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Supply Chains of Products of Animal Origin: A Complex Network Model for Strategic Management

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ABSTRACT

Due to the dynamic evolution of food chains during the past years, currently available chain models are no longer able to meet the needs of operators. This article introduces a model for chain analysis which is used in an analysis of the supply chains of the entire Italian production of Animal Origin which constitute a complex network in which the actors of the agro-food system operate. The new model is innovative for two reasons: it represents many supply chains of products of animal origin from different productive species in a single model and, in addition, allows to represent the complexity of the chain network.

Keywords. Complex Networks; Supply Chains; Products of Animal Origin

1 Introduction and objectives

The agro-food market dynamics have changed considerably since several years. The existing models of supply and demand are no longer able to serve as useful tools for policy and chain actors to cope with the current behavior of markets. Food products are the result of a series of complex processes of production and processing involving many actors in many activities who are connected with each other through relationships of various kinds. These relationships constitute the supply chain and lead to a specific supply and price formation in the market.

The purpose of this study is to utilizing a social network analysis model for evaluating the economic relationships between the actors of the supply chain. Abbasi and Hossain (2012, pp 1 and 2) identified social network analysis (SNA) as "…the mapping and measuring of relationships and flows between nodes of social networks. SNA provides both a visual and a mathematical analysis of human-influenced relationships…Each social network can be represented as a graph made of nodes or actors (individuals, organizations, information) that are tied by one or more specific types of relations (financial exchange, trade, friends, and Web links)….Measures of SNA, such as network centrality, have the potential to unfold existing informal network patterns and behavior that are not noticed before…".

The measures that characterize a complex network fall into two categories,

a) measures that characterize the network as a whole and provide information on its structure and,

b) measures on individual nodes which provide information on the importance of each node and its relevance and convenience regarding being linked from other nodes through the shortest possible path.

Among the measures relating to individual nodes *Centrality Measures* are particularly relevant to evaluate the position of a node in the network and consequently its importance: "…Existing centrality measures for social network analysis describe the importance of an actor and give consideration to actors' given structural position in a network. These existing measures suggest specific attributes of an actor (i.e., popularity, accessibility, and brokerage behavior)…" (Abbasi and Hossain, 2012, p.1). These characteristics support the utilization of the SNA methodology for identifying the network actors who may play a prominent role in supply chains of products of animal origin in Italy.

2 The SNA model concept

The concept of a network model in which all products of animal origin are represented was derived from the project "FoodCast" managed by SISSA (International School for Advanced Studies) in Trieste and ISMEA (Institute of Services for the agricultural and food market) and commissioned by the Region of Lombardy. The focus of the the project was on the forecast of supplies and the analysis of risks in supply chains of major food commodities in Italy (http://foodcast.sissa.it).

The following presentation of the model concentrates on an integrated network view of the dairy supply chains (cow, buffalo, sheep and goat) and the meat chains for beef and pork, with their fresh and cured products. It constitutes a complex network model, made up of 228 nodes and 488 links among the nodes that represent the relationships between the production, processing and any subsequent activities. However, the model is open to the addition of other supply chains such as the poultry chain.

In the context of animal productions the network theory has been used to assess the risk of the spread of diseases (Bigras-Poulin et al., 2006; Natale et al., 2009) and also to study the price formation on the Marseille fish market (Vignes et al., 2011). About commodities in general, a minimal spanning tree network was constructed and used to study correlations and interdependencies of futures contracts for commodities over the period 1998 - 2007 (Sieczka et al., 2009). However, it is the first time that it is applied to a new kind of model and with aims of different type from those of other studies.

3 Networks and their characteristics

According to Newman (2003, p. 168), "…a network is a set of items, which we will call vertices or sometimes nodes, with connections between them, called edges. Systems taking the form of networks (also called "graphs" in much of the mathematical literature) abound in the world. Examples include the Internet, the World Wide Web, social networks of acquaintance or other connections between individuals, organizational networks and networks of business relations between companies, neural networks, metabolic networks, food webs, distribution networks such as blood vessels or postal delivery routes, networks of citations between papers, and many others".

The various terms used in the definition of components of a network may differ between fields of study (Newman, 2003, p. 173). A *Vertex* describes the basic constituent unit of a network which is sometimes also called a *site* (Physics) or *node* (in Computer Science) or *actor* (Social Science). An *edge* describes the line that connects two Vertices. It is also known as *bond* (in Physics), *link* (in Computer Science) or *tie* (Social Sciences).

Furthermore, a link can be directed from the originating node to another one, but not vice versa. Directed links, which are sometimes called *arcs*, can be represented by arrows indicating the direction. A graph is directed if all of its links are directed. A model with directed graphs represents a directed complex network.

The study of networks, in the form of mathematical graph theory, is one of the fundamental pillars of discrete mathematics. Over the years, "network oriented" approaches have been used in many areas for studying Complex Networks. Examples include the spread of viruses, the usefulness of vaccines, the evolution of the writing style of authors in articles or books, the style of music composers, transportation networks, or the communication in social networks. A typical study in the field of social science is about the centrality measures, i.e. about nodes in a network that occupy the most important positions. There are different centrality measures for different properties: as an example, we can measure the importance of nodes by the number of direct contacts with other network nodes (Degree Centrality) or by the largest number of times that it is interposed on the shortest path between two other nodes of the network (Betweenness Centrality).

4 Supply Chain and Network Analysis

The networks of relationships that the food industries intertwine during the production processes are very complex. Some authors argue that supply chains should be treated as a Complex Adaptive Systems and propose to exploit concepts, tools and techniques used in the study of CAS (Complex Adaptive Systems) to characterize and model supply-chain networks. (Surana et al, 2005). The networks of relations include not only manufacturers and processors of raw materials but also packaging companies, companies for disposal of special wastes, and trade and distribution including large-scale retail and deliveries to other companies such as the ones of the group “HO.RE.CA” (hotels, restaurants and catering). From a food chain view the relationships constitute an interorganizational collaboration of many companies that may be completely different from each other.

Supply Chain Analysis (SCA) and Network Analysis (NA) (Lazzarini et al., 2001) have so far been treated separately, as two different and distinct types of analysis suited to studying bonds of different nature in the context of interorganizational collaboration. SCA studies the vertically organized sequential transactions which represent the successive stages of creating value along the supply chain. NA is not particularly concerned with vertically organized links, but rather with horizontal bonds between companies belonging to particular industries or groups. The NA provides several tools for mapping the structure of interorganizational relationships or links between different companies (De Benedictis et al., 2011; Jackson, 2008). It is based on the acknowledgment that the structure of the network constraints is formed by the actions of the network companies (Lazzarini et al.,2001).

In their study Lazzarini et al, (2001) introduce the concept of Netchain Analysis: “…a netchain is a set of networks comprised of horizontal ties between firms within a particular industry or group, which are sequentially arranged based on vertical ties between firms in different layers. Netchain analysis interprets supply chain and network perspectives on inter- organizational collaboration with particular emphasis on the value creating and coordination mechanism sources. We posit that sources of value and coordination mechanisms correspond to particular and distinct types of interdependencies: pooled, sequential, and reciprocal. It is further argued that the recognition and accounting of these simultaneous interdependencies is crucial for a more advanced understanding of complex inter-organizational relations…”.

A Netchain is a network formed by a set of networks composed of horizontal bonds between firms within a particular segment and arranged sequentially according to vertical ties between firms in different layers, or in different segments. Netchain Analysis makes explicit distinction between horizontal bonds (in the same layer) and vertical links (in different layers), mapping how agents in each layer are related to other agents and to agents in the other layers. Some authors apply the NA in contexts that involve the supply chain (Uzzi 1997, Burt 1992; Dyer and Nobeoka 2000; Swaminathan et al., 2000), but the simultaneous assessment of vertical and horizontal relationships was not the main purpose of their study.

A Netchain approach could merge SCA and NA for providing information to actors in policy in food chains. The literature on supply chain management emphasizes the role of managerial discretion in coordinating the flow of products, information, and decision making in the supply chain.

Through the SCA, the manager may coordinate the supply chain in order to minimize transaction costs, optimize production flows, capture value along the supply chain. In literature on NA, interorganizational collaboration is focusing on the development of social links in which the activities are adjusted to each other and not just planned. It supports managerial initiatives towards pursuing flexibility in positioning the company in value networks, benefitting from new information and knowledge (Lazzarini et al., 2001).

5 The network model of products of animal origins

5.1 The baseline model

A former study of the model framework was presented earlier (EFITA, 2013). In this model the network was split into 4 segments of supply chains, production, processing, trade, and consumption. The graphical representation and analysis is based on the software tool *yEd Graph Editor* which allows you to distinguish different network layers, identify substructures, and groups, and to perform qualitative assessments of various kinds.

Since its first presentation the model has been reviewed and improved with regard to the multiplicity of represented activities and the links between network nodes. It also takes into account "side" productions currently of great interest and the focus of attention for some study groups. They involve e.g. the recovery of unsold products for humanitarian purposes or the production from the rendering activities of energy and of other products intended for use in non-food industries.

The revised model is currently made up of 228 nodes connected by 491 links according to specific criteria. In difference to traditional models, all the specified supply chains are embedded within this single model highlighting all the interconnections between them.

5.2 Graphical representation

5.21 General

Figures 1, 2, and 3 demonstrate three exemplary presentations of parts of the network. They build on segments, levels, and directed links which are represented in the graphs as follows:

Segments. The four model segments of supply chains, production, processors, traders, and consumers are represented in the graph through four different colors: rose and red for the production of milk and meat, turquoise (light and dark) for processing of milk and meat, green for trade, and blue for consumption. For production, processing, and trade, the nodes of this network represent activities within the segments. For consumption, the nodes represent the different categories of consumers who constitute the end point of the supply chain for each product considered in this network. A single company may be represented by a single node if that company performs exclusively the activity corresponding to that node, or it may be represented by a series of nodes if it carries more activities in production, processing or trade.

Levels. Each segment is differentiated according to several descriptive levels within the supply chains. The different levels are distinguished by different geometric shapes. The highest level, the segments of the supply chain such as production is characterized by a rectangle shape. Inside segments we find through increasing differentiation sub-segments, groups, sometimes sub-groups, and the individual nodes which are represented by parallelograms, hexagons, octagons, and ellipses, respectively. In some cases some products are grouped into a node-group. This is the case for products of the same category, such as PDO cheeses, or organic products. A node group does not consider links between its elements and allows its consideration as an entity with aggregate data.

Directed links. The relationships among the many nodes in the network are represented by arrows because all the links have a direction. The arrows show the direction of the flow of materials and also the sequence of processes. Since all the links have a direction this network is a directed complex network.

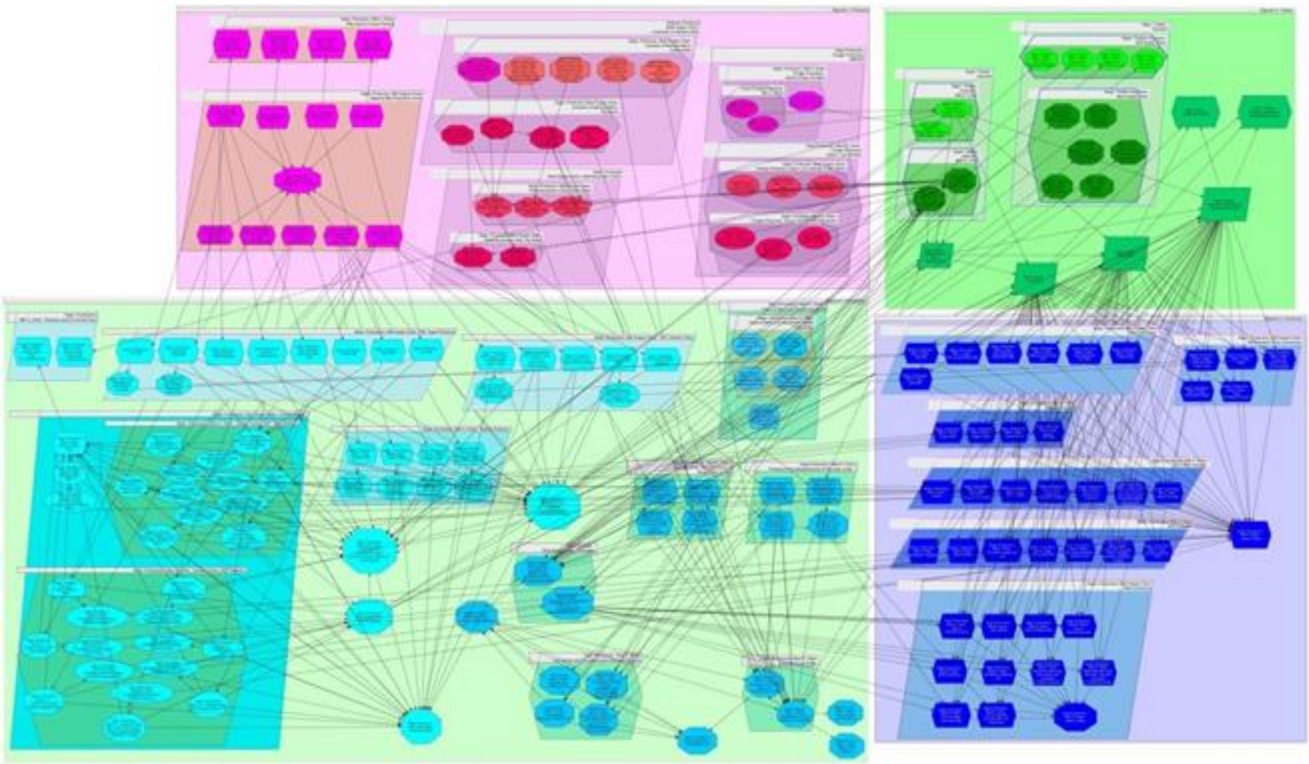

Figure 1. The network with all the groups

Differences in graphical representations (layout). The tool yEd Graph Editor allows to display different layouts of the network and to focus e.g. on certain subnets or to delete sub-segments and sub-groups. The recognition of segments and of the descriptive level is facilitated by the colors and geometric shapes that were used. Figure 3 shows an example, where the color of nodes clarifies the segment they belong to. This allows a different spatial arrangement of nodes that enables to highlight the existence of different subnets, substructures or nodes that occupy a strategic position, a preponderant role compared to the nodes attached to them.

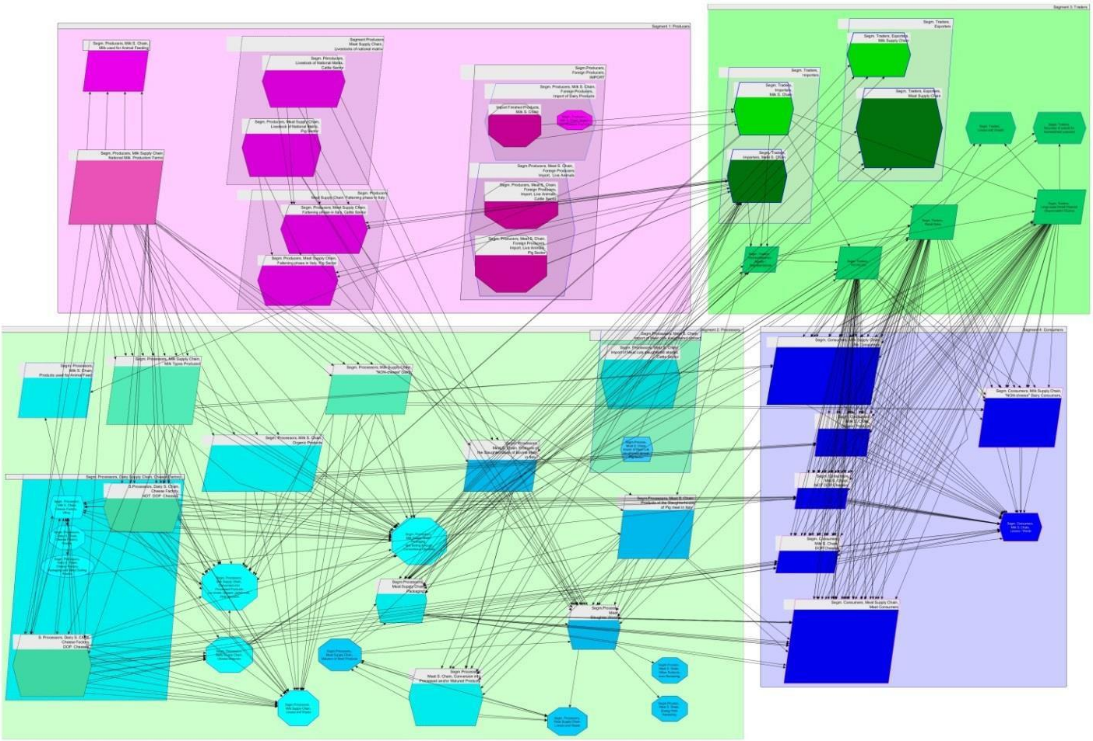

Figure 2. The network with some groups closed

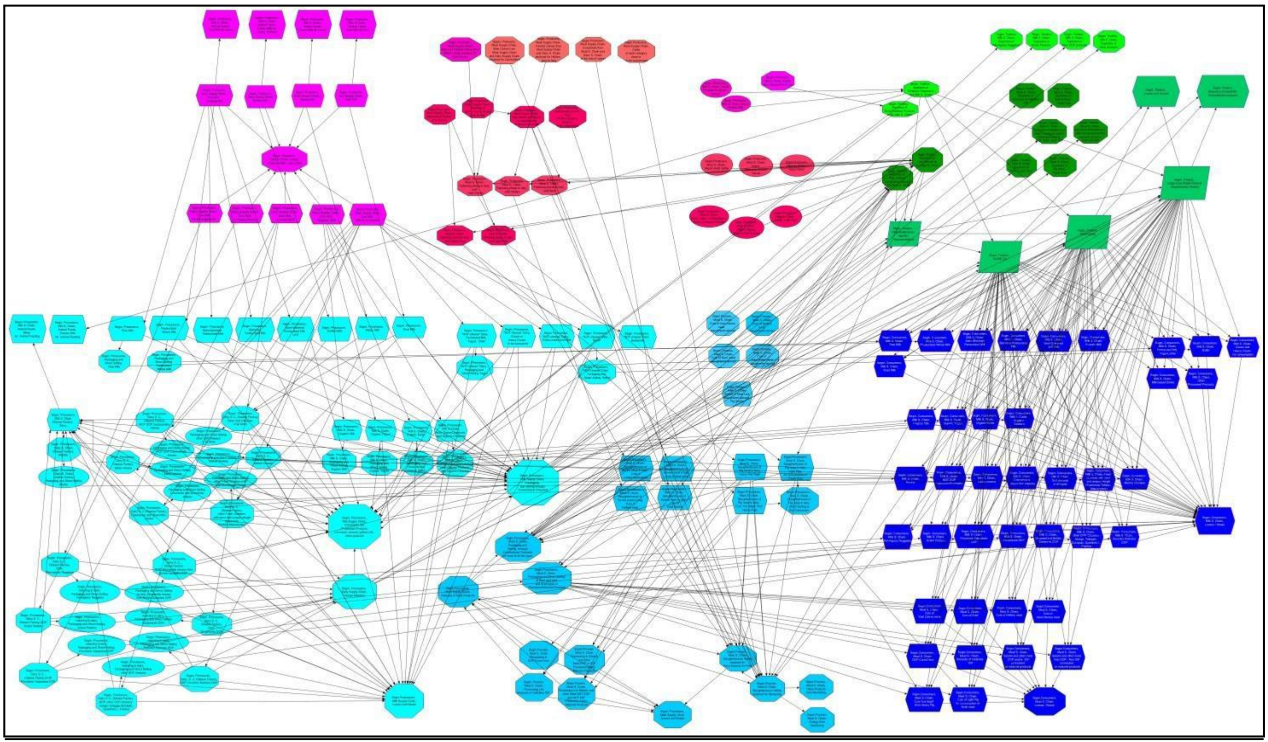

Figure 3: the network without groups

5.22 Focused presentations for node assessment

The following graphs in figure 4 and 5 demonstrate some layouts which support qualitative assessments of the importance of specified network nodes. Alternatives in rearranging the nodes of a network in a different way support the identification or confirmation of certain network features.

The presentation in figure 4 highlights the subnets with some central nodes occupying a strategic position in that subnet. The presentation in figure 5 makes aware that there is a higher concentration of nodes in the center. Those nodes are most involved in the relationships within the network, while nodes at the margins of the figure employ a lower number of relationships within the network, and might therefore be considered of lower importance for the network.

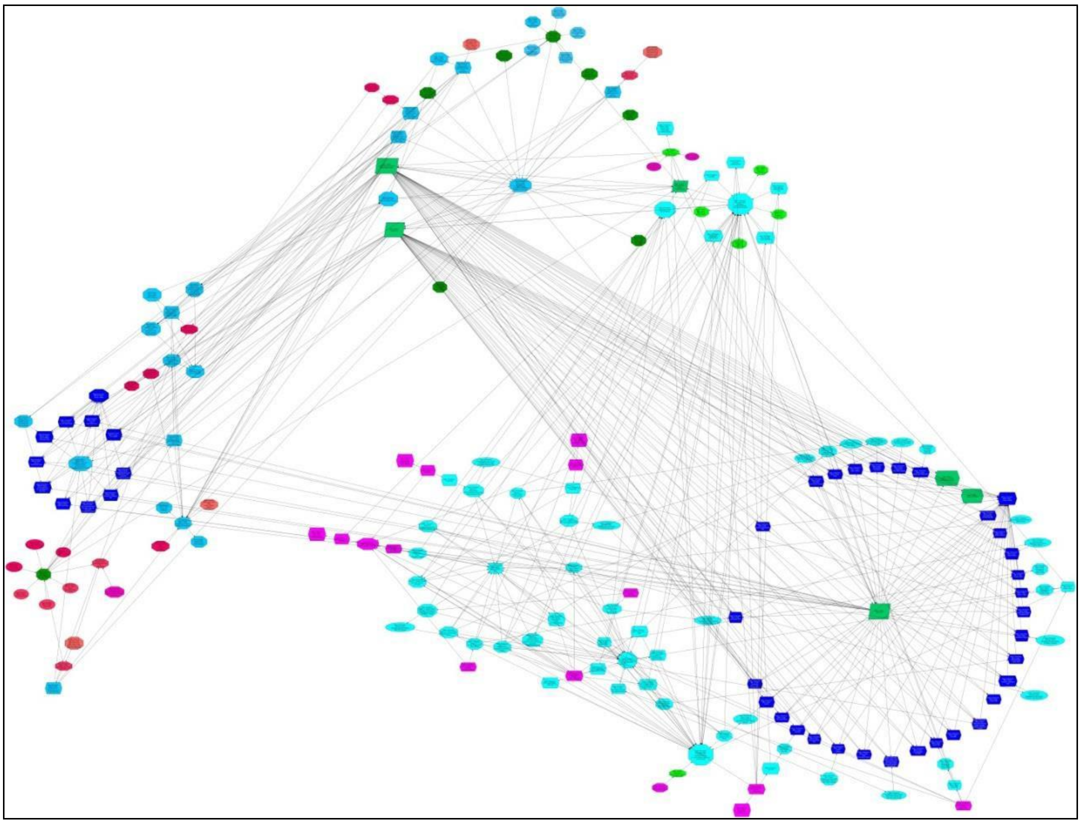

Figure 4. Circular Layout, Custom Groups: it highlights the Subnets with some central nodes occupying a strategic position in that subnet.

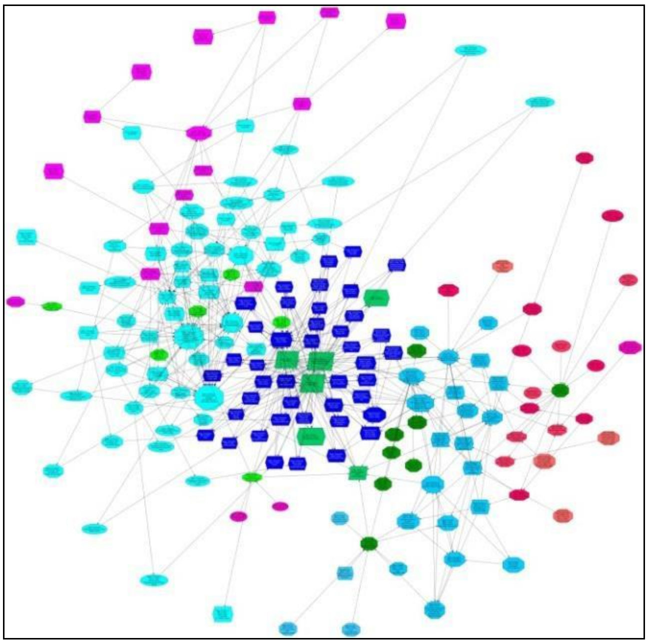

Figure 5. Circular layout, Single Cycle – Organic Disk

6 Centrality assessment of network

6.1 Overview and definition

As the network model of the supply chain is a complex network, nodes have been evaluated according to the centrality measures of complex networks. The evaluation of the positioning of the nodes along the network helps us to understand the importance of a node in the network. The operation of the model allows to make such assessments beyond a simple judgement based on the graphical representations. The assessment was focusing on the centrality criteria of *degree*, *closeness* and *betweenness*.

Each measure of centrality is useful depending on the circumstances and what aspect of the network and the relationships between the nodes one want to investigate (Baggio et al., 2010). For assessing economic aspects, the meaning of centrality concepts such as “popularity” has to be "translated" into its economic relevance (Boccaletti et al., 2006, pp 180-185):

1. *Degree Centrality*: the number of other nodes connected directly to a node is an indicator of an actor’s communication activity and shows popularity of an actor.

2. *Closeness Centrality*: the inverse of the sum of distances of a node to others is a measure of distance where a node in a position closest to another can more efficiently obtain information.

3. *Betweenness Centrality*: the portion of the number of shortest paths that pass through the given node divided by the number of shortest paths between any pair of nodes (regardless of passing through the given node) is a measure of how much a node is crucial for the operation of the network.

4. *Eigenvector Centrality*: It is a measure of the importance of a node in a network based on its connections but considering the relevance of the nodes it connects to. It provides a relative score to all nodes in the network based on the principle that connections to high-scoring nodes contribute more to the score of the node in question than similar connections to low-scoring nodes.

6.2 Assessment

The analysis provides new graphics that highlight the most important nodes of the network according to the centrality measures used for the analysis. The results show that there is not a single node which can be considered of being most important but a group of nodes that are of great importance in a chain of products of animal origin. The analysis of the network model provides an index for each node and for each centrality measure with values between 0 (minimum) and 1 (maximum value).

The graphs in figures 6, 7, and 8 focus on the centrality criteria *degree*, *closeness*, and *betweenness*. The nodes with the highest score for each of the centrality criteria are summarized in tables 1, 2, and 3.

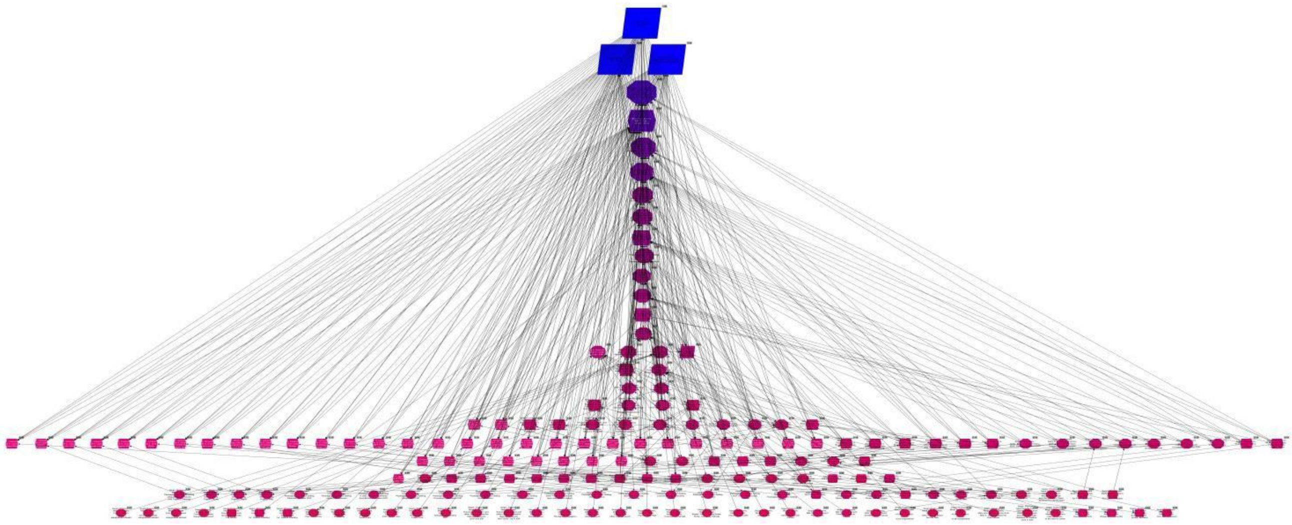

Figure 6. Degree Centrality

Table 1.
Degree Centrality

1. Node Segment Traders, Retail Sales: score 1
2. Node Segment Traders, HO.RE.CA (Hotel-Restaurant-Catering); Node Segment Traders, Supermarket chains : score 0,98
3. Node Segment Processors, Milk Supply Chain, Packaging and Selling through conventional channels: score 0,69
4. Node Segment Consumers, Milk Supply Chain, Losses/Waste: score 0,62
5. Node Segment Processors, Milk Supply Chain, Conversion into processed products (ice cream, dessert, etc.): score 0,52
6. Node Segment Processors, Milk Supply Chain, Losses and Waste: score 0,46
7. Node Segment Processors, Meat Supply Chain, Packaging and Selling through conventional channels for meat of all types: score 0,38

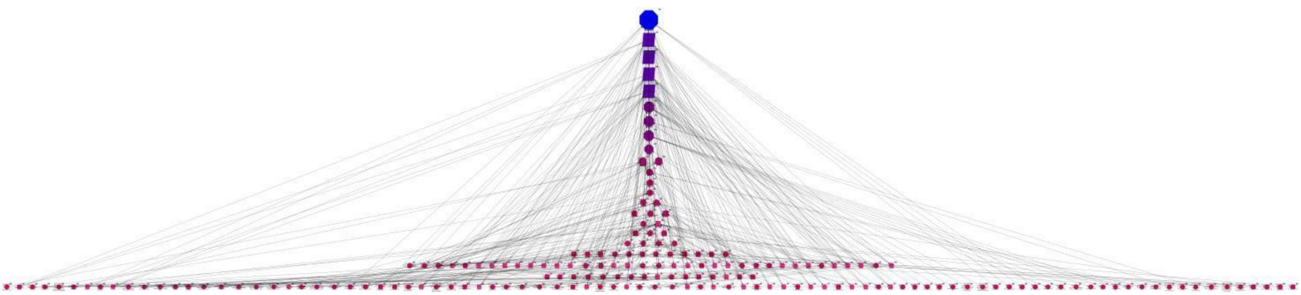

Figure 7. Betweenness Centrality

Table 2.
Betweenness Centrality

1. Node Segment Processors, Milk Supply Chain, Packaging and Selling through conventional channels: score 1
2. Node Segment Traders, Retail Sales: score 0,62
3. Node Segment Traders, Intermediaries/Agents/Representatives: score 0,61
4. Node Segment Traders, HO.RE.CA.: score 0,60
5. Node Segment Traders, Large-scale Retail Channel (Supermarket Chains): score 0,59
6. Node Segment Processors, Meat Supply Chain, Packaging and Selling through conventional channels for Meat of all types: score 0,43
7. Node Segment Processors, Meat Supply Chain, Slaughterhouse Waste destined for rendering: score: 0,41

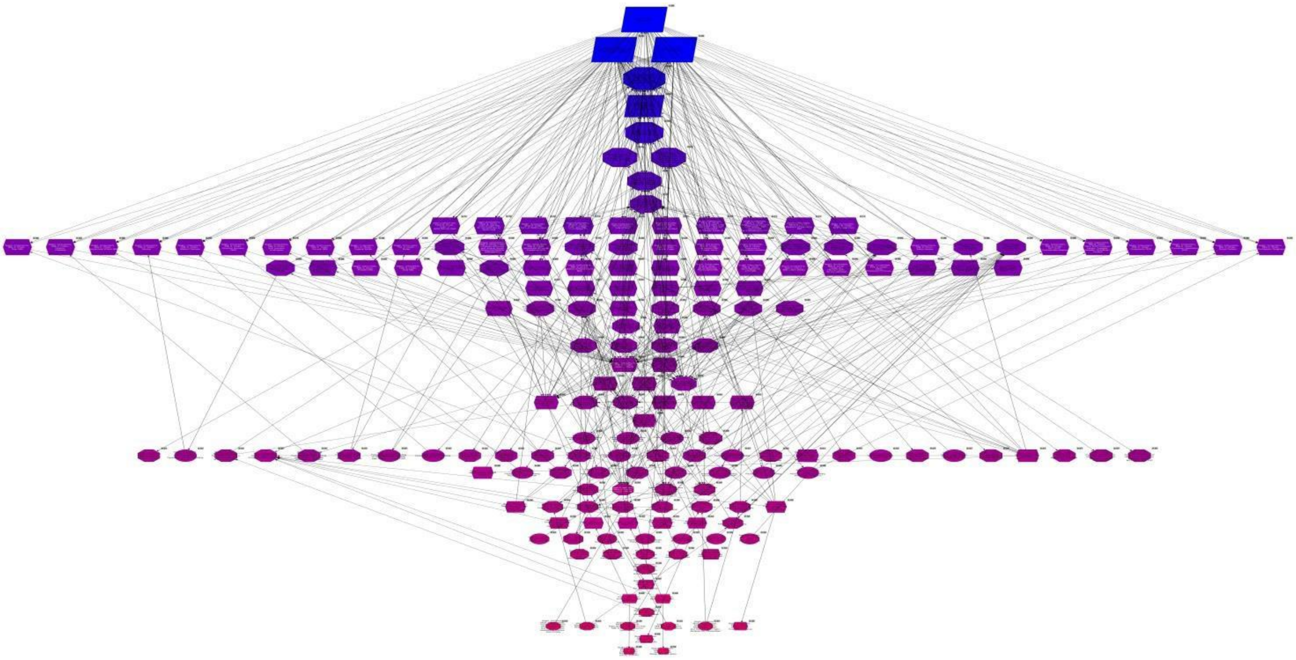

Figure 8. Closeness Centrality

Table 3.
Closeness Centrality

1. Node Segment Traders, Retail Sales: score 1
2. Node Segment Traders, HO.RE.CA; Node Segment Traders, Supermarket chains : score 0,99
3. Node Segment Processors, Milk Supply Chain, Packaging and Selling through conventional channels: score 0,92
4. Node Segment Traders, Intermediaries/Agents/Representatives: score 0,89
5. Node Segment Processors, Milk (Dairy) Supply Chain, Cheese Maturers: score 0,85
6. Node Segment Traders, Importers of Finished Products in the Milk Supply Chain; Node Segment Processors, Meat Supply Chain, Packaging and Selling through conventional channels for meat of all types: score 0,79
7. Node Segment Processors, Meat Supply Chain, Slaughterhouse Waste destined for rendering: score 0,78

7 Conclusions

This is a preliminary study on a complex directed network which has its main focus on qualitative results for centrality criteria. The rankings of nodes are not yet definite but they demonstrate the relevance of nodes in segment *Trade* and *Processing* for all three of the centrality criteria (table 4). Most relevant nodes in trade include the nodes related to large-scale trade of supermarkets, retail sales, *HO.RE.CA*. (hotels, restaurants, and catering), and to a lesser extent the node of Agents/Intermediaries. Most relevant nodes in processing focus on *Packaging and Selling through conventional channels* (including the nodes dedicated to direct sales). It is striking that the most relevant nodes in processing focus solely on the Milk Supply Chain. However, when including the results for the 7 most relevant nodes the node *Packaging & Selling through conventional channels* stands out as well for the Meat Supply Chain.

Table 4.
Most relevant nodes (upper three) regarding various centrality criteria

Ranking	**Degree Centrality**	**Betweenness Centrality**	**Closeness Centrality**
1	Node Segment Traders, 1. Retail Sales: score 1	Node Segment Processors, 1. Milk S. C. Packaging and Selling through conventional channels: score 1	Node Segment Traders, 1. Retail Sales: score 1
2	Node Segment Traders, 1. HO.RE.CA; 2. Supermarket chains: score 0,98	Node Segment Traders, 1. Retail Sales: score 0,62	Node Segment Traders 1. HO.RE.CA; 2. Supermarket chains: score 0,99
3	Node Segment Processors, 1. Milk S.C. Packaging and Selling trough conventional channels: score 0,69	Node Segment Traders, 1. Intermediaries / Agents / Representatives: score 0,61	Node Segment Processors, 1. Milk S. C. Packaging and Selling trough conventional channels: score 0,92

The rankings shown in table 4 are based on the measurements of the three different centrality measures which are based respectively on the number of direct links, on the number of interpositions along the path between the various pairs of the network and on the number of steps that measure the distance of a node from the others. It must be mentioned that these rankings do not take into account the weight of relationships between the various nodes which may change the overall picture. This is to be expected, as an example, for the node *Retail Sales*, which is certainly connected with a very high number of nodes in a direct manner, but will probably prove to be less relevant in a weighted analysis in comparison with the node *Supermarket Chains.*

Even without weights, however, the information provided (table 4) is useful as it identifies the most important elements with regard to their position in the supply chain network. Further studies will need to further elaborate on the economic consequences of these rankings and incorporate the weight of relationships. Furthermore, the analysis will need to go beyond the discussion of the role of single nodes and include measures that consider the whole structure, its functioning, its performance, and its limitations.

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