The application of graph theory for vulnerability assessment in service triads

ABSTRACT

A supply chain triad is increasingly regarded as a unit of analysis of complex supply chain networks, allowing the realization of properties such as certain risks manifesting at the level of supply chain networks, and which are not necessarily observed at the level of supply chain dyads or individual supply chain partners. This study investigates a type of supply chain triad - service triads - and explores cross-organizational pathways according to which risks can emerge and propagate within such triadic structures. The aim of the study is to design an analytical model with the view to facilitate the assessment of vulnerability in service triads according to the aforementioned cross-organizational pathways of risk emergence and propagation. Using graph theory, a range of service triad reference models are developed, which formalize the typology and direction of the relationships between members of the supply chain triad. Adopting the notion of matrix permanent allows calculating the vulnerability levels of distinct service triad models, accounting for the formalized typology and direction of the relationships within the models. A case study in a corporate bonds context is conducted to illustrate the applicability of the proposed approach to vulnerability assessment in the service industry context.

Keywords: service triad; disruption; graph theory
The application of graph theory for vulnerability assessment in service triads

Globalization and recent technological advancements, coupled with the need to cut costs and gain competitive advantage in volatile global markets, have resulted in an ever-increasing vulnerability of supply networks to disruptions (Ambulkar, Blackhurst, & Grawe, 2015; Vilko & Hallikas, 2012). In the context of the service sector, this growing vulnerability is a product of increased outsourcing activities rather than vertical integration practiced by firms in service supply networks (Hayes, 2008; Holcomb & Hitt, 2007). In view of the growing complexity of modern, highly diversified supply chains, it becomes apparent that the traditional focus on supply chain dyads needs to be extended in order to reflect the network nature of the modern supply chains. (Carter, Rogers, & Choi, 2015; Wu, Choi, & Rungtusanatham, 2010). To provide a more comprehensive account of the network structure and inherent characteristics of the modern supply chains, a number of studies suggested shifting the analytical focus from supply chain dyads to triads seen as the elementary form of supply networks (Choi & Wu, 2009a; Niranjan & Metri, 2008). The modelling focus on triadic relationships in supply chains allows one to account for the interrelations between two supply chain members and the effect their interactions have on the third member, thereby capturing specific properties of network behavior at the most elementary level of the supply network (Choi & Wu, 2009a).

The literature has distinguished a number of common types of supply chain triads, including: buyer-supplier-customer (e.g., Li & Choi, 2009; Niranjan & Metri, 2008; Rossetti & Choi, 2005; Rossetti & Choi, 2008), buyer-supplier-supplier (e.g., Choi & Wu, 2009b; Choi, Zhaohui, Ellram, & Koka, 2002; Dubois & Fredriksson, 2008; Wilhelm, 2011; Wu & Choi, 2005; Wu et al., 2010), and buyer-buyer-supplier (e.g., Choi & Kim, 2008). The early literature on supply chain triads predominantly considered the manufacturing context in
which supply chain triads operate (e.g., Choi & Hong, 2002; Rossetti & Choi, 2005), while the context of service industries has received considerably less attention from the studies investigating supply chain triads (e.g. (Bastl, Johnson, Lightfoot, & Evans, 2012). Our study addresses this research gap focusing specifically on supply chain triads that support the service outsourcing processes (e.g. Niranjan & Metri, 2008; Li & Choi, 2009; van der Valk & van Iwaarden, 2011; Perdikaki et al., 2015).

To date, no theoretically grounded approaches have been suggested to support reasoning about the potential risk scenarios associated with service triads. The literature has not yet structured the potential vulnerabilities concerned with relational properties between the members of supply chain triads and has not provided a structured analytical approach towards the assessment of such vulnerabilities. We noticed that this issue could be effectively resolved using the modelling apparatus of graph theory, a mathematical approach widely adopted in operations research (e.g., Ahmadi-Javid, Ardestani-Jaafari, Foulds, Hojabri, & Farahani, 2015; Li, Kilgour, & Hipel, 2005; Ng, Cheng, Bandalouski, Kovalyov, & Lam, 2014).

The aim of this study is two-fold: (i) using the toolset of graph theory, to model different cross-organizational pathways according to which risks can emerge and propagate in service triads seen as an elementary form of service supply networks; and (ii) to provide a method for vulnerability assessment of the suggested graph models of service triads, taking into consideration the typology and direction of the cross-organizational relationships within graph models of supply chain triads.

The aim of the study is addressed by formally categorizing service supply network risks, including risks causing failure in service outsourcing practices, as reported in the service supply chain literature (Bastl, Johnson, & Choi, 2013; Choi, Wallace, & Wang, 2016;
As a result, a coherent framework grounded in graph theory (e.g., Bollobás, 1998) is suggested, allowing the categorization and evaluation of risks emerging within supply chain service triads according to their structural and relational characteristics. The graph theoretical perspective used in this study allows one to schematically represent the factors influencing major service supply chain disruptions and to suggest an analytical approach for vulnerability assessment of supply networks based on the notion of matrix permanent. The applicability of the suggested approach to vulnerability assessment in supply chain service triads is illustrated in the context of the service industry (in this case, corporate bond issuance).

The remainder of this paper is organized as follows: based on the body of literature, we identify the pathways of emergence and propagation of risk events that lead to disruptions in service triads. We then build an analytical model grounded in the graph theory to quantify vulnerability in service triads. This is followed by a case study in the context of corporate bonds issuance in Iran. The case study is conducted to demonstrate the practical application of the proposed analytical approach. Finally, we make concluding remarks and outline further implications for research on evaluating vulnerability in service triads and more complex networks.

BACKGROUND

Risks and Vulnerability of Service Triads

The emerging theory of the supply chain (Carter et al. (2015) grounded in systems theory (e.g., Simon, 1996) and network theory (e.g., Wasserman & Faust, 1994), conceptualizes supply chains as: (a) networks consisting of focal organizations that are linked to upstream and downstream partners; and (b) complex adaptive systems, which exhibit such properties as self-organization, emergence and limited visibility of individual partners. This view suggests
that all members of a supply chain can be viewed as self-organizing, adaptive agents that are interconnected in such a manner that the behavior of one agent commonly affects the behavior of the whole system (Choi & Hong, 2002; Nair, Narasimhan, & Choi, 2009). In today’s dynamic and highly interconnected environment, supply chain risks, and specifically supply chain disruptions, are commonly considered as natural, or ‘normal’ (i.e., using the language of the normal accident theory) properties of the modern supply chains (Marley, Ward, & Hill, 2014). From the point of view of the emerging theory of the supply chain, such risks represent emergent properties of the service supply network structures (Carter et al., 2015). However, in view of the high level of interconnectedness between members of the supply chain networks and lower levels of control (as compared to the vertically integrated supply chains), the risks of supply chain disruptions represent a particular concern due to their high impact and the ability to carry the adverse effects of such events across organizational boundaries (Lodree Jr & Taskin, 2008). Recent examples in the literature include the propagation of detrimental effects across the members of the supply chain network of such major events as bankruptcy (Garvey, Carnovale, & Yeniyurt, 2015) and terrorist attacks (Bueno-Solano & Cedillo-Campos, 2014).

The enhanced ability to respond to changes in demand and to benefit from associated business opportunities often goes hand in hand with the increasing dependency on the quantum of work outsourced by service companies to their suppliers, leading to extension of the supply chains both in size and complexity (Ellram, Tate, & Billington, 2008; Harland, Brenchley, & Walker, 2003; Tate, Ellram, & Brown, 2009). In addition, along with the increasing profit margins and other performance improvement outcomes achieved through the growing complexity and dynamism of the modern supply networks, comes the issue of the increased vulnerability of the supply networks and their individual members (Choi et al., 2016; Sodhi & Tang, 2012; Wagner & Bode, 2008). Service companies seek to establish
proper relationships with supply chain members participating in outsourcing practices, and consider such relationships as key for achieving a desirable level of services delivered (Bastl, Johnson, Lightfoot, & Evans, 2012; Pawar, Beltagui, & Riedel, 2009). Given the importance of such relationships, the companies today are urged to establish additional forms of disruption response strategies and control procedures as part of their profiles to avoid new disruptions including, for example, adversarial buyer-supplier relations or winning customers over by suppliers (Choi & Kim, 2008; Li & Choi, 2009).

In one of the early studies investigating service triads, Li and Choi (2009) adopted the social network lens to highlight an emerging condition, referred to as structural holes (Burt, 1992), which differentiates buyer-supplier-customer triads in service industries from other business contexts, such as manufacturing. For instance, while in manufacturing the role of the buyer as a bridge between supplier and the buyer’s customer remains stable, in service industries this relationship is more dynamic and is typically the function of time relative to the outsourcing of specific services. At the negotiation stage, the buyer maintains the bridge position. This starts to decay during outsourcing when the supplier gets into direct contact with the buyer. This may then lead to the ‘bridge transfer’ phase when the customer may find it more comfortable working directly with the supplier without the buyer serving as intermediary in this triadic relationship. This transition from the ‘bridge’ to the ‘bridge decay’ position reflects the loss of control by the buyer upon the communication channel between the supplier and the customer, and results in the redistribution of relational benefits originally shared by members of the supply chain triad to the members of the newly formed dyadic business model.

Another example is the study by Niranjan and Metri (2008) who considered the relational properties in client-vendor-consumer service triads, outlined the factors that lead to quality erosion in this triadic relational model and discussed the tensions between business-to-
business and business-to-customer dimensions forming this triadic relationship. Focus has been on *buyer-subcontractor-end customer* triads and the supervisory attempts that contribute to the development of more robust contracts for services outsourcing purposes (van der Valk and van Iwaarden (2011)). This problem is further discussed (van Iwaarden and van der Valk (2013)) when a case-based approach is used to demonstrate how the service delivery process can be controlled at the early stages by devising control mechanisms in the associated service level agreements.

More recently, based on the analysis of archival data from the Compustat database, Kim and Henderson (2015) demonstrated the unequivocal nature of supplier and customer benefits with an increasing dependency upon the focal firm in concentrated triadic relationships: the economic benefits of customer dependency diminish beyond a certain point, while those of supplier dependency continue to increase above that threshold. Modi, Wiles, and Mishra (2015) used the event study methodology to investigate 146 cases of security breaches as part of the broader investigation of the effects of service failures caused by service providers in the context of service outsourcing triads. Summarizing the above, vulnerability in the context of service triads may result from the weakness or threat brought by one member of the supply chain triad or as a relational property of two members of the supply chain triad.

Finally, Wynstra, Spring, and Schoenherr (2015) continued the investigation into the various configurations of buyer-supplier-customer triads, outlining the theoretical approaches supporting the conceptualization of the notion of triads, describing a number of distinctive properties of service triads, and broadening the perspectives for future research in this growing body of operations and supply chain management literature. Their study is probably the most complete literature review of the published research on supply chain triads in both service and manufacturing sectors. None of the prior studies reviewed by Wynstra et al. (2015) investigated risk as a phenomenon which characterizes the relationships between the
members of the supply chain triads in services or manufacturing. Naturally, the mechanisms that shape and transform the relationships between the members of the supply chain triads (such as, for example, bridge, bridge decay, and bridge transfer mechanisms suggested by Li and Choi (2009) relate to the emergence of risky scenarios in triads (e.g., buyer losing control at a bridge decay stage and ultimately leaving the business model when the bridge transfer takes place). However, the studies that did contribute to the improved understanding of the drivers of risk within supply chain triads did not consider the phenomenon of risk per se as the object of their investigation.

**Service Triads as Complex Adaptive Systems**

A considerable amount of risks threatening the continuity of operations in supply networks, including service supply networks and their individual service triads, are context-specific. Such risk events largely depend on the nature of operational processes and inbuilt controls of organizations forming supply networks, as well as the characteristics of external environment in which they operate (Lewis, 2003; Neiger, Rotaru, & Churilov, 2009; Tan, Lee, & Goh, 2012). Moreover, both emergence of these risks and their propagation across organizational boundaries are closely associated with the properties of the supply networks (Carter et al., 2015), and specifically service triads, and the nature of the relationships between its members (Mizgier, Jüttner, & Wagner, 2012). Some of the core properties of supply networks through the lens of network theory and complex adaptive systems are outlined below.

According to the principles of network theory, a triad is defined as “a subset of three actors and the (possible) tie(s) among them” (Wasserman & Faust, 1994). A service triad is commonly regarded as an independent elementary form of a service supply network and shares certain structural and behavioral characteristics of the network (Havila, Johanson, & Thilenius, 2004; Niranjan & Metri, 2008). The term 'possible tie(s)' used in Wasserman’s
(1994) definition of triads, implies up to six different types of triads built on a continuum of inter-organizational relationships from less to more connected members (for more details, see Peng, Lin, Martinez, & Yu, 2010). For the study of service triads, an extension to the original six types of triads is considered, with the aim of taking into account all three bipartite relationships of service triad members in order to determine the possible pathways of emergence and propagation of risks that may lead to disruptions within the service triad.

One of the distinctive characteristics of supply networks, as seen from this theoretical perspective, is the notion of emergence, i.e., “the rising of new, unexpected structures, patterns, properties, or processes in a self-organizing system” (Choi, Dooley, & Rungtusanatham, 2001). This notion is grounded in systems theory (Daellenbach, 1994; Simon, 1996) and, in the later literature, on complex adaptive systems (Choi & Hong, 2002; Nair et al., 2009). From the systems perspective, a service triad as an elementary form of a service supply network, possesses the characteristics of a complex adaptive system whose “behavior ... is induced not by a single entity but rather by the simultaneous and parallel actions of agents within the system itself” (Choi et al., 2001). Thus, a service triad exhibits unique characteristics, or emergent properties, which are not properties of its distinct components but the whole network. Along with drivers of value creation in supply chain triads, risks associated with the design and functioning of the service triads represent properties pertinent to the triadic system where they emerge. One of the innate characteristics of such risks is their ability to propagate across the boundaries of individual organizations forming the triad (Garvey et al., 2015). For example, among other disruptive events or states, the literature reports on the propagation of the adverse effects produced by terrorist acts (Bueno-Solano & Cedillo-Campos, 2014) and bankruptcies (Garvey et al., 2015) across inter-organizational boundaries within supply chain triads.
To date, the literature investigating the issues of disruption modelling and vulnerability assessment in the context of service triads is still scarce. The need to account for the interactions among all members when conducting vulnerability assessment of service triads makes it problematic to directly adopt the formal approaches to vulnerability assessment commonly applied to individual organizations or dyadic cross-organizational relationships. We address this research gap by adopting a graph theory analytical approach to model disruptions and assess vulnerability in service triads. In the next section, the relevant analytical model is presented.

**ANALYTICAL MODEL**

**Graph Theory**

The versatility of graphs in modelling the relationships between members of networks has made graph theory widely applicable in social, technological, informational and biological networks (Borgatti & Halgin, 2011; Borgatti & Li, 2009; Newman, 2003; Wasserman & Faust, 1994). Graph theory provides the analytical means to study diverse types of relations (i.e., edges) between a set of entities (i.e., vertices) in an environment characterized by the relationship between two and more entities (Bollobás, 1998). A graph $G = (V, E)$ consists of a set of vertices $V_G = \{v_1, v_2, \ldots \}$ and a set of edges $E_G = \{e_1, e_2, \ldots \}$ where each edge is defined by a pair of vertices. Each vertex in graphs may represent a property of a system or an entity which makes part of the modelled system, while edges denote the relational properties between the vertices and commonly reflect such notions as flows of material, information, finances between such agents as companies and individuals (Bondy & Murty, 1976; West, 1996). These characteristics of graph models make graphs an appropriate tool for modelling flows of information and goods in service supply networks, including service triads.
Graphs have been long used to model interdependencies in triadic structures and more complex social networks (e.g., Davis, 1967; Harary, 1965; Holland & Leinhardt, 1970), however their application to modelling the supply chain triads and their properties has been very limited. In a review article on network analysis approaches in the context of supply chain management, Borgatti and Li (2009) report on the application of the graph theoretical approach to model the structure and relevant properties of supply chain networks. By adopting a graph theoretical approach, Kim, Chen, and Linderman (2015) suggest a network structural perspective towards the study of supply network disruption and resilience. In particular, the authors stress the importance of differentiating between disruptions on the node level (i.e., disruptions in internal processes of firms) and on the dyadic level (i.e., disruptions in the interrelations between each pair of firms). Our study follows this line of literature.

**A graph theoretical approach for vulnerability assessment in service triads**

A directed graph (digraph) represents a set of interconnected nodes where the edges are directed from one node to another. When applying digraphs for vulnerability assessment in service triads, the members of a service triad are modelled as vertices of the graph and the direction of the edge between each member reflects the direction according to which risk may propagate between the members of a given service dyad which forms the triadic relationship. Weights assigned to the directed edges in such graphs show the severity of disruptions occurring between the bipartite members. Thus, directed weighted edges are used as indicators of direction and magnitude of potential disruptive events occurring between any two members of a service triad (i.e., between each pair of vertices).

In Figure 1, all the possible configurations of triads in a network (Holland & Leinhardt, 1970) are depicted. In the context of this study, a unidirectional arrow between vertex A and vertex B ($A \rightarrow B$) shows that A is imposing disruptions to the processes of B (asymmetric
relationship). A two directional arrow \( A \leftrightarrow B \) shows both \( A \) and \( B \) disrupting each other’s processes (mutual relationship). Also, no arrow indicates no disruption between \( A \) and \( B \) (null relationship). The triads are labelled in accordance with the number of mutual \((M)\), asymmetric \((A)\), and null \((N)\) pairs in each triad, defined as MAN labelling. For instance, supply chain service triad labelled as 102 shows that there is one mutual (i.e., disruption directed from both vertices), no asymmetric, and two null pairs of relationships in the triad. As another example, the label 003 denotes a disruption-free service triad with no mutual, no asymmetric and three null pairs. The letters are also used to further distinguish between the triads \( D \) for Down, \( U \) for Up, \( T \) for transitive, and \( C \) for Cycle\). The sixteen different types of triads proposed by Holland and Leinhardt (1970) are tailored for triads with identical members. For a triad with non-identical members (e.g., buyer-supplier-customer triad, buyer-supplier1-supplier2 triad, etc.) the total number of variations for the triads that reflect potential disruptions occurring between the members of the triad equals to \( 3! \times 16 = 96 \) different configurations. Identifying the types of triads as presented in Figure 1, helps network analysts to test their hypotheses on the structural properties of the networks such as transitivity and intransitivity (Faust, 2006; Wasserman & Faust, 1994), which provides interesting avenues for future research in the context of both manufacturing and service triads in operations management. Using the configurations presented in this section, we aim to model service triads and quantify their vulnerability levels depending on the nature of the relationships between their members.

--- Insert Figure 1 about here ---

Some of the configurations of the triads presented in Figure 1 have been discussed in the literature on supply chain triads, including service triads. For example, the characteristics of the supply chain triad labelled as 021U correspond to the so called structural holes (Burt, 1992, 2005). A the same time, the properties of 021U triad reflect such characteristics of
service triads described by Li and Choi (2009) as bridge, bridge decay, and bridge transfer. These characteristics reflect the situation where the supplier tries to solidify its bridge position by making stronger ties with the customer and by disrupting the relationship between the customer and the buyer (Supplier→Buyer and Customer→Buyer) by luring away the customer. Specifically, the triad type 012 reflects a disruption in the buyer-customer relationship (Customer→Buyer) in the bridge transfer stage but no disruption in buyer-supplier or supplier-customer relationship. Zhan, Lawrence, and Anderson (2015) highlight conflicts between buyer (i.e., the main service provider outsourcing services to a third party supplier) and supplier, resulting in increased costs of services (Supplier→Customer) and customers being unhappy with both supplier (Customer→Supplier) and buyer (Customer→Buyer). This scenario is reflected in the triad type 111U.

Despite the evidence presented above, a vast majority of possible configurations of disruptions emerging and propagating in service triads have yet to be identified and addressed in the published service triad models. Moreover, in almost all of the aforementioned instances, vulnerabilities associated with the internal processes of the firms forming service triads, as well as the adverse effects of these vulnerabilities on triads, were not considered. Furthermore, the focus of the literature investigating the risks of supply chain disruptions is still largely on the probability and impact parameters of the disruption events themselves, while the propagation of the adverse effects of such events across the boundaries of individual organizations largely remains outside the scope of the research studies. For instance, what are the possible developments associated with the outsourcing case presented in Li and Choi (2009), i.e., what happens after the bridge transfer phase when the buyer realizes that the supplier had lured the customer away? Would the relationship between buyer and supplier be disrupted? How might it impact the whole supply network? Moreover, after identifying the type of triad that represents correctly disruptions between its members, how
could the overall vulnerability of the triad be assessed? To address the questions above, we introduce *matrix permanent* as a tool used to conduct vulnerability assessment in supply service triads and more complex supply networks.

**Matrix Permanent and its Application in Service Triads**

To assess how the proposed graph models could help assess vulnerabilities to disruptions in service triads, we use the notion of *matrix permanent*, which originates in multi-linear algebra and combinatorics (*Marcus & Minc, 1965; Ryser, 1963*). For instance, the permanent of a 0,1 matrix representing a bipartite graph is the number of perfect matchings in the graph. Permanents have been already used in different operational contexts as indicators of cost effectiveness (*Sabharwal & Garg, 2013*), effectiveness of risk mitigation strategies (*Rajesh, Ravi, & Venkata Rao, 2014*), ranking agility enablers in a manufacturing environment (*Aravind Raj, Sudheer, Vinodh, & Anand, 2013*), and others. The same approach has been adopted by *Wagner and Neshat (2010)* and *Wagner and Neshat (2012)* to calculate vulnerabilities of supply chains to different types of supply chain risks. They considered vulnerability drivers as the vertices and their interdependencies as edges and by calculating the resultant matrix permanent, they introduced a quantified supply chain vulnerability index. Our model is different from the latter in that we simultaneously incorporate vulnerabilities observed both in the internal processes of triad members (representing diagonal elements) and in their relationships with other members (representing off-diagonal elements) and its adverse effect on the triad’s vulnerability as a whole.

Alternative methods are presented to calculate the permanent function of a matrix (*Brualdi & Ryser, 1991; Glynn, 2010; Ryser, 1963*). For the convenience of the computational procedure, in this study we follow Rao’s (*2007*) work that expanded the permanent for the \( M \times M \) matrix representation of digraph \( J \) with the equation (2) as follows:
\[
J = \begin{bmatrix}
A_1 & a_{12} & \cdots & a_{1M} \\
a_{21} & A_2 & \cdots & a_{2M} \\
\vdots & \vdots & \ddots & \vdots \\
a_{M1} & a_{M2} & \cdots & A_M
\end{bmatrix}
\]

\[
\text{per}(J) = \prod_{i=1}^{M} A_i + \sum_{i=1}^{M-1} \sum_{j=i+1}^{M} \cdots \sum_{M=m+1}^{M} (a_{ij}a_{kl} + a_{il}a_{kj}a_{ji})A_mA_mA_o \cdots A_mA_M \\
\text{where } M \neq \text{pus}
\]

\[
+ \sum_{i=1}^{M-2} \sum_{j=i+1}^{M-1} \sum_{k=j+1}^{M} \cdots \sum_{M=m+1}^{M} \sum_{M=t+1}^{M} (a_{ij}a_{kl}a_{li} + a_{il}a_{kj}a_{ji})A_mA_mA_o \cdots A_MA_M \\
\text{where } M \neq \text{pus}
\]

\[
+ \sum_{i=1}^{M-3} \sum_{j=i+1}^{M-2} \sum_{k=j+1}^{M-1} \sum_{l=k+1}^{M} \cdots \sum_{M=m+1}^{M} \sum_{M=t+1}^{M} (a_{ij}a_{kl}a_{ml}a_{mi} + a_{im}a_{ml}a_{ik}a_{jli})A_MA_M \cdots A_MA_M \\
\text{where } M \neq \text{pus}
\]

\[
+ \sum_{i=1}^{M-5} \sum_{j=i+1}^{M-4} \sum_{k=j+1}^{M-3} \sum_{l=k+1}^{M-2} \sum_{m=l+1}^{M-1} \sum_{M=t+1}^{M} \sum_{M=m+1}^{M} \sum_{M=n+1}^{M} (a_{ij}a_{kl}a_{ml}a_{mn}a_{mi} + a_{im}a_{mn}a_{ml}a_{ik}a_{jli})A_MA_M \cdots A_MA_M \\
\text{where } M \neq \text{pus}
\]

where \(a_{ij}, i, j = 1, \ldots, M\) denotes the relative value of attribute \(a_{ij}\), which in our case is the relative vulnerability detected in the relationship between member \(i\) and member \(j\) within a triad. Also, \(A_i, i = 1, \ldots, M\) is the absolute value for the \(i\)th attribute, which is interpreted as the measure of vulnerability to disruptions for each triad member in its internal processes to
disruptions irrespective of its interrelations with other triad members. The acronym *pus* stands for *previously used subscripts*, which means that $k,l,m,...,M$ take subscripts in (2) that are not previously used. There are overall $M + 1$ groups of terms in (2) with each group showing the relative importance measures of attributes in the digraph $J$. For instance, the first group shows the measures of $M$ unconnected vulnerability attributes corresponding to internal vulnerabilities of members. The second group illustrates a bipartite vulnerability measure. Third group of terms shows the vulnerability between each set of three attributes and vulnerability measures of $M - 2$ attributes, and so on.

Considering graph $A$ ($V_A = \{A_1, A_2, A_3\}, E_A = \{a_{12}, a_{21}, a_{13}, a_{31}, a_{23}, a_{32}\}$) (representing a triad) and (2), permanent of graph $A$ can be presented as follows:

$$ per(A) = A_1A_2A_3 + (a_{12}a_{21}A_3 + a_{13}a_{31}A_2 + a_{23}a_{32}A_1) + (a_{12}a_{23}a_{31} + a_{13}a_{32}a_{21}) $$

(3)

Service supply networks with $n \geq 3$ vertices consist of $\binom{n}{3} = \frac{n!}{(n-3)!3!}$ triads. Thus in order to capture the vulnerability level for the network, all different types of triadic models associated with potential disruption events should be considered and evaluated. Next, for the purposes of illustrating the use of the suggested modelling and vulnerability assessment approach using graphs, we consider the corporate bonds network with five vertices. In doing so, we show the measures that should be taken into account when assessing vulnerability in service supply networks, such as service triads.

**APPLICATION OF THE ANALYTICAL MODEL**

To test our proposed approach of identifying disruptions in service triads and quantifying the resultant vulnerabilities as the core elements of service supply networks, we conduct
several case studies in the corporate bonds setting of Iran (financial industry service sector, according to the classification suggested by Wynstra et al. (2015)). In the next subsection we provide a brief overview of the corporate bonds market in Iran and describe the corporate bonds network, as well as the associated risks. We then present the cases and report on the results obtained from applying our proposed analytical approach informed by the graph theory to the corporate bonds service triads.

Corporate bonds network context

Corporate bonds for the last two decades have become one of the main tools to fund large corporations around the globe (Massa, Yasuda, & Zhang, 2013; Mizen & Tsoukas, 2012; Thomas, Oliver, & Hand, 2005). A simple corporate bonds network consists of corporate customers as issuers, a bank and its corporate bank or a bank and an external investment bank as underwriters, and investors who purchase the bonds. When making the decision to issue bonds, the issuer refers to an underwriter to receive services such as pricing, marketing, documenting, and selling the bonds as well as insurance for the unsold bonds and other types of services (Yasuda, 2005, 2007). There have been numerous cases of fraud and disruptive behavior reported in the context of corporate bonds network (see, Andres, Betzer, & Limbach, 2014; Shivdasani & Song, 2011), leading to a stronger information asymmetry (Healy & Palepu, 2001), financial distress (Berlin, John, & Saunders, 1996), and realized default and credit risk (see among, Altman, 1989; Giesecke, Longstaff, Schaefer, & Strebulaev, 2011; Güntay & Hackbarth, 2010; He & Xiong, 2012; Krishnan, Ritchken, & Thomson, 2005; Vassalou & Xing, 2004) for the members of the network. In addition to the realized risks mentioned above that may potentially disrupt the continuity of the bipartite relationships between the members of the corporate bonds network, each member may also experience disruptions within its own organizational processes that could propagate across the organizational boundaries and affect other members and on the triad as well. Here, our
goal is to investigate the vulnerability of a given supply chain triad to these different levels of disruption in the context of corporate bonds service triads.

Case Study: Corporate Bonds Service Networks

The emerging nature of Iranian financial market and its fixed 20 percent coupon on corporate bonds offer significant investment opportunities (Lynn, 2014; Rao, 2014). Especially after the lift of financial sanctions on Iran, the country looks to issue billions of dollars in bonds (and at least $500 million in foreign-currency-denominated bonds) to repair its economy (Fitch, 2015). Especially, after corporate banking was introduced to this financial market in 2007, the corporate bonds market has become even more competitive with both investment banks and corporate banks aiming to gain a larger share of the market. Usually, in very large projects, banks decide to use both their corporate bank and at least one external investment bank to collaborate on bond underwriting and issuance processes. To better understand the bottlenecks (i.e., most vulnerable service triads) of the corporate bonds network, we investigated networks comprised of corporate customers, banks and their corporate banks, investment banks, and investors (see Figure 2). Using semi-structured interviews, we investigated the emergence and propagation of disruptions in different service triads that form part of the Iranian corporate bonds service network. We then assessed and compared vulnerability scores of the identified triads and discussed the results.

--- Insert Figure 2 about here ---

Our semi-structured interview process involved multiple stakeholders. We interviewed heads of four main banks and their corporate banks - i.e., Eghtesad Novin (EN) Bank, Mellat Bank, Melli Bank, and Saman Bank - along with four external investment banks (Amin, Novin, Omid, Sepehr) that cooperated with these banks to issue corporate bonds. We also interviewed a number of corporate customers of these banks that were involved in extensive
bonds issuance and underwriting projects. Moreover, we interviewed representative groups of individual investors that were investing in the bonds issued by the above mentioned banks. In total, 22 interviews were conducted, which included 6 interviews with the bank and corporate bank representatives, 8 interviews with the investment banks, and 4 interviews with corporate customers and investors. The key informants included senior-level managers, mainly CEOs, CFOs or heads of relevant departments. The criterion for the selection of interviewees was their involvement in the process of issuing and underwriting corporate bonds (see Appendix A for the profile of the respondents). The names of the corporate customers are not disclosed in this study due to confidentiality reasons. Moreover, pseudonyms are used to represent vertices in the corporate bonds network: Bank (Ba), Corporate Bank (CB), Investment Bank (IB), Corporate Customer (CC), Investor (In).

The interviews were conducted from December 2012 to April 2013 on site, with the interview duration ranging from approximately one hour to three hours. Respondents were first asked to introduce themselves and talk about their responsibilities. Next, using a 10-point Likert scale, interviewees were asked to identify and assess types of disruptions in the internal processes of the organization they were associated with and their impact on the corporate bonds network which they were part of (Question 02). Next, the critical incident technique (Gremler, 2004) was adopted to question the informants’ opinions on the most significant adverse events and situations in their interactions with the other two members of the corporate bonds service triad. Participants were then asked to prioritize the impact of those adverse events using a 10-point Likert scale (Questions 03-06, see Appendix B for the interview protocol). Three investigators conducted the interviews in order to increase the confidence level of the research outcomes (Benbasat, Goldstein, & Mead, 1987; Dubé & Paré, 2003).
Overall, four different corporate bonds networks were investigated, consisting of either one of the abovementioned banks, their corporate banks, a unique external investment bank and their corporate customers and investors. Table 1 shows the results of the analysis of one of the four corporate bonds networks (i.e., Mellat corporate bonds network). According to Table 1, initially all possible forms of \( \binom{5}{3} = 10 \) service triads are identified. The graph representations of disruptions in these triads are visualized upon interviewees’ comments on the severity of disruptions at vertex and dyad levels that could have affected the triads. The graph models are followed by the specification of the types of triads using MAN labelling and their matrices are presented. In the Vulnerability score column, the vulnerability level of each triad is quantified using equation (3). While each triad is attributed its own specific type of disruptions reported in Table 1, we consider some common types of vertex-level disruptions for the internal processes of the members, such as bureaucracy and obsolete IT systems for the bank, investment bank and corporate bank, financial instability for the corporate customer, and unwillingness to purchase the bonds (emergence of parallel markets with higher interest rates, increased risk of corporate bonds, etc.) for investors. This is in line with the frequency of these disruptions reported by the interviewees. Disruption(s) description column shows disruptions on node and dyad level.

--- Insert Table 1 about here ---

Among the vulnerability scores from Table 1, three most vulnerable service triads in the corporate bonds network #1 are: IB-Ba-CB (T₁, score: 986), Ba-IB-CC (T₃, score: 448), and In-CB-Ba (T₆, score: 378). In the IB-Ba-CB triad, the main concerns of the interviewees were the lack of coordination between investment bank, bank and its corporate bank which might in turn lead to delays, decreased quality of services, and financial losses for all members of this triad. Participants, especially top executives of the bank, were concerned about the
opportunistic behavior of suppliers in luring away the corporate customers by offering them superior services or by reducing the leverage of the bank (by having control on the flow of information and finances between the investment bank and the corporate customer) in the Ba-IB-CC triad. Also, not having an accurate credit check of the corporate customer by the corporate bank might result in adverse consequence to the bank presenting wrong information to its stakeholders on returns of their investments. In case of a high default risk and the inability of the bank and the corporate customer to pay the expected interest rates for the bonds, this would harm bank’s reputation and could lead to future financial losses. The participants did not mention any particular disruptions in CB-In-IB, CC-In-IB, and CC-In-CB service triads, which seems logical since members of these triads do not interact much in the corporate bonds network. The vulnerability of the whole supply network equals the aggregated vulnerability of its individual triads.

Following a similar procedure, we conducted the same analyses for the remaining three corporate bonds networks and calculated vulnerability scores for the identified triadic structures in those networks. Table 2 illustrates the vulnerability scores obtained for all four corporate bond networks. Tejarat Bank received the highest overall vulnerability score among the four banks investigated with triads CB-CC-Ba, CB-CC-IB, and In-CB-Ba, demonstrating a significantly higher vulnerability than the other three banks. The analysis of the adjacency matrices of Tejarat’s corporate bonds members, leads to a conclusion that in those particular triads, the internal vulnerability of Tejarat’s corporate bank (CB node) corresponds to the sudden increase in the permanents (i.e., vulnerability scores). Thus, Tejarat bank should be advised to overview the processes associated with the bond issuance and underwriting with its own corporate bank. The same type of comparison can be made between other identified triads in the corporate bond networks of the four banks, thus identifying the most vulnerable node in the network.
The outcomes reported in Table 2 were shared with and double-checked by key informants representing all four banks, along with the representatives of corporate and investment banks, to assure internal and external validity (Barratt, Choi, & Li, 2011; Stuart, McCutcheon, Handfield, McLachlin, & Samson, 2002). In several separate meetings with the aforementioned representatives from each of the four corporate bonds networks, we communicated the main factors contributing to vulnerability in the network. The nature of these factors was relational or residing within a specific member of a given supply chain triad. The representatives confirmed that these findings reflected what seemed to be the main problem(s) in the bond issuance and underwriting processes of their corporate bond networks.

CONCLUDING REMARKS AND FUTURE RESEARCH

The present study aimed to address the issue of vulnerability in supply networks and specifically in service supply networks through the lens of service triads. Considering service triads as the most elementary form of complex adaptive systems and the building block of service supply networks, the study used the modelling apparatus of graph theory to model a variety of pathways according to which disruptions may emerge and propagate in service networks. In our approach to vulnerability assessment, we adopted the notion of matrix permanent to quantify vulnerabilities which may be induced by various configurations of risk emergence and propagation within supply chain triads.

The suggested analytical approach allows the visualization of disruption pathways as graph models and, based on the notion of matrix permanent, the calculation of the corresponding vulnerability scores associated with specific configurations of service triads. To demonstrate the relevance of the suggested analytical approach for modelling service triads and for calculation of the associated vulnerability levels, a case study grounded in the
context of corporate bonds issuance in Iran, was conducted. The adopted analytical approach supported the identification of the most vulnerable triadic structures in the corporate bonds network, which in turn allowed the cross-case comparisons for a selective number of those service triads. Overall, the approach improved visibility of risks emerging and propagating in the context of service supply networks.

The example used in this study demonstrated how graph theory can be adopted to evaluate the vulnerability of more complex service networks. The vulnerability levels of several types of supply networks, such as block-diagonal, scale-free, centralized, and diagonal, as explored by Kim et al. (2015), could be further investigated in various industrial and service contexts. Moreover, for supply networks with significant differences in their triad types (according to the MAN labelling), additional correspondence analyses could be conducted to understand the patterning of triad space in terms of its mutual, asymmetric and null dyads (Faust, 2006). This would help to better understand the types and frequencies of risk relationships in supply networks.

Finally, since the suggested graph theoretical modelling approach has been successfully implemented in our study to support the visualization of risk propagation pathways and for vulnerability assessment in the context of corporate bonds issuance in Iran, this presents the opportunity to apply this method in the context of other service industries across the globe and to compare our findings in other supply network contexts.
REFERENCES


FIGURE 1

Different configurations of triads using MAN labelling (denoting mutual (M), asymmetric (A), and null (N) pairs in each triad)
FIGURE 2

Corporate bonds network with five main members

Bank (Ba) - Corporate Bank (CB) - Investment Bank (IB) - Corporate Customer (CC) - Investor (In)
TABLE 1

Graph models of disruption pathways and corresponding vulnerability scores in Mellat corporate bonds network

<table>
<thead>
<tr>
<th>Triad type</th>
<th>Disruption(s)</th>
<th>Corresponding graph</th>
<th>Corresponding matrix ((T_i))</th>
<th>Vulnerability score</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB-Ba-CB</td>
<td>Lack of coordination (Ba-CB and CB-Ba)</td>
<td><img src="IB-Ba-CB" alt="Graph" /></td>
<td>(T_1 = \begin{bmatrix} IB &amp; 7 &amp; 7 &amp; 5 \ CB &amp; 5 &amp; 3 &amp; 7 \end{bmatrix})</td>
<td>986</td>
</tr>
<tr>
<td></td>
<td>Lack of coordination (Ba-IB and IB-CB)</td>
<td><img src="IB-Ba-CB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of coordination (IB-CB and CB-IB)</td>
<td><img src="IB-Ba-CB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of skills and low experience (CB)</td>
<td><img src="IB-Ba-CB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB-Ca-Ba</td>
<td>Low quality of services (CB-CC)</td>
<td><img src="CB-Ca-Ba" alt="Graph" /></td>
<td>(T_2 = \begin{bmatrix} CB &amp; 9 &amp; 5 &amp; 0 \ Ba &amp; 0 &amp; 0 &amp; 5 \end{bmatrix})</td>
<td>135</td>
</tr>
<tr>
<td></td>
<td>Dissatisfaction and mistrust (CC-Ba)</td>
<td><img src="CB-Ca-Ba" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ba-IB-Cc</td>
<td>Insufficient supervision (Ba-IB)</td>
<td><img src="Ba-IB-Cc" alt="Graph" /></td>
<td>(T_3 = \begin{bmatrix} Ba &amp; 5 &amp; 7 &amp; 0 \ IB &amp; 0 &amp; 7 &amp; 7 \end{bmatrix})</td>
<td>448</td>
</tr>
<tr>
<td></td>
<td>Opportunistic behavior (IB-CC)</td>
<td><img src="Ba-IB-Cc" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dissatisfaction and mistrust (CC-Ba)</td>
<td><img src="Ba-IB-Cc" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB-Ca-IB</td>
<td>Untimeliness and low quality of services (CB-CC)</td>
<td><img src="CB-Ca-IB" alt="Graph" /></td>
<td>(T_4 = \begin{bmatrix} IB &amp; 5 &amp; 3 &amp; 0 \ CC &amp; 7 &amp; 0 &amp; 3 \end{bmatrix})</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>Untimeliness and low quality of services (IB-CC)</td>
<td><img src="CB-Ca-IB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lack of coordination (IB-CB and CB-IB)</td>
<td><img src="CB-Ca-IB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC-Ba-In</td>
<td>Lowering the price of bonds for marketing purposes and high commissions (Ba-CC)</td>
<td><img src="CC-Ba-In" alt="Graph" /></td>
<td>(T_5 = \begin{bmatrix} CC &amp; 3 &amp; 5 &amp; 0 \ Ba &amp; 0 &amp; 0 &amp; 1 \end{bmatrix})</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Financial loss and dissatisfaction of corporate customer (CC-Ba)</td>
<td><img src="CC-Ba-In" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Ca-Ba</td>
<td>Providing false credit information and unrealistic prices to investors (Ba-In)</td>
<td><img src="In-Ca-Ba" alt="Graph" /></td>
<td>(T_6 = \begin{bmatrix} In &amp; 1 &amp; 0 &amp; 7 \ Ba &amp; 7 &amp; 0 &amp; 5 \end{bmatrix})</td>
<td>378</td>
</tr>
<tr>
<td></td>
<td>Reputation loss (In-Ba)</td>
<td><img src="In-Ca-Ba" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inaccuracy in credit check of issuing corporate and faulty pricing (IB-Ba)</td>
<td><img src="In-Ca-Ba" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-Ba-Cc</td>
<td>Providing false credit information and unrealistic prices to investors (Ba-In)</td>
<td><img src="In-Ba-Cc" alt="Graph" /></td>
<td>(T_7 = \begin{bmatrix} In &amp; 1 &amp; 0 &amp; 5 \ Ba &amp; 5 &amp; 0 &amp; 5 \end{bmatrix})</td>
<td>210</td>
</tr>
<tr>
<td></td>
<td>Reputation loss (In-Ba)</td>
<td><img src="In-Ba-Cc" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CB-In-IB</td>
<td>-</td>
<td><img src="CB-In-IB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC-In-IB</td>
<td>-</td>
<td><img src="CC-In-IB" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CC-In-Cb</td>
<td>-</td>
<td><img src="CC-In-Cb" alt="Graph" /></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Ba (Bank), CB (Corporate Bank), CC (Corporate Customer), IB (Investment Bank), In (Investor)  
\(^2\) MAN label
**TABLE 2**

Comparison of the vulnerability scores between the four identified corporate bond networks

<table>
<thead>
<tr>
<th>Triad type</th>
<th>Mellat</th>
<th>Melli</th>
<th>Tejarat</th>
<th>Saman</th>
</tr>
</thead>
<tbody>
<tr>
<td>IB-Ba-CB</td>
<td>986</td>
<td>810</td>
<td>1170</td>
<td>618</td>
</tr>
<tr>
<td>CB-CC-Ba</td>
<td>135</td>
<td>189</td>
<td>567</td>
<td>175</td>
</tr>
<tr>
<td>Ba-IB-CC</td>
<td>448</td>
<td>282</td>
<td>162</td>
<td>210</td>
</tr>
<tr>
<td>CB-CC-IB</td>
<td>222</td>
<td>282</td>
<td>666</td>
<td>162</td>
</tr>
<tr>
<td>CC-Ba-In</td>
<td>30</td>
<td>50</td>
<td>270</td>
<td>42</td>
</tr>
<tr>
<td>In-CB-Ba</td>
<td>378</td>
<td>52</td>
<td>462</td>
<td>196</td>
</tr>
<tr>
<td>In-IB-Ba</td>
<td>210</td>
<td>430</td>
<td>224</td>
<td>430</td>
</tr>
<tr>
<td>CB-In-IB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CC-In-IB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CC-In-CB</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total vulnerability score</td>
<td>2409</td>
<td>2095</td>
<td>3521</td>
<td>1833</td>
</tr>
</tbody>
</table>

*Note: for the sake of space, the complete name of the network is replaced by the name of the banks (e.g., 'Mellat corporate bonds network' is replaced by 'Mellat').*
APPENDIX A

Profile of the Interviews

<table>
<thead>
<tr>
<th>No.</th>
<th>Organization</th>
<th>Interviewee’s functional position</th>
<th>Date (2012-2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Mellat Bank</td>
<td>Head of Corporate Banking Division</td>
<td>18 December</td>
</tr>
<tr>
<td>2</td>
<td>Mellat Bank</td>
<td>Head of Research and Planning Centre</td>
<td>20 December</td>
</tr>
<tr>
<td>3</td>
<td>Amin Investment Bank</td>
<td>Head of the Investment Bank</td>
<td>25 December</td>
</tr>
<tr>
<td>4</td>
<td>Omid Investment Bank</td>
<td>Head of the Investment Bank</td>
<td>31 December</td>
</tr>
<tr>
<td>5</td>
<td>Melli Bank</td>
<td>Member of Board of Directors</td>
<td>8 January</td>
</tr>
<tr>
<td>6</td>
<td>Omid Investment Bank</td>
<td>Head of Financial Risk Management Division</td>
<td>16 January</td>
</tr>
<tr>
<td>7</td>
<td>Novin Investment Bank</td>
<td>Head of the Investment Bank</td>
<td>22 January</td>
</tr>
<tr>
<td>8</td>
<td>Tejarat Bank</td>
<td>Head of Retail Banking Division</td>
<td>24 January</td>
</tr>
<tr>
<td>9</td>
<td>Saman Bank</td>
<td>Member of Board of Directors</td>
<td>30 January</td>
</tr>
<tr>
<td>10</td>
<td>Novin Investment Bank</td>
<td>Head of Financial Risk Planning and Controlling Division</td>
<td>5 February</td>
</tr>
<tr>
<td>11</td>
<td>Sepehr Investment Bank</td>
<td>Director, Research and Development Department</td>
<td>9 February</td>
</tr>
<tr>
<td>12</td>
<td>Saman Bank</td>
<td>Member of Board of Directors</td>
<td>12 February</td>
</tr>
<tr>
<td>13</td>
<td>Amin Investment Bank</td>
<td>Head the Investment Bank</td>
<td>14 February</td>
</tr>
<tr>
<td>14</td>
<td>Sepehr Investment Bank</td>
<td>Director, Risk Analysis and Management Division</td>
<td>20 February</td>
</tr>
<tr>
<td>15</td>
<td>Corporate Customer #1*</td>
<td>Director, CFO Division</td>
<td>28 February</td>
</tr>
<tr>
<td>16</td>
<td>Corporate Customer #2*</td>
<td>Head of Strategic Management</td>
<td>3 March</td>
</tr>
<tr>
<td>17</td>
<td>Corporate Customer #3*</td>
<td>Director, CFO Division</td>
<td>6 March</td>
</tr>
<tr>
<td>18</td>
<td>Corporate Customer #4*</td>
<td>Director, CFO Division</td>
<td>12 March</td>
</tr>
<tr>
<td>19</td>
<td>Investors’ Representatives #1*</td>
<td>Director, CFO Division</td>
<td>18 March</td>
</tr>
<tr>
<td>20</td>
<td>Investors’ Representatives #2*</td>
<td>Director, CFO Division</td>
<td>20 March</td>
</tr>
<tr>
<td>21</td>
<td>Investors’ Representatives #3*</td>
<td>Director, CFO Division</td>
<td>27 March</td>
</tr>
<tr>
<td>22</td>
<td>Investors’ Representatives #4*</td>
<td>Director, CFO Division</td>
<td>3 April</td>
</tr>
</tbody>
</table>

* To maintain confidentiality of the information entrusted by the nominated banks and investment banks to the authors, names of corporate customers are not revealed in this study.
## APPENDIX B
### Interview Protocol: Corporate Customers’ Perspective

#### Interview info

<table>
<thead>
<tr>
<th>Interview number:</th>
<th>Date:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time:</td>
</tr>
<tr>
<td></td>
<td>Location:</td>
</tr>
<tr>
<td></td>
<td>Co-interviewer:</td>
</tr>
</tbody>
</table>

#### Interviewee’s information

<table>
<thead>
<tr>
<th>Full name:</th>
<th>Age:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position:</td>
<td>Working experience in finance (years):</td>
</tr>
<tr>
<td>Years in current position:</td>
<td></td>
</tr>
</tbody>
</table>

#### Guidelines

- Appreciating the interviewee for his/her participation and appointment.
- Explaining the research purpose and scientific terms required to respond to the questions.
- Explaining the risks/benefits of participation.
- Explaining their withdrawal rights.
- Asking if they have any concerns/questions.
- Getting their permission to use the voice recorder.
- Turning on the voice recorder.

#### Questions

| Q01 | Please tell us about your working experience in this position and your main responsibilities. |
| Q02 | Please explain the main risk drivers in your internal processes that if realized could disrupt your active role in the corporate bonds network. Please prioritize (Likert 1-10 scale). |
| Q03 | Describe situation(s), if any, which you considered to be adversely affecting your relations with the corporate bank and/or bank while receiving services for issuing and underwriting bonds. |
| Q04 | How much has the adverse situation(s) affected your manner of cooperation with the investment bank and/or the bank in the bond underwriting processes? Please explain and prioritize (Likert 1-10 scale). |
| Q05 | Describe situation(s), if any, which you considered to be adversely affecting your relations with the investment bank and/or bank while receiving services for issuing and underwriting bonds. |
| Q06 | How much has the adverse situation(s) affected your manner of cooperation with the investment bank and/or the bank in the bond underwriting processes? Please explain and prioritize (Likert 1-10 scale). |
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Author/s:
Pournader, M; Rotaru, K; Harrison, N

Title:
The Application of Graph Theory for Vulnerability Assessment in Service Triads

Date:
2017-08

Citation:

Persistent Link:
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