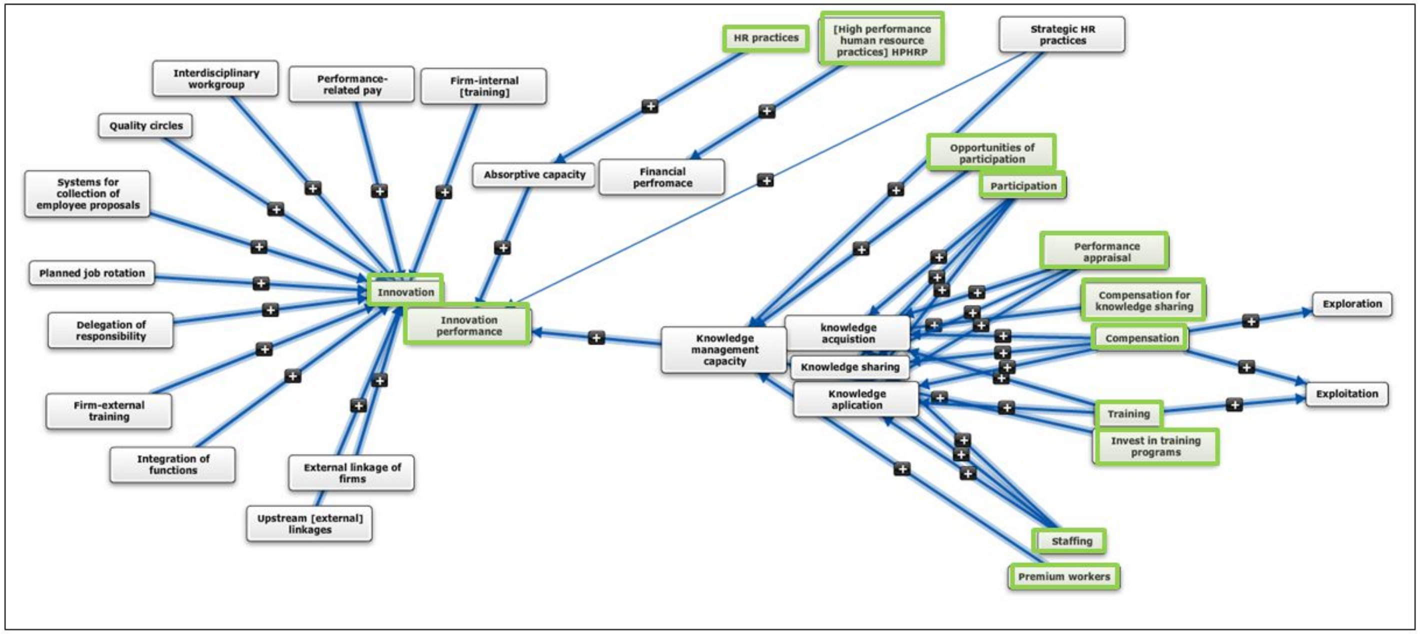

Figure 80- Human Resource Management Map, identical concepts identified

1. [High performance human resource practices] HPHRP := Strategic human resource (HR) practices
2. HR practices:= Strategic human resource (HR) practices
3. Innovation:= Innovation performanc
4. Staffing:= Staffing premium workers
5. Training:=Invest in training programs
6. Compensation:=Compensation for knowledge sharing
7. Participation:= Opportunities of participation

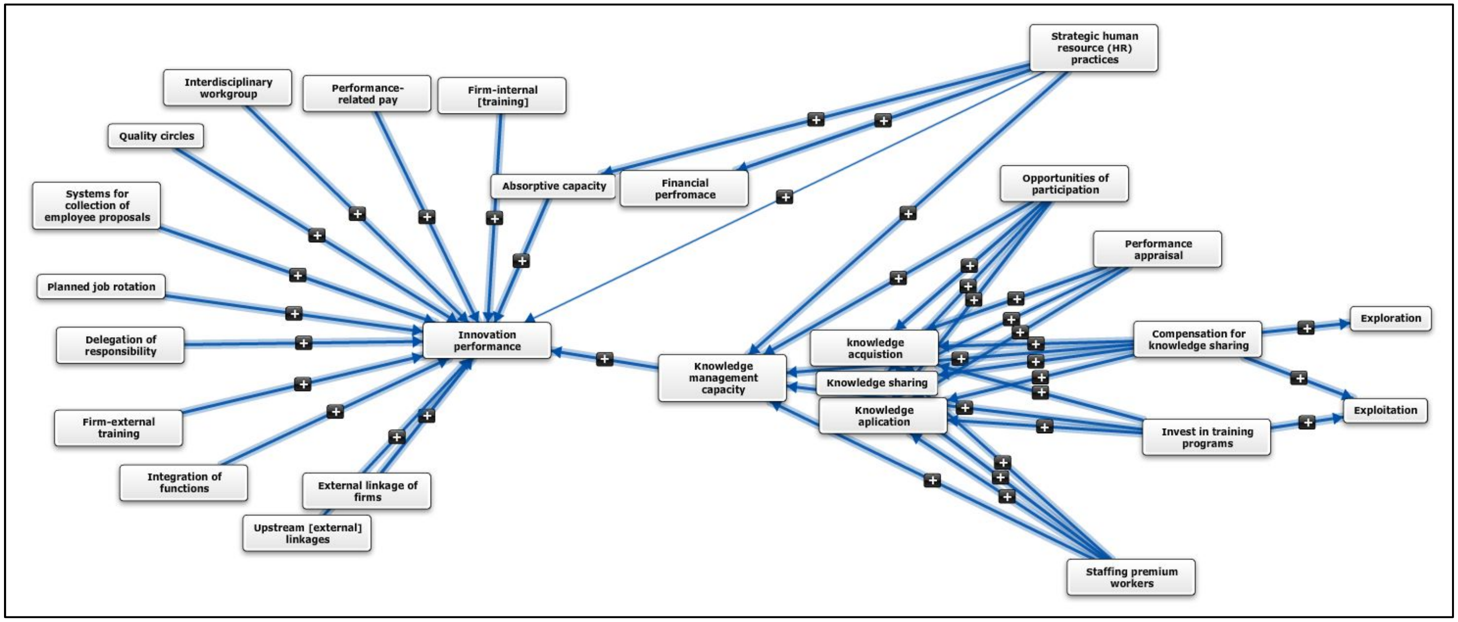

Figure 81- Human Resource Management Map, after consolidating identical concepts

Step 3: Adopt consistent terminologies for conceptually similar concepts

Not applicable.

Step 4- Tune the granularity for concepts and sub-concepts

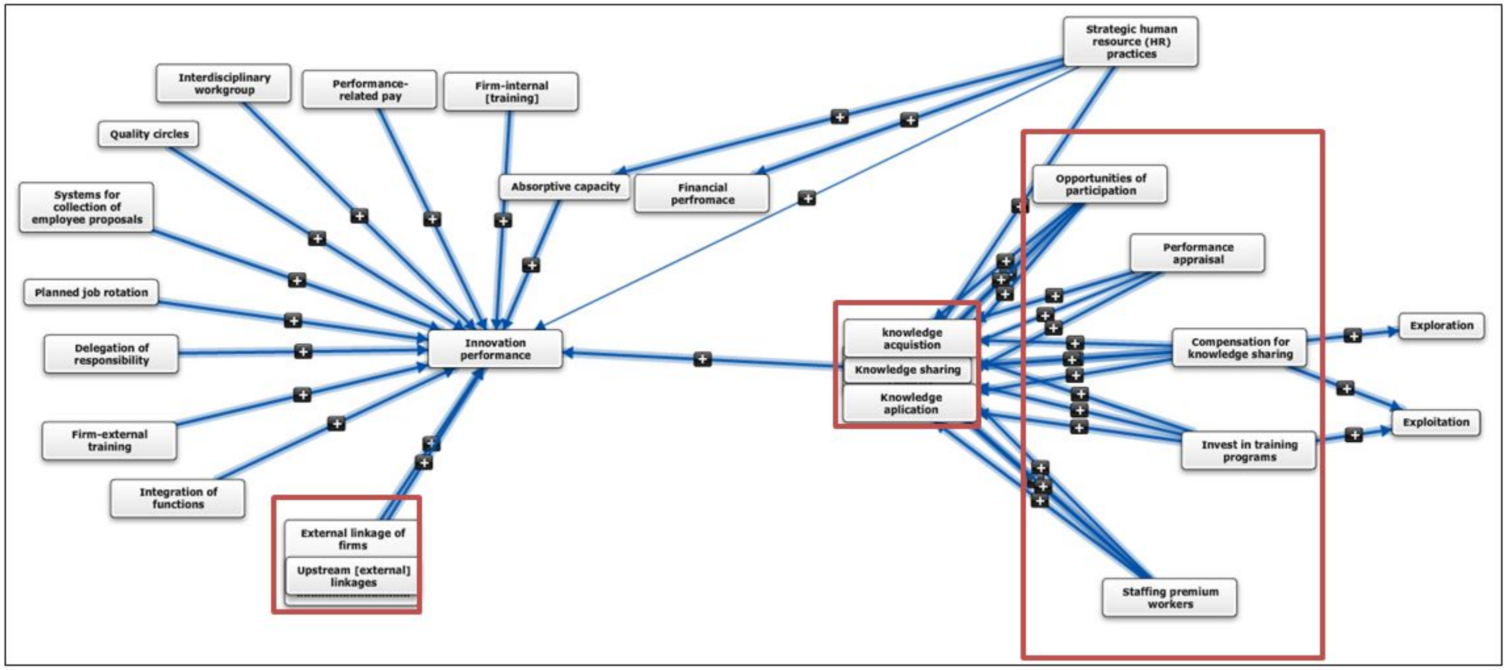

Figure 82- Human Resource Management Map granularity analyzed

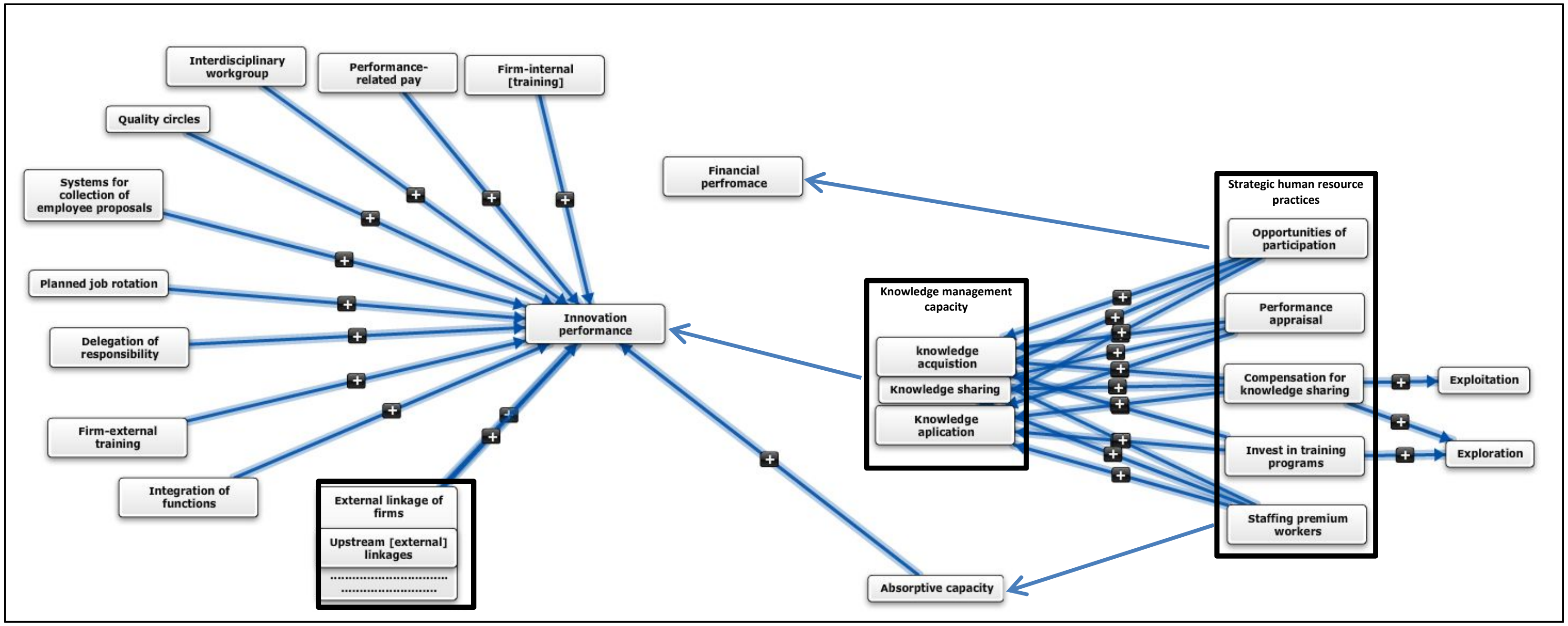

Figure 83- Human Resource Management Map with tuned granularity

Step 5-Identify and close the gaps, Receiver-Only Concepts Analysis (ROCA)

The other technique is to look for the receiver-only concepts; those with no outbound relationships. If not the object of the study themselves, then obviously they have no input to the state of the objects of the study.

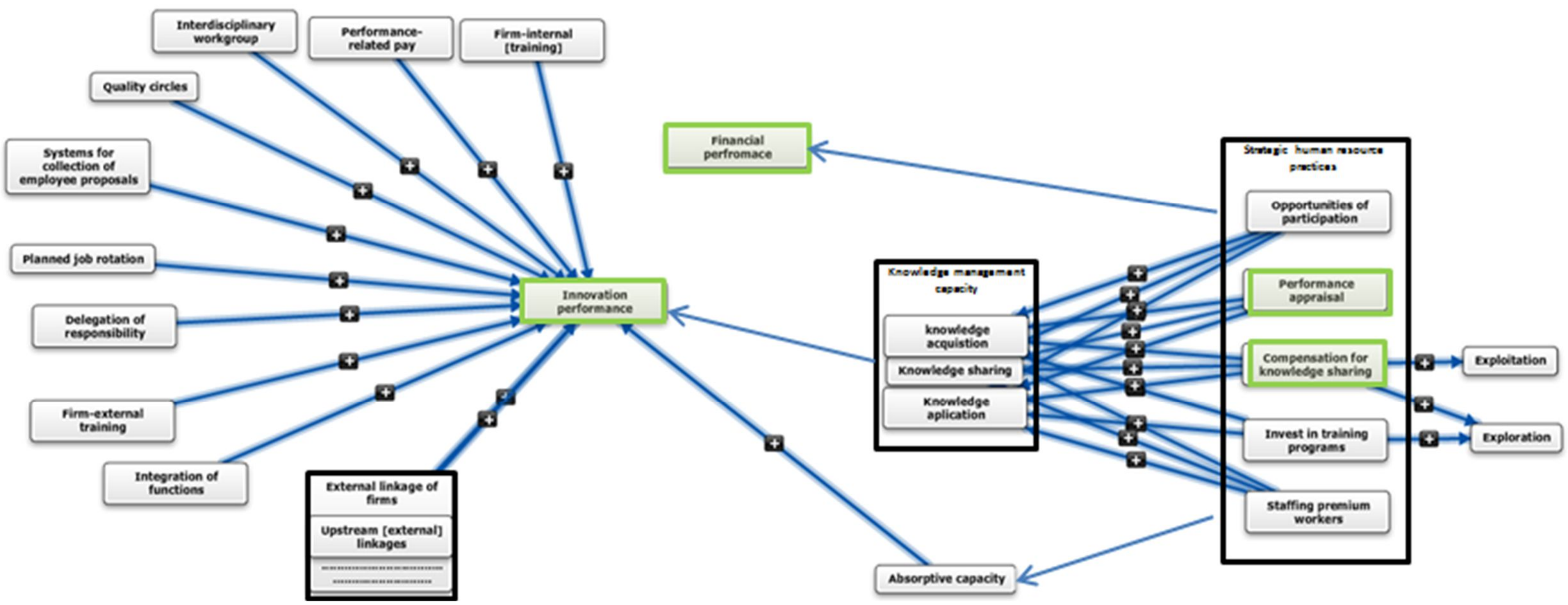

Figure 84- Human Resource Management Map with receiver-only concepts identified

Looking at the receiver concepts above, it seems obvious that *exploration* and *exploitation* are accsoisated with innovation performance. One way to solev this would be adding direct connections between exploration and exploitations to innovation performance. But it could also be resolved if considering the exploration and exploitation as subsets of innovation –or innovation performance. It is important to consider the implications of such modifactions. In this case by making this latter change we would be implying that all the *startegic human resource practices* and not only the *compensation for knowledge sharing* and *invest in training programs* –as suggested by one study- are conceted to *exploration* and *exploiation* through a mediator, *knowledge management capacity*. Also relationships in between exploration, exploitation and innovation performance will remain unclear-based on inofrmations extracted in human resource literature. In case of *innovation performance* and *financial performance*, a piece of information from ambidexterity theory could be used later on that shows a positive connection in between them.

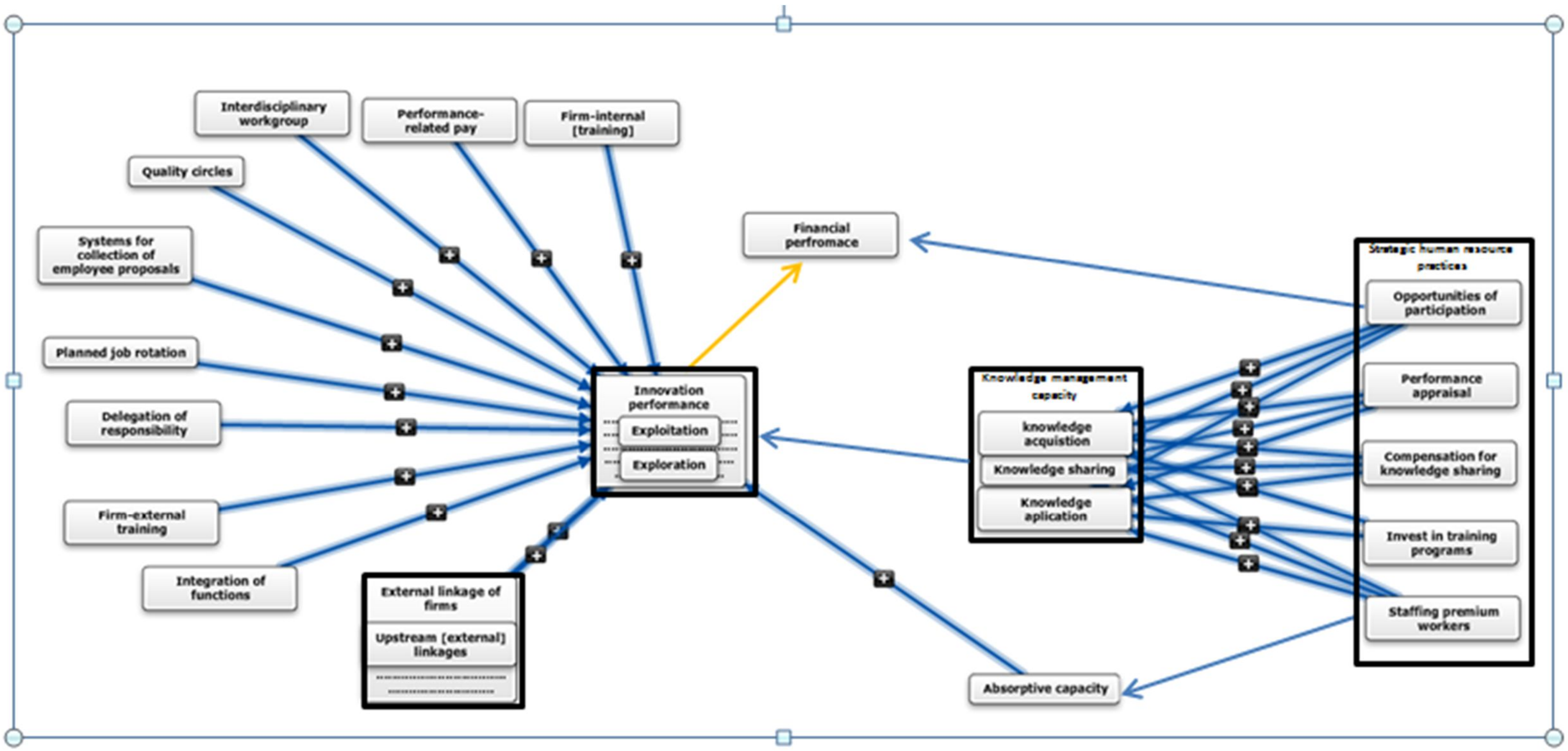

Figure 85- Human Resource Management Map after ROCA

Look up for redundant conncetions, by finding the existance of both direct and indirect conections in between two concepts. For example *strategic human resource practices* have positive impact directly on *financial performace* and indirectly through *knowledge management capacity/absorptive capacity*, and *innovation performance*. So the firect conncetion- shown as dashed line- might be a redundant connceltion if the relation is a full mediation effect.

Open Innovation Theory

Step 1: Draw the raw FCM based on the original text terminology

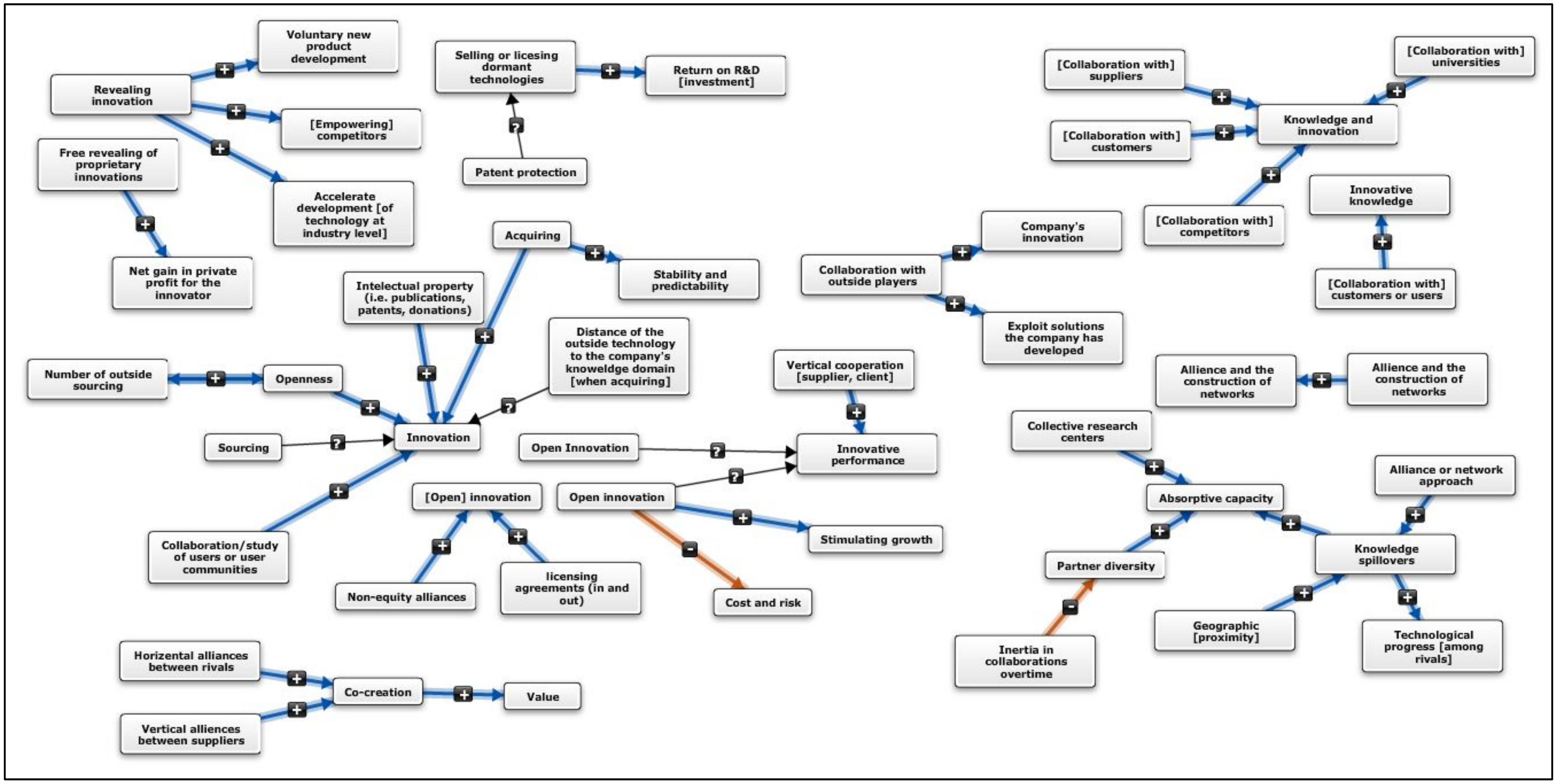

Figure 86- Open innovation map as extracted from the text

Step 2: Consolidate the identical concepts

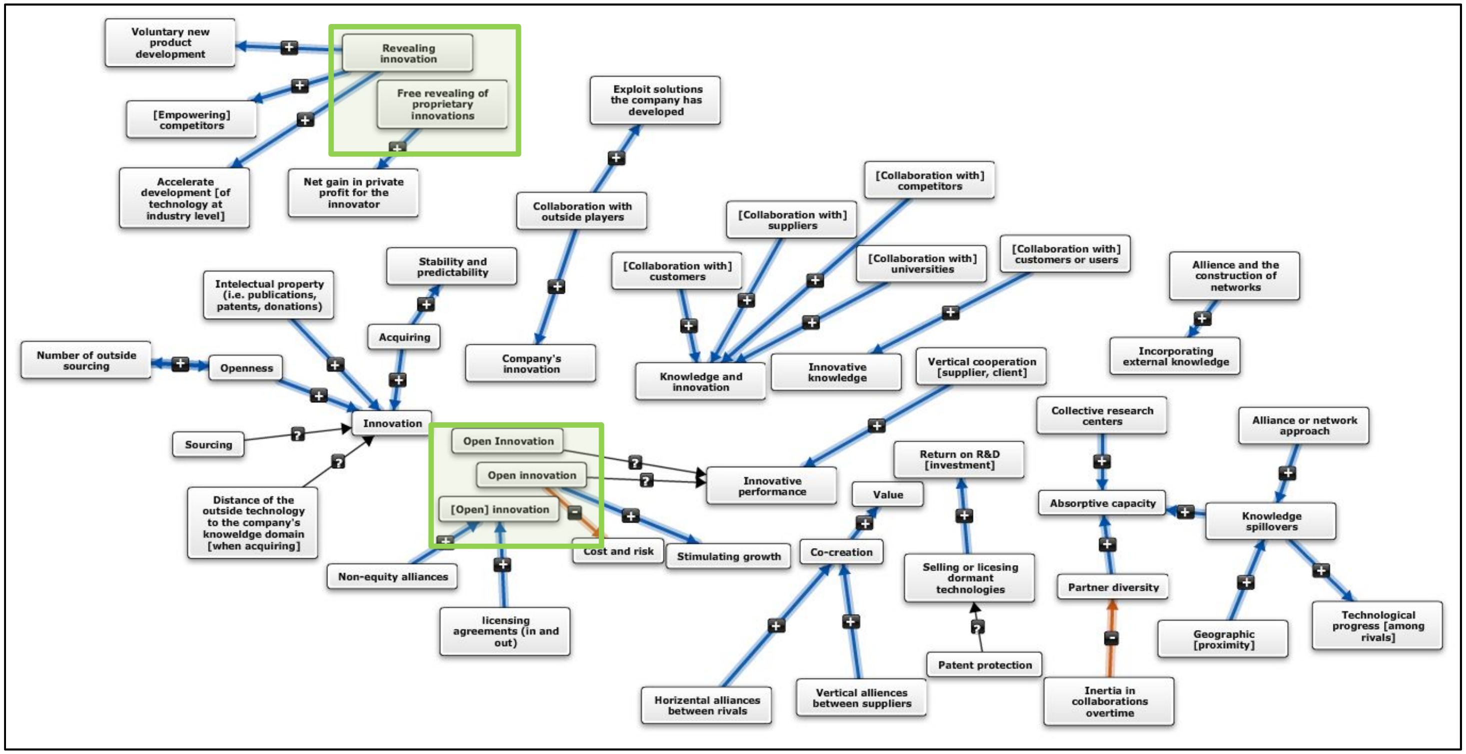

Figure 87- Open Innovation Theory Map, with identical concepts identified

1. Revealing innovation:= Free revealing of proprietary innovations
2. [open] innovation:= Open innovation

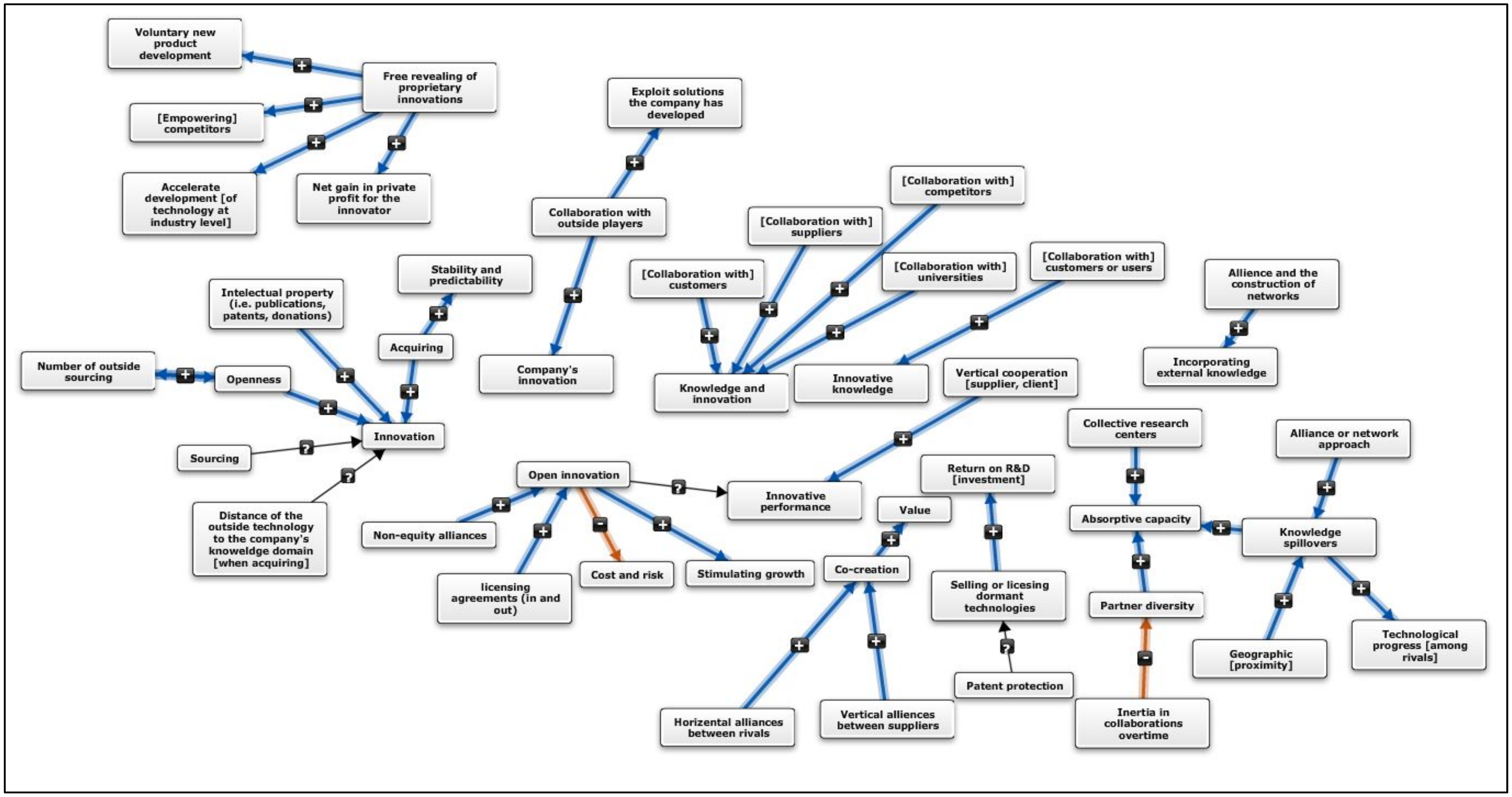

Figure 88- Open Innovation Theory Map, after consolidating identical concepts

Step 3: Adopt consistent terminologies for conceptually similar concepts

Not applicable.

Step 4- Tune the granularity for concepts and sub-concepts Step 5-Identify and close the gaps, Isolated graphs analysis (IGA)

This could be done partly by inspecting the connectedness (density) of the cognitive map. When there are isolated groups of concepts it suggests that there are either missing relations or concepts or both. Reason could be the inability of the researcher to find and extract the relevant pieces from the literature review or the lack of explicit mention of such pieces in the given stream of research. Looking at the open innovation FCM, nine isolated graphs is recognized.

Not applicable.

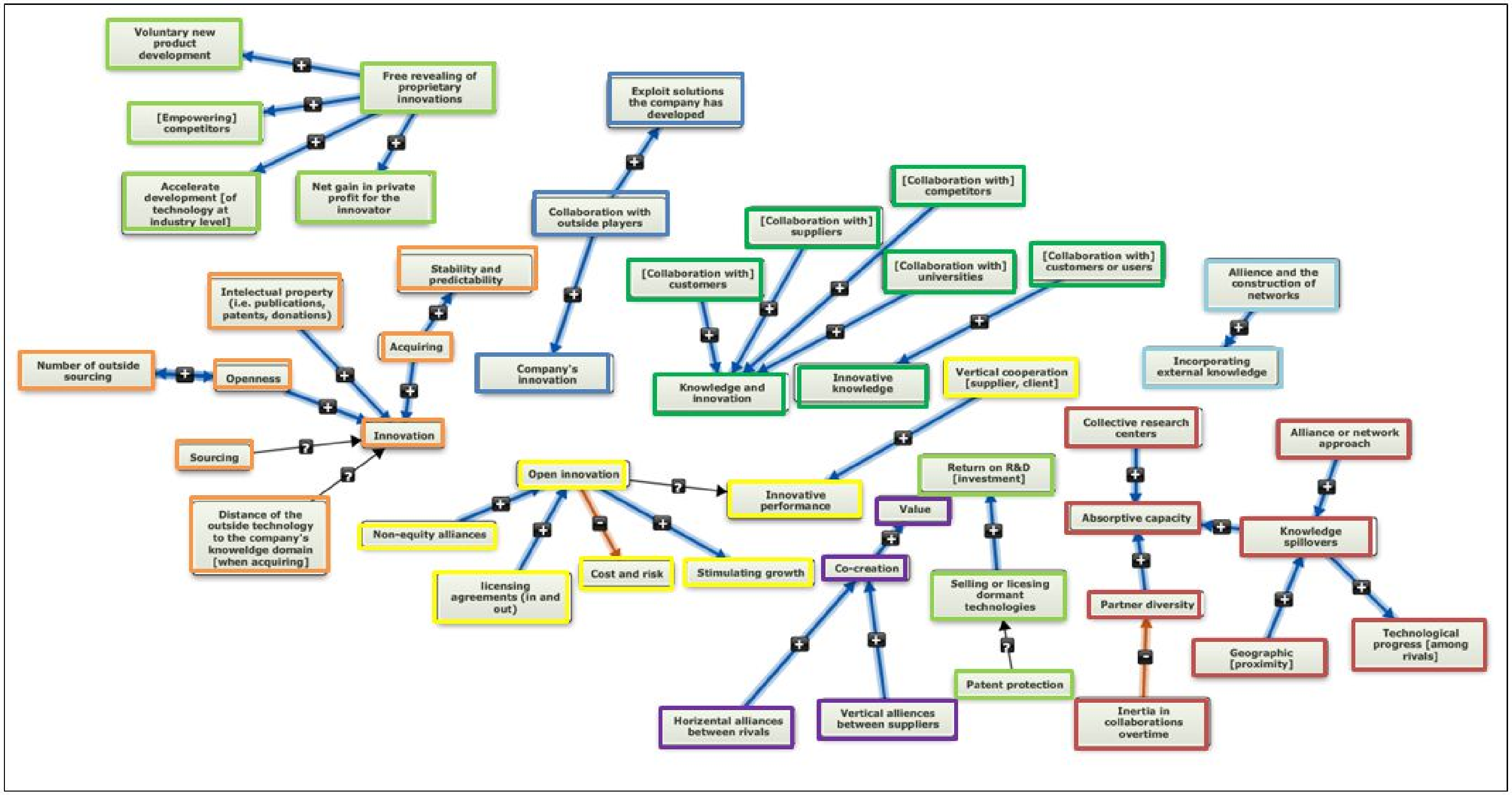

Figure 89- Open innovation theory map with isolated graphs identified

Missing connections are most likely to be found in between core concept-one with the most receiving connections- of each isolated graph. In other words that would make the most optimized/fastest network for pulses reach from any point to any point. For instance, potential connections in between open innovation, innovation, absorptive capacity, knowledge and innovation, and co-creation could be observed and speculated. The other technique is to look for the receiver-only concepts; those with no outbound relationships. If not the object of the study themselves, then obviously they have no input to the state of the objects of the study.

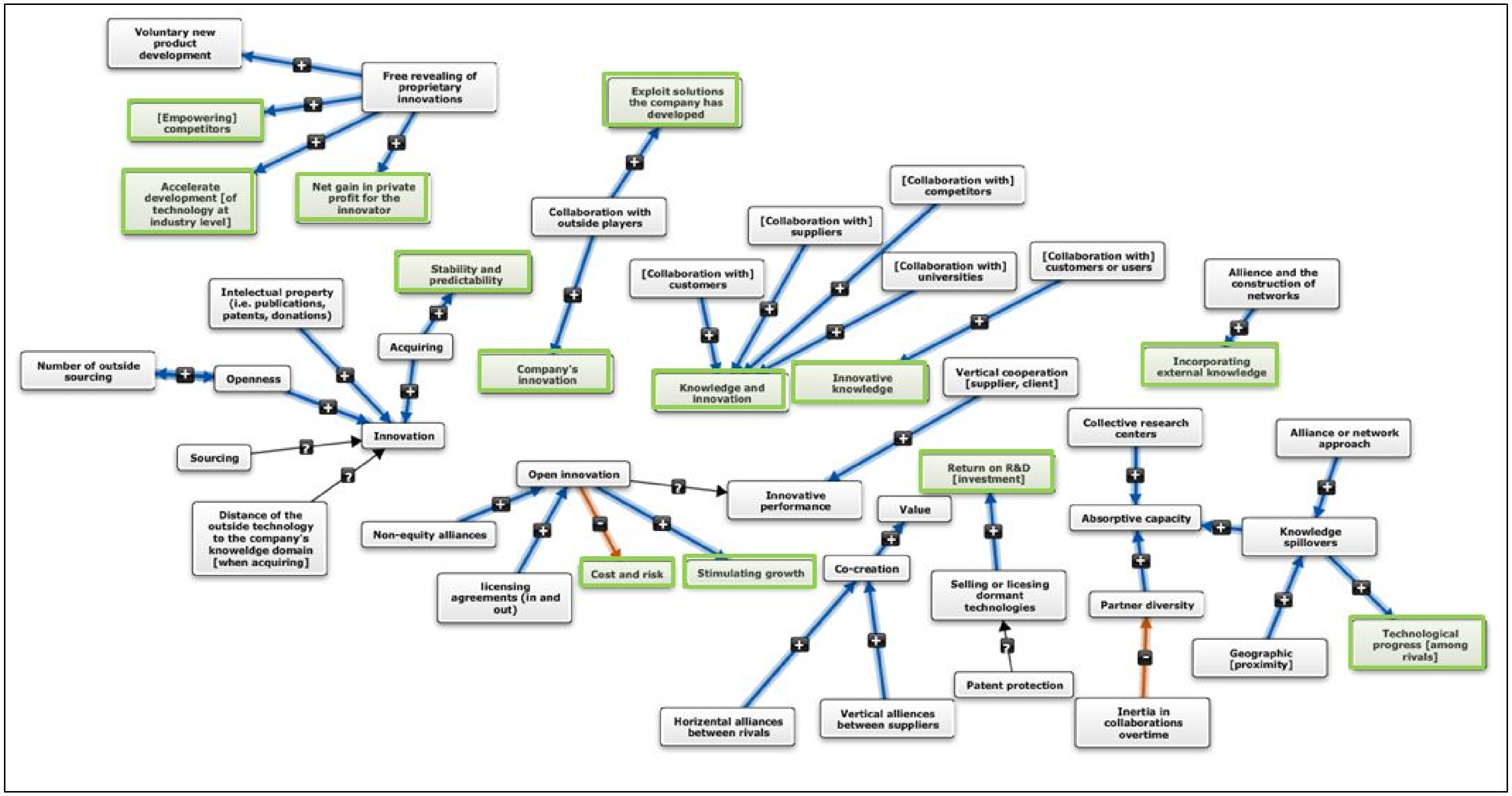

Figure 90- Open innovation theory map with receiver-only concepts identified

A clustering technique is suggested based on patterns observed among concepts. For instance here concepts are found to be part of three clusters; "who to interact", "Method of interaction" and "outcome". Receiver only concepts that fall into the outcome cluster are less of concern than other concepts such as "Empowering competitors" and "Voluntarily new product development". It now seems obvious that there should be connections between these loose ends and components inside the outcome cluster. Such connections need be investigated again.

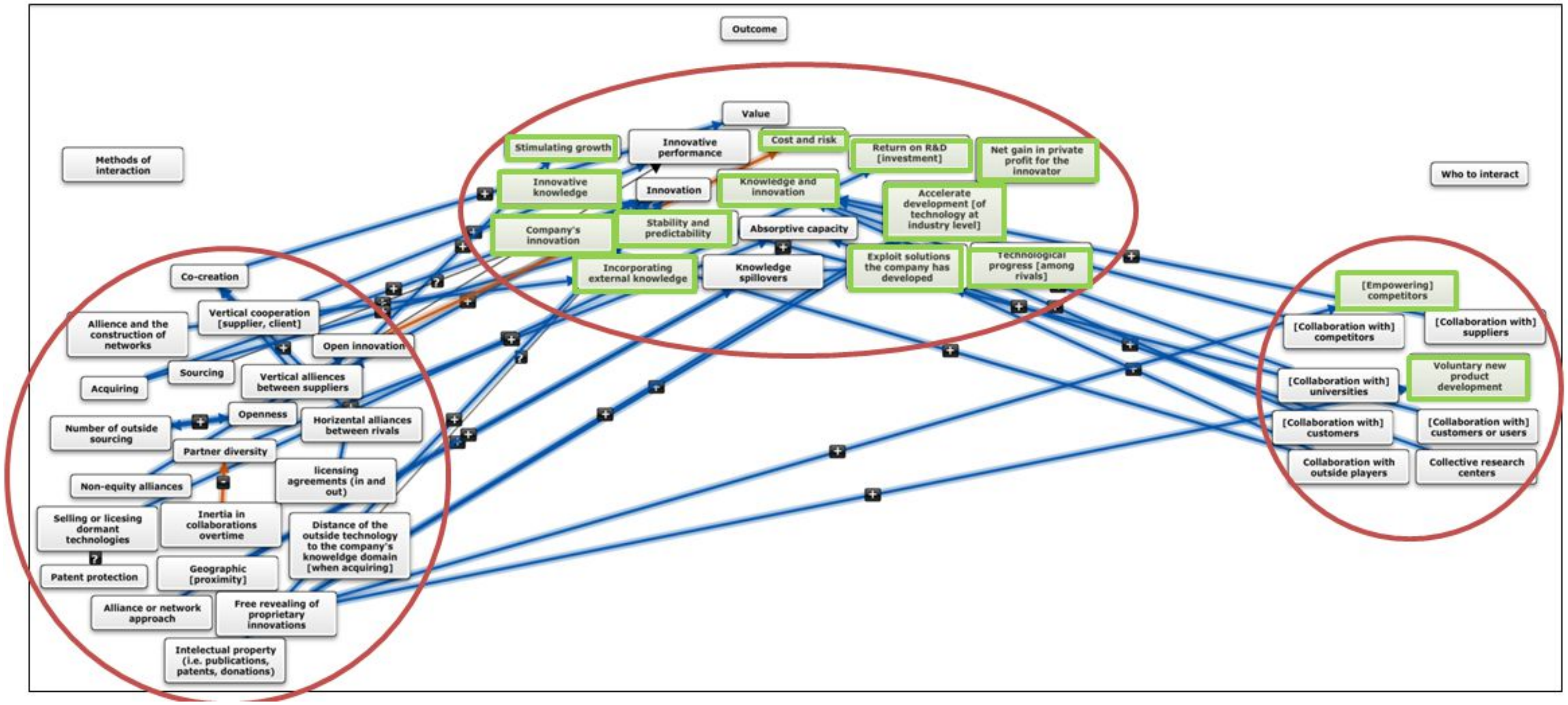

Figure 91- Open innovation theory map with receiver-only concepts analysis

1. Add positive link from "Technological progress [among rivals]" to "Stimulating growth"
2. Add positive link from "Return on R&D [investment] to "Innovation performance"
3. Add positive link from "Absorptive capacity" to "Knowledge and innovation"
4. Add link from "Incorporating external knowledge" to "Knowledge and innovation"
5. Merge Innovative knowledge" to "Knowledge and innovation"
6. Add positive link from "Innovation performance" to "Value"
7. Merge "Company's innovation" with "Knowledge and innovation"
8. Add positive link from "Exploit solutions the company has developed" to "Value"

9. Merge “Innovation” to “Knowledge and innovation”
10. Add positive link from “[Empowering] competitors” to “Technological progress [among rivals]”
11. Add positive link “Knowledge and innovation” to “Innovative performance”.
12. Add Negative link from “Cost and risk” to “Innovative performance”
13. Add positive link from “Open innovation” to “Innovative performance”.

Project Management

Step 1: Draw the raw FCM based on the original text terminology

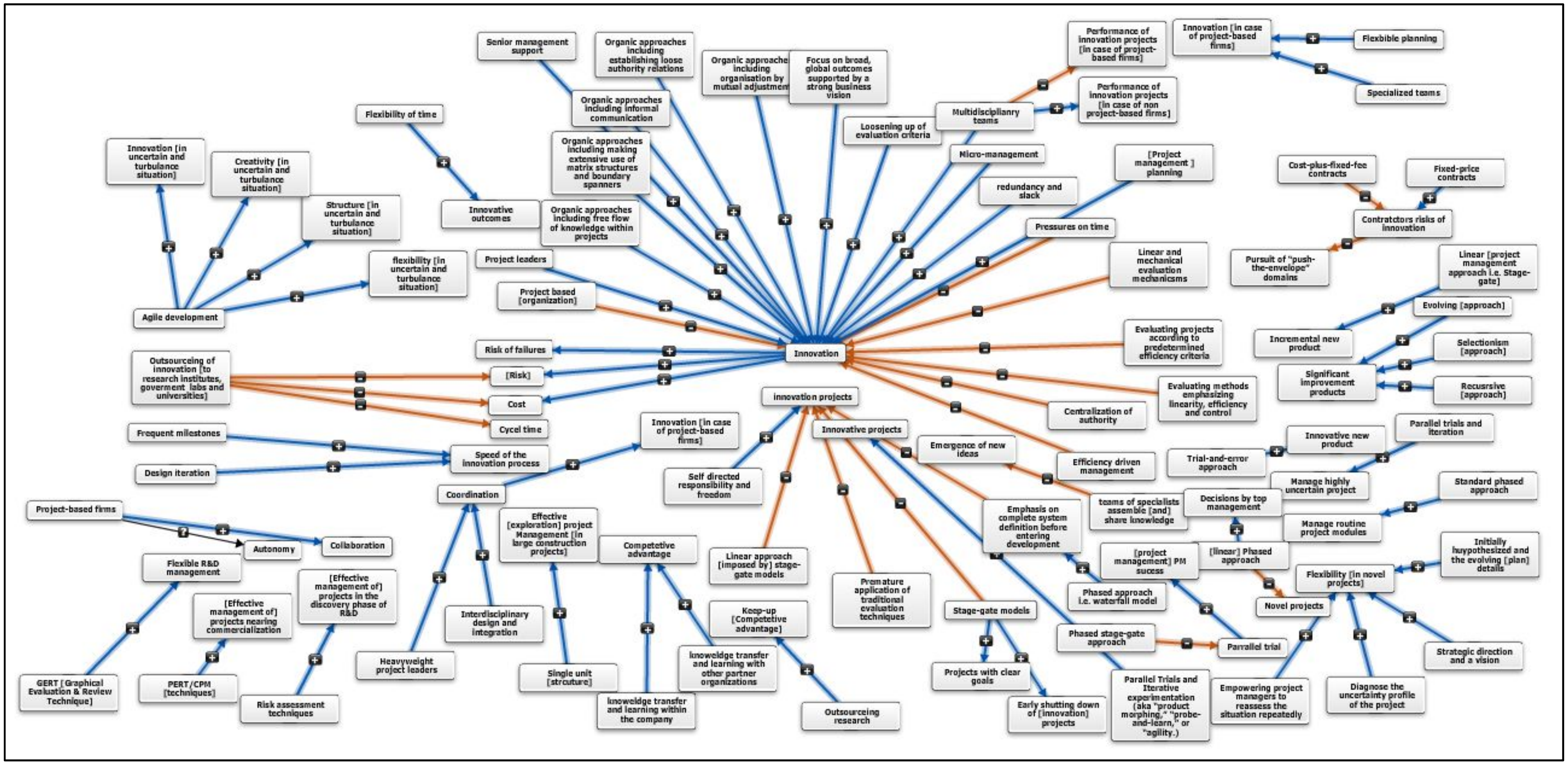

Figure 92- Raw Project Management Theory Map as extracted from the text

Step 2: Consolidate the identical concepts

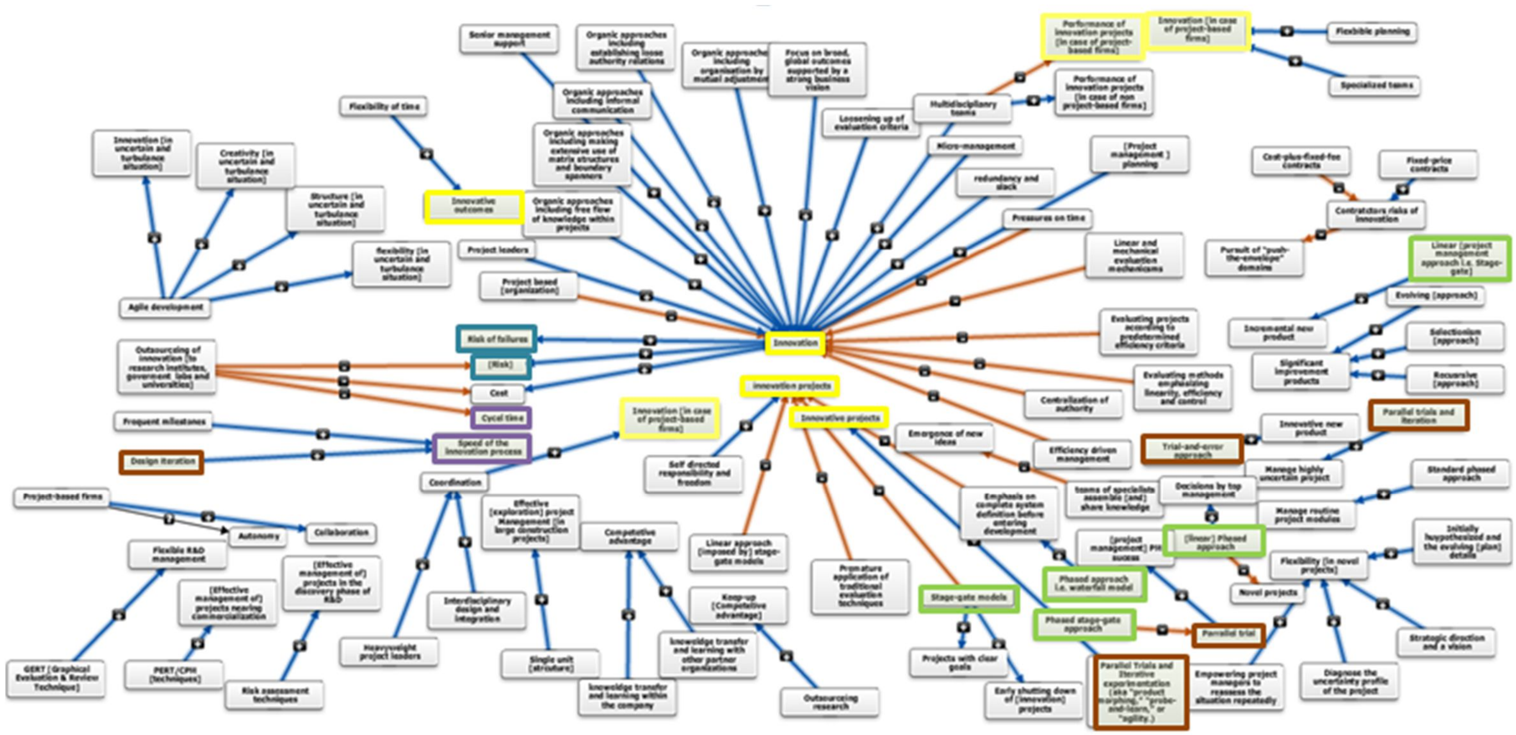

Figure 93- Project Management Theory Map, with identical concepts identified- Total number of concepts 101, number of total connections 77

1. Innovation projects:=Innovation
2. Innovative outcomes:=Innovation
3. Risk:=Risk of failure
4. Cycle time:=Innovation cycle time
5. Speed of innovation process:= Innovation cycle time
6. Merge: Innovation [in case of project based firms]
7. Split: Parallel trials and iteration> Parallel trials , Design Iteration
8. Split: Parallel Trials and Iterative experimentation (aka "product morphing," "probe-and-learn," or "agility.) > Parallel trials , Design Iteration
9. Trial-and-error approach:= Parallel trials
10. Parallel trail:= Parallel trials
11. Phased approach i.e. waterfall model:= [Linear] phased approach (i.e. waterfall models and stage-gate)
12. Stage gate models:= [Linear] phased approach (i.e. waterfall models and stage-gate)
13. Phased stage-gate approach:= [Linear] phased approach (i.e. waterfall models and stage-gate)

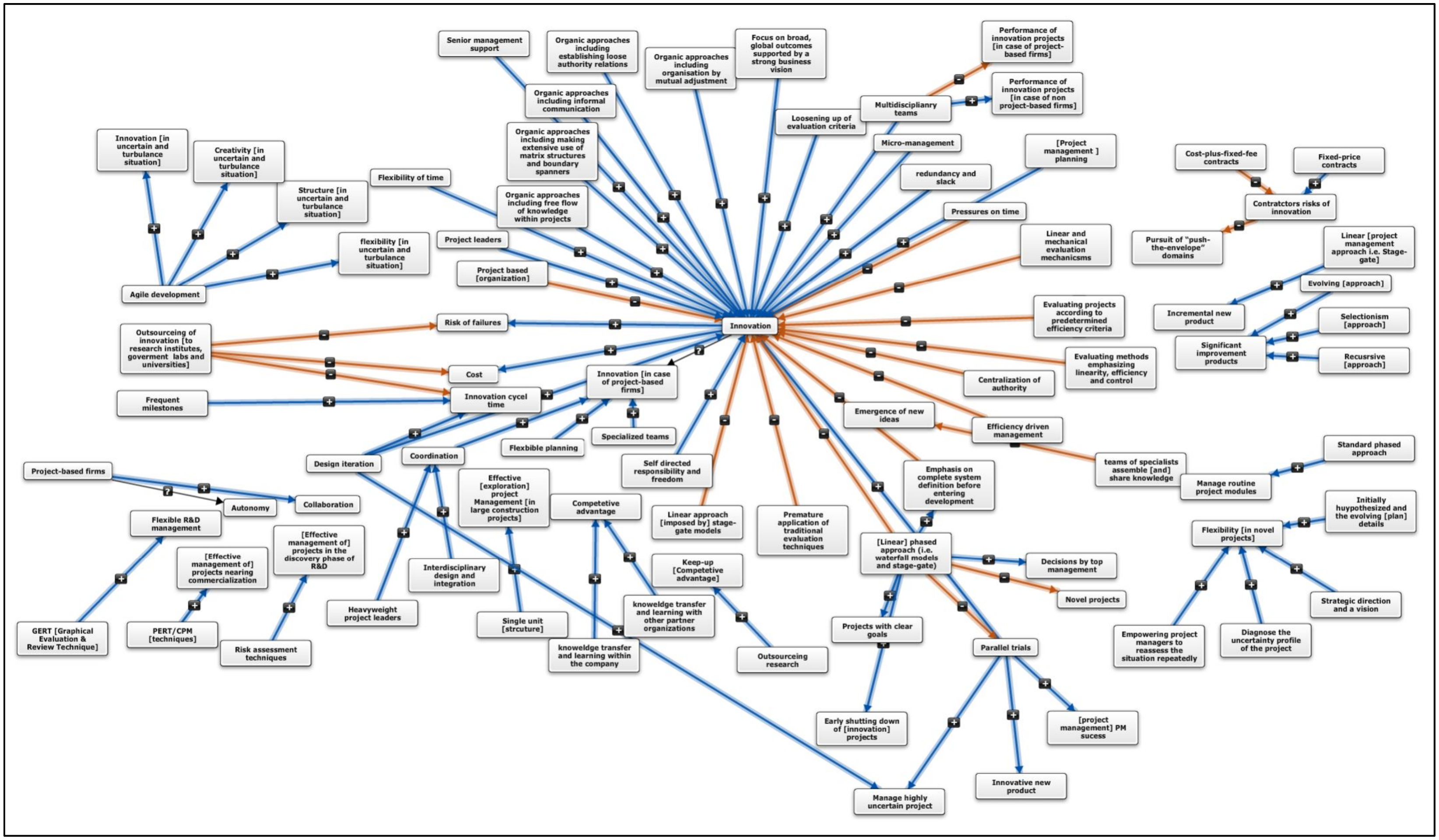

Figure 94- Project Management Theory Map, after consolidating identical concepts

Collective FCM

Before incorporating inter-coder reliability check inputs:

{Ambidexterity CollectiveFCM Rev2-1 (5-6-17)}

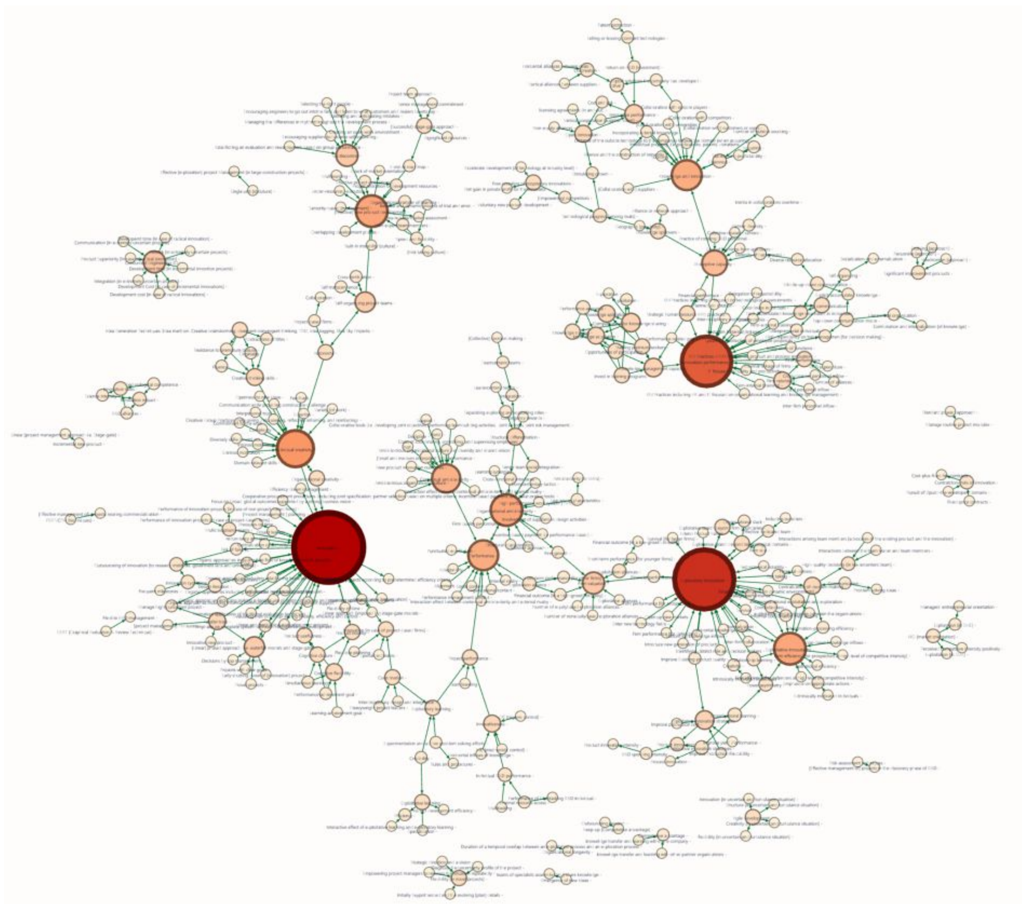

Figure 95-Ambidexterity CollectiveFCM Rev2-1 (5-6-17)

After incorporating inter-coder reliability check inputs:

1- Objection is accepted, the FCM would be changed to consider the creating an open work environment as child of Subtle control
2- Objection is accepted, the FCM would be changed to consider the "Encouraging engineers' as child of Subtle control
3- 1 and 2 got expanded to all the children of the Subtle control
4- Objection, is acceptable, direction of causality remain the same but the sign will be corrected

5- Objection is accepted, the FCM would be changed to consider the "Alliance and the .." as child of incorporating external knowledge (External knowledge was removed)

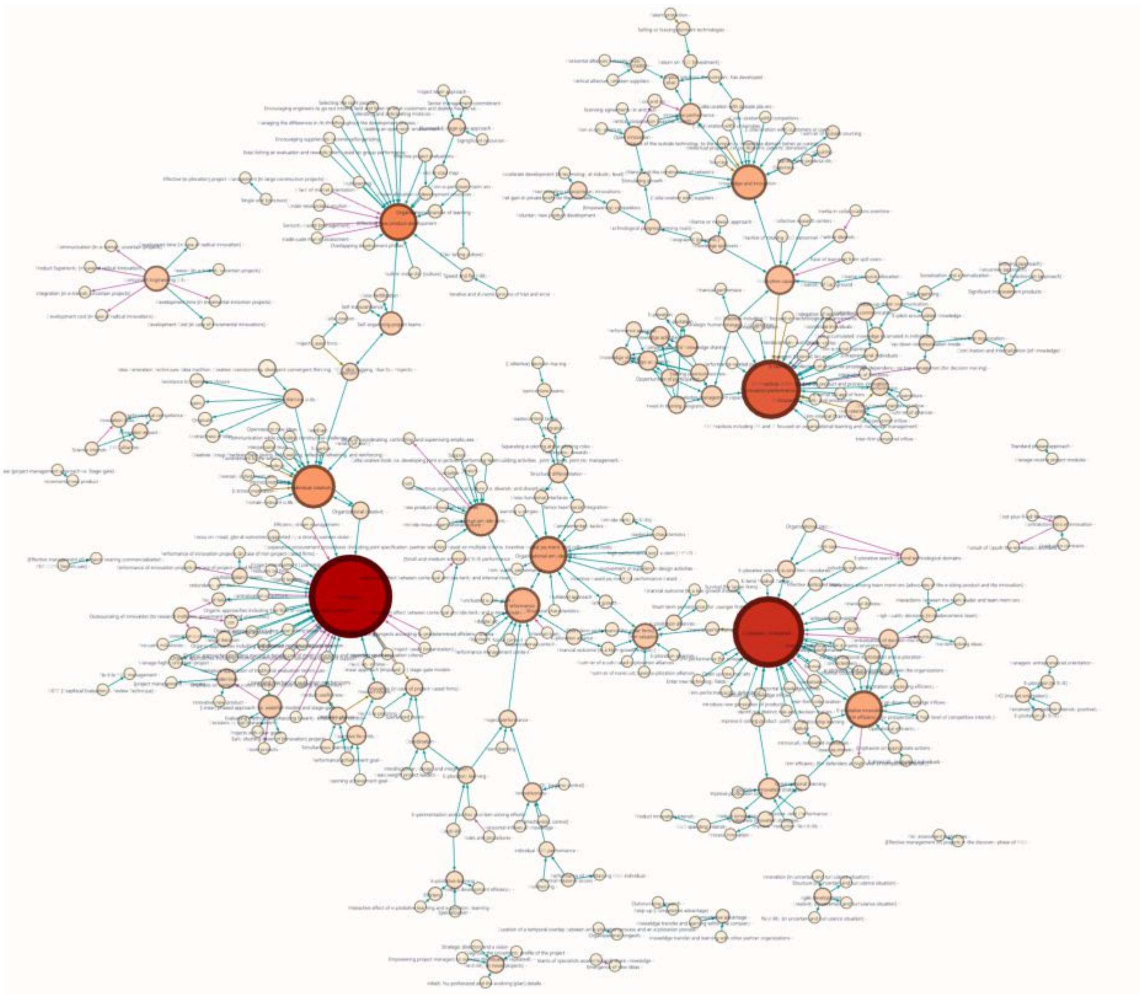

Figure 96- Ambidexterity CollectiveFCM Rev2-1 (5-6-17) after incorporating inter-coder reliability check inputs

Double check all the steps at individual FCM levels:
Following changes for HRM fcm (parent children) was implemented

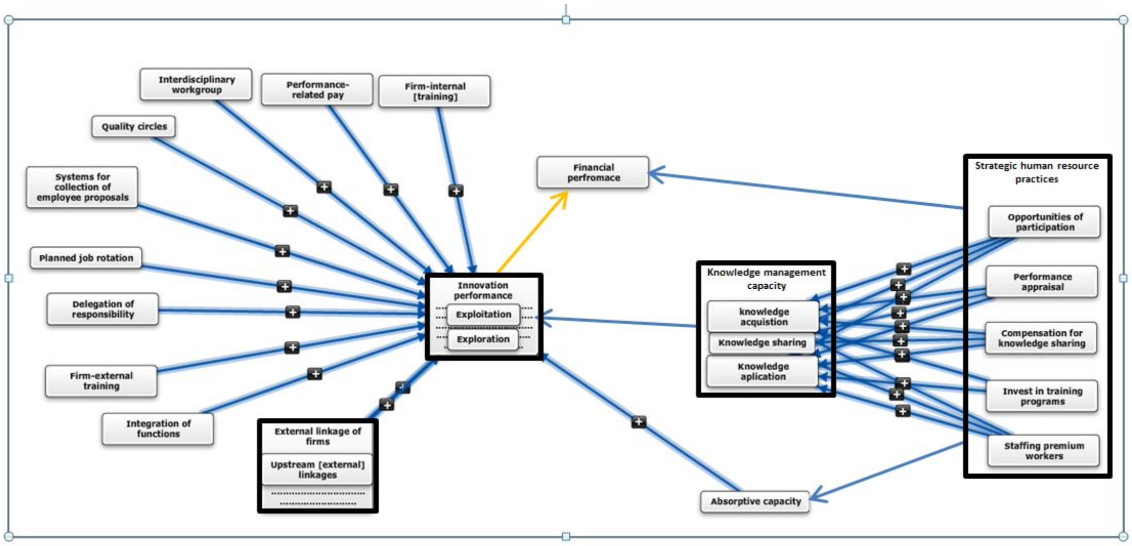

Figure 97- HRM network after modifications for granularity

Strategic human resource practices were removed and children were preserved. All children inherited a causal link to absorptive capacity as well. For the knowledge management capacity in the other parent was preserved and children were realized to be not important for the map so removed. Exploration and exploitation were left for now

This was not implemented at the individual level since for inter-coder reliability check actually suggested causal effects were needed but now collective FCM is reviewed by researcher before sending out to the experts.

Applying 5 steps to collective FCM:

Now I am going through same iterations for the collective FCM that I did for individual ones as following:

Step1-Draw the raw FCM based on the original text terminology

This is Ambidexterity CollectiveFCM Rev3 (5/7/17). Note that many of the concepts have merged or modified during the first tuning at individual FCM level. So this collective FCM might is not raw in a sense that was used at that level.

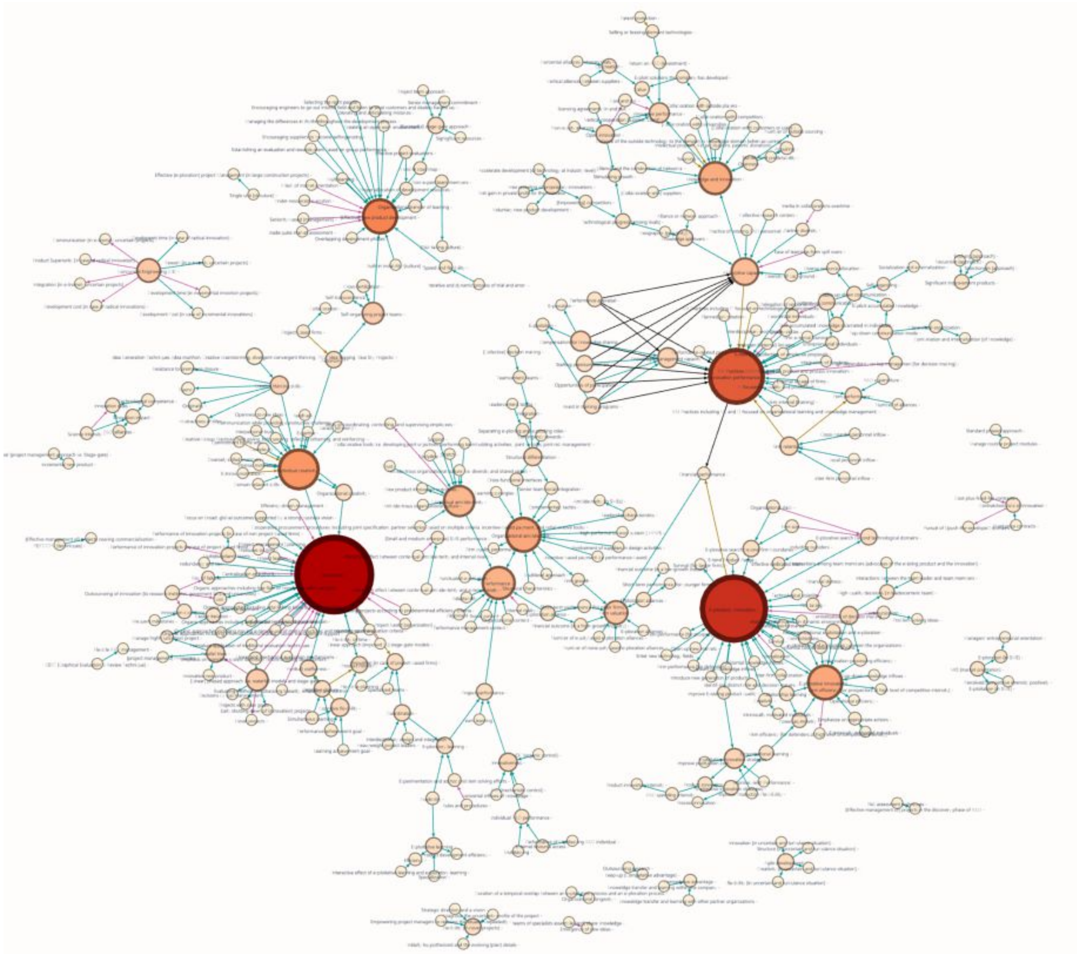

Figure 98- Raw collective FCM

Step2- Consolidate the identical concepts

1- Merge Exploration alliance and Exploration alliances and keep the “Exploration alliances” label
2- Merge Ambidextrous organizational culture (i.e. diversity and shared vision) and Ambidextrous organizational culture (remove the second one)
3- Merge “Cost” and “Cost and risk”, merge “Cost” and Merge “Risk” and “Risk of failure”

Step3- Adopt consistent terminologies for conceptually similar concepts

Not applicable.

Step4- Tune the granularity for concepts and sub-concepts

Not Applicable.

Step5- Identify and close the gaps

- Isolated graph analysis

Add a positive link from Concurrent engineering to "[Effective] new product development"
Add a positive link from "Innovation rates" to "Innovation"
Add a positive link from "Innovation impact" to "Innovation"
Add a positive link from "Significant improvement products" to "Exploratory innovation"

There is no explicit mention of how different product development methods fit for exploratory or exploitative innovations?

Add a positive link from "Flexibility [in uncertain and turbulence situation]" to "Exploratory innovation"

Merge "Flexibility [in uncertain and turbulence situation]" into "Speed and flexibility"

Merge "Improve production flexibility" into "Speed and flexibility"

Add a positive link from "Flexibility in novel projects" to "Speed and flexibility"

Merge "Creativity" to "Individual creativity"

Merge "Creativity [in uncertain and turbulence situation]" to "Individual creativity".

Add a negative link from "Contractors risk of innovation" to "Knowledge and innovation"

Merge the "Sourcing" to "[Collaboration with] suppliers] and call them "Sourcing and [Collaboration with] suppliers"

Outcome would be as represented by Ambidexterity CollectiveFCM Rev5-0(5-13-17) as shown below

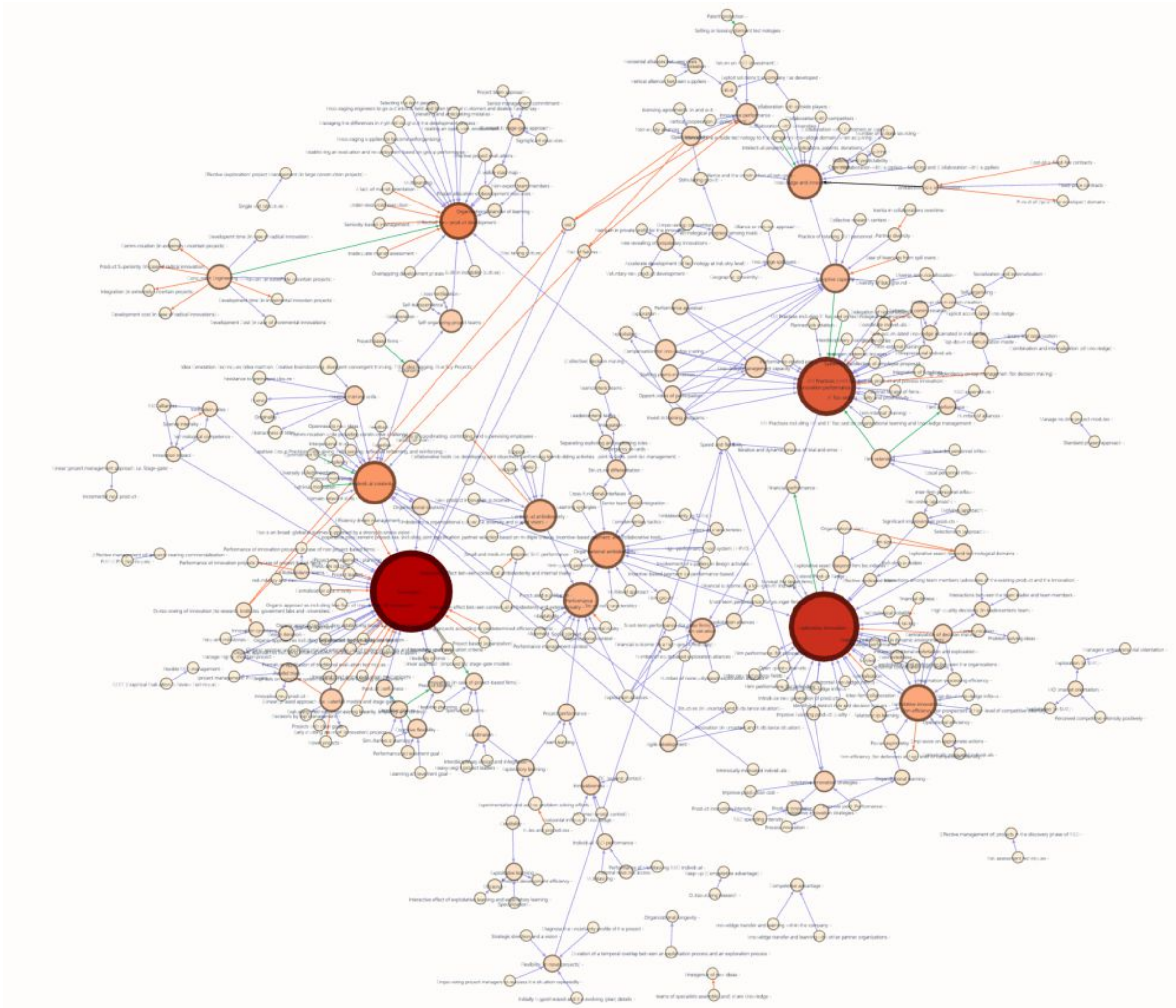

Figure 99- Collective FCM after modifications

Performed layout algorithm, ForceAtlas2, for a better view of isolated graph analysis as shown below:

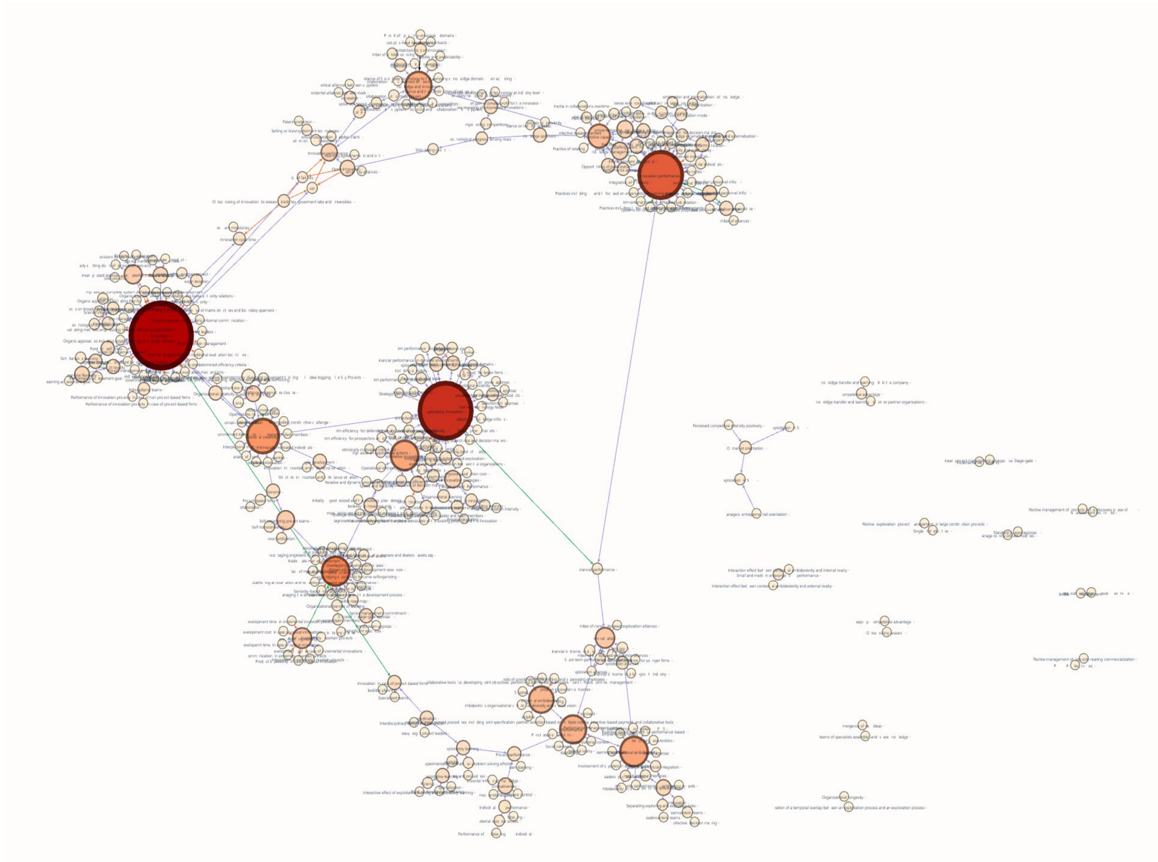

Figure 100-Collective FCM before Isolated graph analysis

Now with disconnected graphs identified,

Merge “Exploration [in SME]” to “Exploratory innovation”

Merge “Exploitation [in SME]” to “Exploitative innovation]”

Merge “Keep-up [competitive advantage]” into “Competitive advantage”

Merge “Survival”, “Survival [for larger firms]” into “Organizational longevity”

Add a positive link from “Incremental new product” to “Exploitative innovation”

Merge “[Small and medium enterprise] SME performance” into “Performance”

Add a positive link from “Effective [exploration] project Management [in large construction projects]” to “Exploitative innovation”

Add a positive link from “Effective [exploration] project Management [in large construction projects]” to “Exploratory innovation”

Add a positive link from “Competitive advantage” to “Performance”

Add a positive link from “[Effective management of] projects nearing commercialization” to “exploitative innovation”

Add a positive link from “Emergence of new ideas” to “Exploratory innovation”

Add a positive link from “Flexible R&D management” to “Exploratory innovation”

Add a positive link from “Manage routine project modules” to “Exploitative innovation”

Result as shown in figure below is a giant component as saved in Ambidexterity CollectiveFCM Rev5-1(5-13-17)

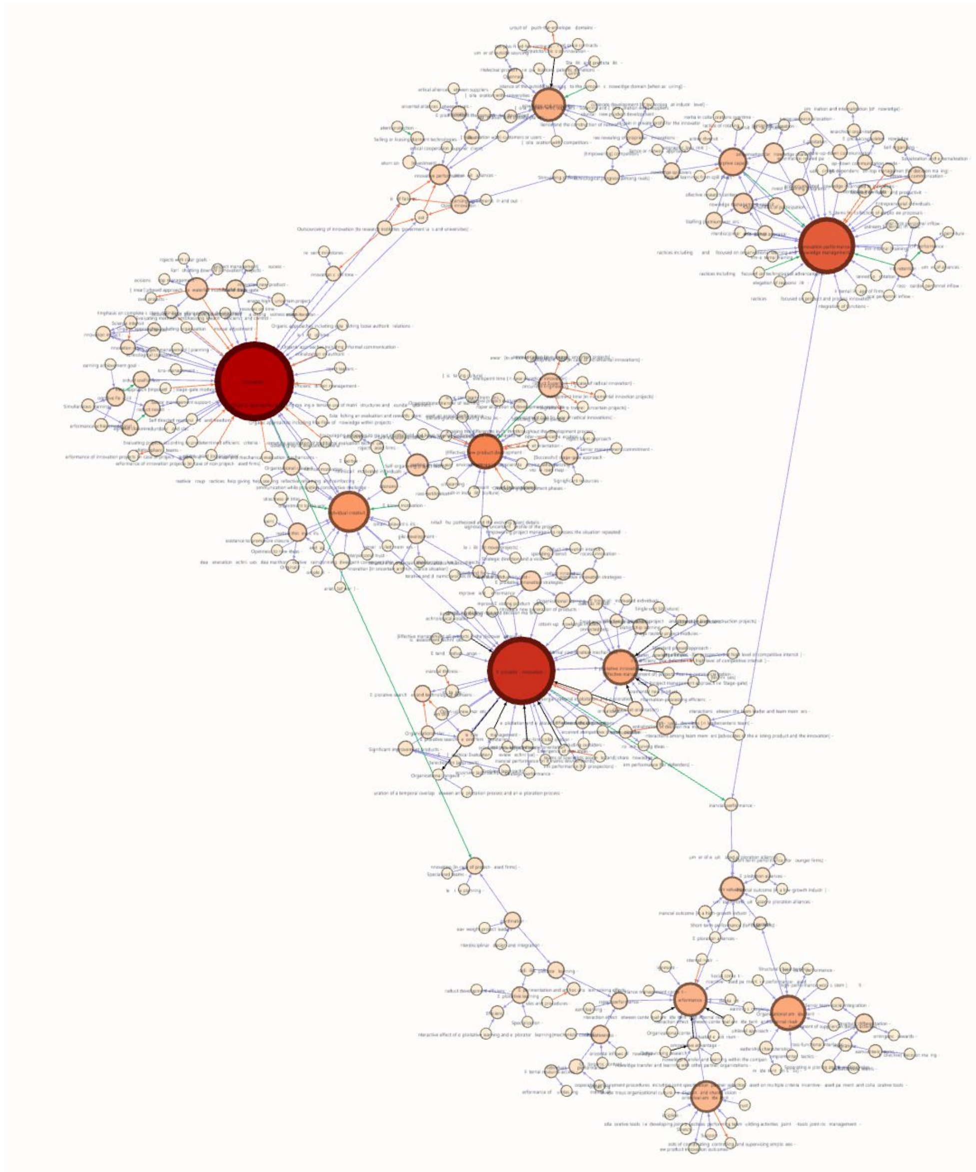

Figure 101-Collective FCM after Isolated graph analysis

Receiver only Concept analysis

Firm performance is an receiver-only concept so it can be merged “Firm performance” into “Performance” and call it “Merge performance”

Ambidexterity CollectiveFCM Rev5-2(5-13-17)

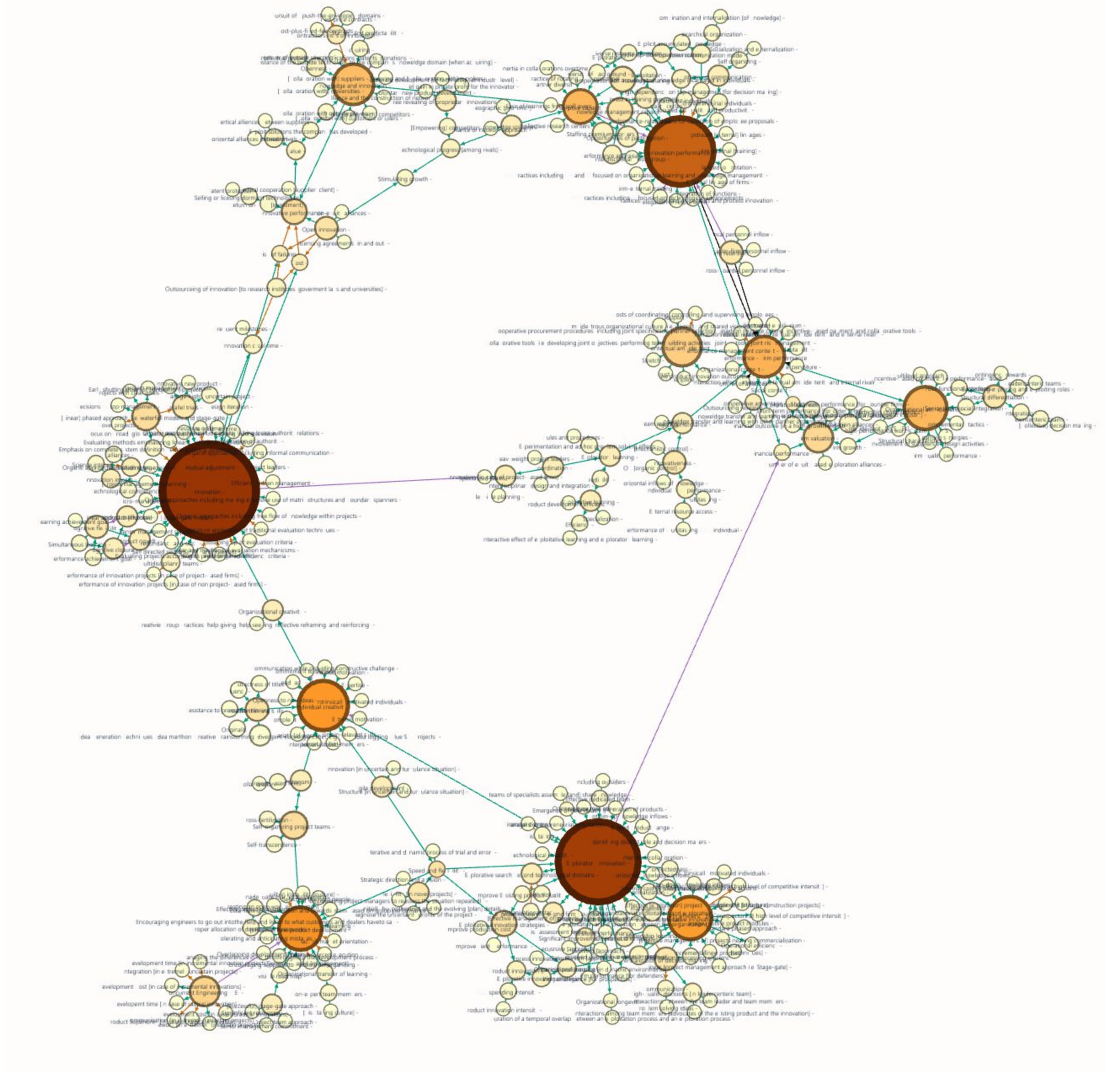

Figure 102- Collective FCM after Receiver Only Concept Analysis

"Innovation [in case of project based firm]" is a receiver only concept, a positive link is added from "Innovation [in case of project based firm]" to "Innovation"

After all the modifications as described in extreme scenario analysis (Rev 7-3)

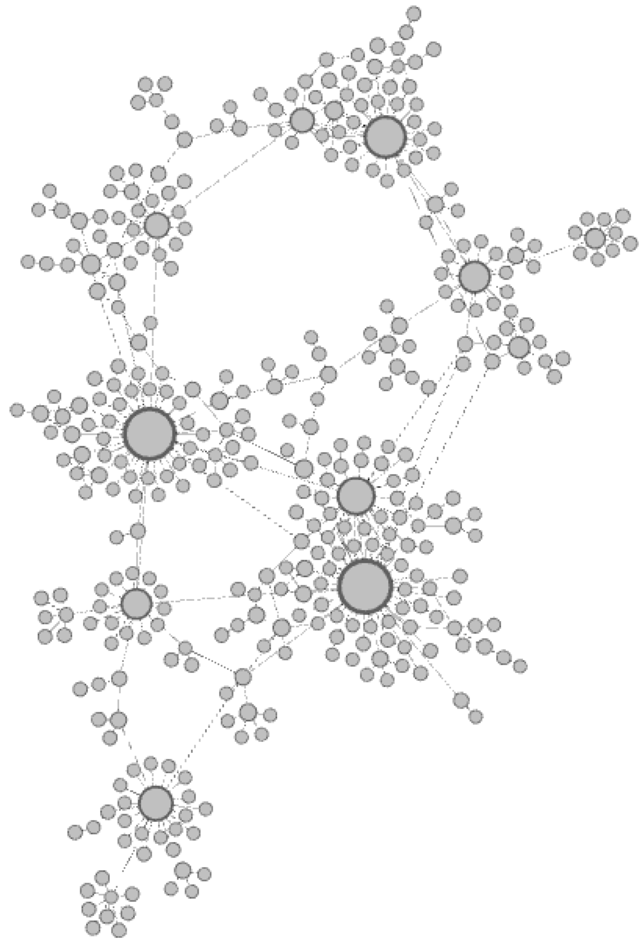

Figure 103- Collective FCM after all the modifications

Now with performing ROCA again finds that following concepts have 1 zero-out degree:

Table 13- concepts with 1 zero-out degree

ID	INDEGREE	OUTDEGREE	ACTION
[EFFECTIVE] NEW PRODUCT DEVELOPMENT	21	0	Can't be activated See note
PERFORMANCE	18	0	OK-Outcome
FIRM VALUATION	8	0	OK-Outcome
PRODUCT INNOVATION	3	0	OK-Outcome
HIGH-QUALITY DECISIONS [IN LEADER ENTERIC TEAM]	3	0	Can't be activated
VALUE	3	0	OK-Outcome
INNOVATION CYCLE TIME	3	0	See note
INTEGRATION	2	0	See note
ORGANIZATIONAL LONGEVITY	2	0	OK-Outcome
EXPLOITATION	2	0	See note
STIMULATING GROWTH	2	0	Can't be activated
MANAGE HIGHLY UNCERTAIN PROJECT	2	0	Can't be activated
EXPLICIT ACCUMULATED KNOWLEDGE	2	0	Can't be activated
PURSUIT OF "PUSH-THE-ENVELOPE" DOMAINS	1	0	Can't be activated
[RISK TAKING CULTURE]	1	0	See note
DEVELOPMENT COST [IN CASE OF RADICAL INNOVATIONS]	1	0	OK-Outcome
PRODUCT SUPERIORITY [IN CASE OF RADICAL INNOVATION]	1	0	OK-Outcome
COMMUNICATION [IN EXTREMELY UNCERTAIN PROJECTS]	1	0	OK-Outcome
REWORK [IN EXTREMELY UNCERTAIN PROJECTS]	1	0	OK-Outcome
INTEGRATION [IN EXTREMELY UNCERTAIN PROJECTS]	1	0	See note
DEVELOPMENT TIME [IN INCREMENTAL INNOVATION PROJECTS]	1	0	OK-Outcome
DEVELOPMENT COST [IN CASE OF INCREMENTAL INNOVATIONS]	1	0	OK-Outcome
DEVELOPMENT TIME [IN CASE OF RADICAL INNOVATION]	1	0	OK-Outcome
PROCESS INNOVATION	1	0	Can't be activated
PRODUCT INNOVATION INTENSITY	1	0	Can't be activated
FINANCIAL PERFORMANCE [IN DYNAMIC ENVIRONMENTS]	1	0	Can't be activated
PROBLEM SOLVING IDEAS	1	0	Can't be activated
STRATEGIC PERFORMANCE	1	0	OK-Outcome
FIRM EFFICIENCY [FOR DEFENDERS AT HIGH LEVEL OF COMPETITIVE INTENSITY]	1	0	OK-Outcome

FIRM EFFICIENCY [FOR PROSPECTORS AT HIGH LEVEL OF COMPETITIVE INTENSITY]	1	0	OK-Outcome
CONTINGENCY REWARDS	1	0	Can't be activated
SHORT-TERM PERFORMANCE [FOR YOUNGER FIRMS]	1	0	OK-Outcome
FINANCIAL OUTCOME [IN A LOW-GROWTH INDUSTRY]	1	0	OK-Outcome
FIRM PERFORMANCE [FOR PROSPECTORS]	1	0	OK-Outcome
FIRM PERFORMANCE [FOR DEFENDERS]	1	0	OK-Outcome
AMBIDEXTERITY [IN SMES]	1	0	Can't be activated
PERFORMANCE OF MULTITASKING R&D INDIVIDUAL	1	0	OK-Outcome
COSTS OF COORDINATING, CONTROLLING, AND SUPERVISING EMPLOYEES	1	0	Can't be activated
FIRM QUALITY PERFORMANCE	1	0	Can't be activated
NEW PRODUCT INNOVATION OUTCOMES	1	0	Can't be activated
ORIGINALITY	1	0	Can't be activated
ABSTRACTNESS OF TITLES	1	0	Can't be activated
FLUENCY	1	0	Can't be activated
RESISTANCE TO PREMATURE CLOSURE	1	0	Can't be activated
EXPLORATION	1	0	See note
VOLUNTARY NEW PRODUCT DEVELOPMENT	1	0	Can't be activated
ACCELERATE DEVELOPMENT [OF TECHNOLOGY AT INDUSTRY LEVEL]	1	0	Can't be activated
STABILITY AND PREDICTABILITY	1	0	Can't be activated
NET GAIN IN PRIVATE PROFIT FOR THE INNOVATOR	1	0	OK-Outcome
PROJECTS WITH CLEAR GOALS	1	0	See note
EARLY SHUTTING DOWN OF [INNOVATION] PROJECTS	1	0	Can't be activated
STRUCTURE [IN UNCERTAIN AND TURBULENCE SITUATION]	1	0	Can't be activated
INNOVATION [IN UNCERTAIN AND TURBULENCE SITUATION]	1	0	OK-Outcome
COLLABORATION	1	0	See note
PERFORMANCE OF INNOVATION PROJECTS [IN CASE OF PROJECT-BASED FIRMS]	1	0	OK-Outcome
PERFORMANCE OF INNOVATION PROJECTS [IN CASE OF NON PROJECT-BASED FIRMS]	1	0	OK-Outcome
[PROJECT MANAGEMENT] PM SUCCESS	1	0	OK-Outcome
DECISIONS BY TOP MANAGEMENT	1	0	See Note
NOVEL PROJECTS	1	0	See note
INNOVATIVE NEW PRODUCT	1	0	See note
SOCIALIZATION AND EXTERNALIZATION	1	0	Can't be activated
COMBINATION AND INTERNALIZATION [OF KNOWLEDGE]	1	0	Can't be activated

A positive link was added from “[Effective] new product development” to “Exploitative innovation”.

A positive link was added from “integration” to “Exploitative innovation”.

A negative link was added from “Innovation cycle time” to “performance”

Exploitation was added merged with “Exploitative innovation”, thus a positive connection was added from “Compensation for knowledge sharing” and “Invest in training program” to ““Exploitative innovation”.

“Exploration” was merged with “Exploratory innovation” thus a positive connection was added from “Compensation for knowledge sharing” to “Exploratory innovation”.

[Risk taking culture] was merged into Risk taking, thus a positive link was added from “Non-expert team members” to “Risk taking”

Integration [in extremely uncertain projects] was merged into “Integration” thus a positive link from “Concurrent engineering (CE)” was added to “Integration”.

A positive link was added from “Projects with clear goals” to “Exploitative innovation”

A negative link was added from “Emphasis on complete system definition before entering development”

Collaboration was merged into “Inter-firm collaboration” thus a positive link was added from “Project-based firm” to “Inter-firm collaboration”.

A link was added from “Decisions by top management” to “High dependency on top management [for decision making]”

“Novel projects” was merged into “Exploratory innovation” thus a negative link was added from “[Linear] phased approach [i.e. water fall models and stage-gate]”.

A positive link was added from” Innovative new product” to Exploratory innovation”.

A positive link was added from “New product innovation outcomes” to “[Effective] new product innovation”

A positive link was added from “Costs of coordinating, controlling, and supervising employees” to “Cost”.

A negative link was added from “Risk of failure” to “Exploratory innovation” and “Exploitative innovation”.

A positive link was added from “Value” to “Firm valuation”

Now following 57 concepts has out degree of zero from the new 365 concept/469 connection FCM. (Rev8-2)

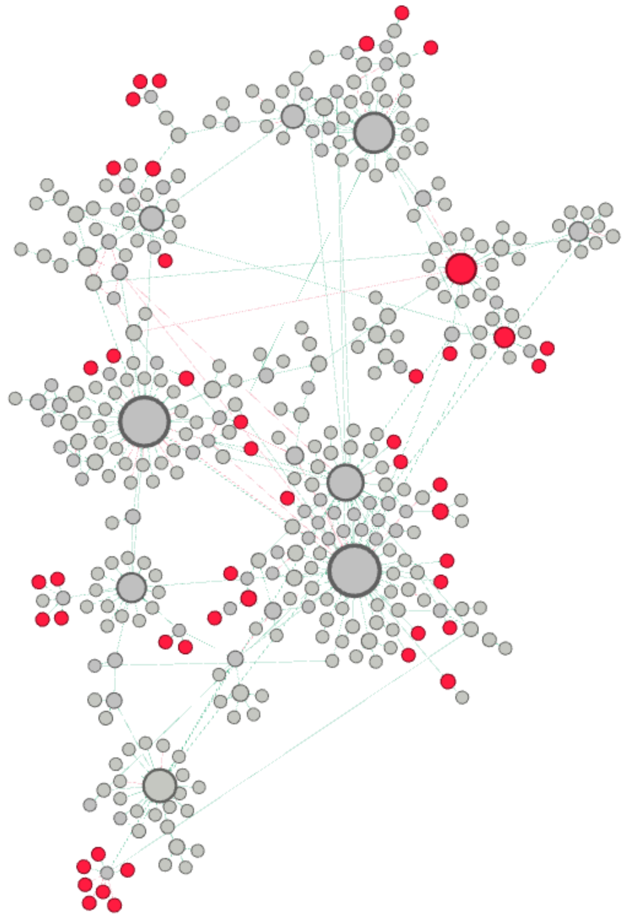

Figure 104- 57 concepts has out degree

So while many of these concepts are outcome variables and can't be manipulated directly, the rest our either changed by factors outside of the modeled system or they might have potentially connections to other concepts that are not discovered in the literature. Regardless of the reason, these concepts have no impact on the value of other concepts, including exploitative innovation, exploratory innovation and ambidexterity and therefore it could easily be taken out from the calculations -if their change in the value is not of the interest- or at least they don't need to be included as an activated concept in any initial vector. Same is true to all the predecessors of these concepts that are only causing these dead-ended concepts. (Rev8-3)

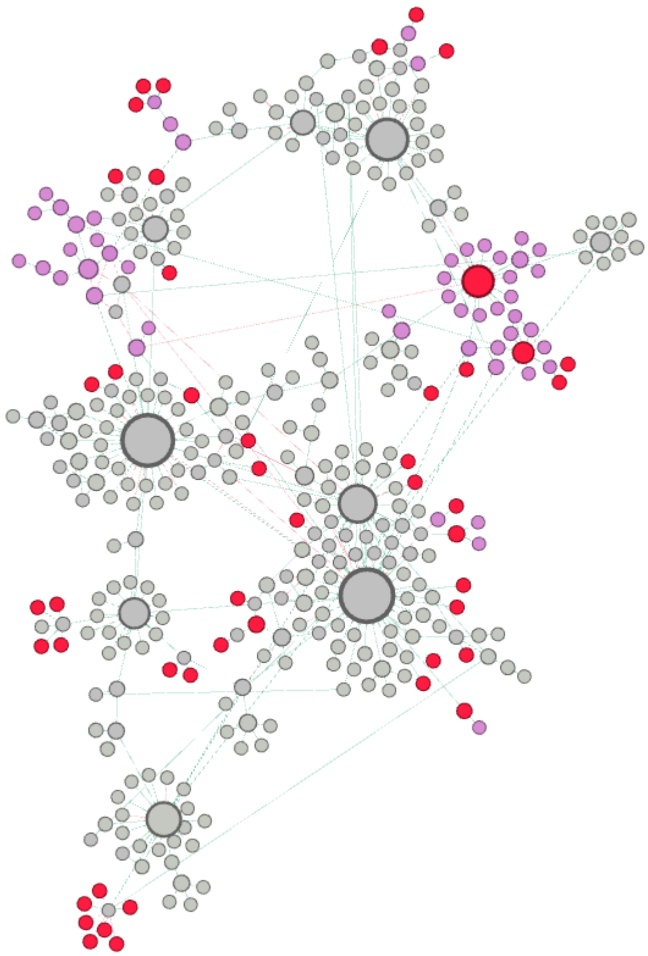

Figure 105- Concepts leading only to out degree concepts

That expands the list of concepts that don't need to be included in the initial vectors to the following (total 107):

(that by itself reduces the number of possible permutations of initial the combination of 4 of 258 (365-107), **180,352,320.**

Table 14- Concept to be excluded from being activated in initial vectors

[EMPOWERING] COMPETITORS
[PROJECT MANAGEMENT] PM SUCCESS
ABSTRACTNESS OF TITLES
ACCELERATE DEVELOPMENT [OF TECHNOLOGY AT INDUSTRY LEVEL]
ADAPTABILITY
ALIGNMENT
AMBIDEXTERITY [IN SMES]
CO-CREATION
COMBINATION AND INTERNALIZATION [OF KNOWLEDGE]
COMMUNICATION
COMMUNICATION [IN EXTREMELY UNCERTAIN PROJECTS]
CONTINGENCY REWARDS
COST
DEVELOPMENT COST [IN CASE OF INCREMENTAL INNOVATIONS]
DEVELOPMENT COST [IN CASE OF RADICAL INNOVATIONS]
DEVELOPMENT TIME [IN CASE OF RADICAL INNOVATION]
DEVELOPMENT TIME [IN INCREMENTAL INNOVATION PROJECTS]
DURATION OF A TEMPORAL OVERLAP BETWEEN AN EXPLOITATION PROCESS AND AN EXPLORATION PROCESS
EARLY SHUTTING DOWN OF [INNOVATION] PROJECTS
EXPERIMENTATION AND AD HOC PROBLEM SOLVING EFFORTS
EXPLICIT ACCUMULATED KNOWLEDGE
EXPLOIT SOLUTIONS THE COMPANY HAS DEVELOPED
EXPLOITATION ALLIANCES
EXPLORATION ALLIANCES
EXTERNAL RESOURCE ACCESS
FINANCIAL OUTCOME [IN A HIGH-GROWTH INDUSTRY]
FINANCIAL OUTCOME [IN A LOW-GROWTH INDUSTRY]

FINANCIAL PERFORMANCE
FINANCIAL PERFORMANCE [IN DYNAMIC ENVIRONMENTS]
FIRM EFFICIENCY [FOR DEFENDERS AT HIGH LEVEL OF COMPETITIVE INTENSITY]
FIRM EFFICIENCY [FOR PROSPECTORS AT HIGH LEVEL OF COMPETITIVE INTENSITY]
FIRM GROWTH
FIRM PERFORMANCE [FOR DEFENDERS]
FIRM PERFORMANCE [FOR PROSPECTORS]
FIRM QUALITY PERFORMANCE
FIRM VALUATION
FLUENCY
FREE REVEALING OF PROPRIETARY INNOVATIONS
FREQUENT MILESTONES
HIERARCHICAL ORGANIZATION
HIGH-QUALITY DECISIONS [IN LEADER ENTERIC TEAM]
HORIZONTAL ALLIANCES BETWEEN RIVALS
HORIZONTAL INFLOWS OF KNOWLEDGE
INDIVIDUAL R&D PERFORMANCE
INNOVATION [IN UNCERTAIN AND TURBULENCE SITUATION]
INNOVATION CYCLE TIME
INNOVATIVE PERFORMANCE
INNOVATIVENESS
INTERACTION EFFECT BETWEEN CONTEXTUAL AMBIDEXTERITY AND EXTERNAL RIVALRY
INTERACTION EFFECT BETWEEN CONTEXTUAL AMBIDEXTERITY AND INTERNAL RIVALRY
INTERACTIONS AMONG TEAM MEMBERS [ADVOCATES OF THE EXISTING PRODUCT AND THE INNOVATION]
INTERACTIONS BETWEEN THE TEAM LEADER AND TEAM MEMBERS
INTERNAL RIVALRY
KNOWLEDGE TRANSFER AND LEARNING WITH OTHER PARTNER ORGANIZATIONS
KNOWLEDGE TRANSFER AND LEARNING WITHIN THE COMPANY
LICENSING AGREEMENTS (IN AND OUT)
MANAGE HIGHLY UNCERTAIN PROJECT
MC [MECHANISTIC CONTROL]
MULTITASKING
NET GAIN IN PRIVATE PROFIT FOR THE INNOVATOR
NEW PRODUCT INNOVATION OUTCOMES
NON-EQUITY ALLIANCES
NUMBER OF ALLIANCES
NUMBER OF EQUITYBASED EXPLORATION ALLIANCES
NUMBER OF NONEQUITYBASED EXPLORATION ALLIANCES

OC [ORGANIC CONTROL]
OPEN INNOVATION
ORGANIZATIONAL AMBIDEXTERITY
ORGANIZATIONAL CONTEXT
ORGANIZATIONAL LONGEVITY
ORIGINALITY
OUTSOURCING RESEARCH
PATENT PROTECTION
PERFORMANCE
PERFORMANCE MANAGEMENT CONTEXT
PERFORMANCE OF INNOVATION PROJECTS [IN CASE OF NON PROJECT-BASED FIRMS]
PERFORMANCE OF INNOVATION PROJECTS [IN CASE OF PROJECT-BASED FIRMS]
PERFORMANCE OF MULTITASKING R&D INDIVIDUAL
PROBLEM SOLVING IDEAS
PROCESS INNOVATION
PRODUCT INNOVATION
PRODUCT INNOVATION INTENSITY
PRODUCT SUPERIORITY [IN CASE OF RADICAL INNOVATION]
PROJECT PERFORMANCE
PUNCTUATED EQUILIBRIUM
PURSUIT OF "PUSH-THE-ENVELOPE" DOMAINS
R&D EXPENDITURE
RESISTANCE TO PREMATURE CLOSURE
RETURN ON R&D [INVESTMENT]
REWORK [IN EXTREMELY UNCERTAIN PROJECTS]
RULES AND PROCEDURES
SELF ORGANIZING
SELLING OR LICENSING DORMANT TECHNOLOGIES
SHORT-TERM PERFORMANCE [FOR OLDER FIRMS]
SHORT-TERM PERFORMANCE [FOR YOUNGER FIRMS]
SOCIAL CONTEXT
SOCIALIZATION AND EXTERNALIZATION
STABILITY AND PREDICTABILITY
STIMULATING GROWTH
STRATEGIC PERFORMANCE
STRUCTURE [IN UNCERTAIN AND TURBULENCE SITUATION]
TEAM LEARNING
TECHNOLOGICAL PROGRESS [AMONG RIVALS]
VALUE
VERTICAL ALLIANCES BETWEEN SUPPLIERS

VERTICAL COOPERATION [SUPPLIER, CLIENT]

VOLUNTARY NEW PRODUCT DEVELOPMENT