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A Hybrid Approach for Supply Chain Analysis: An Application of Network and Cluster Analysis

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Outline

- Supply Chain Management
- Network Analysis
- Study Case
- Results
- Conclusion

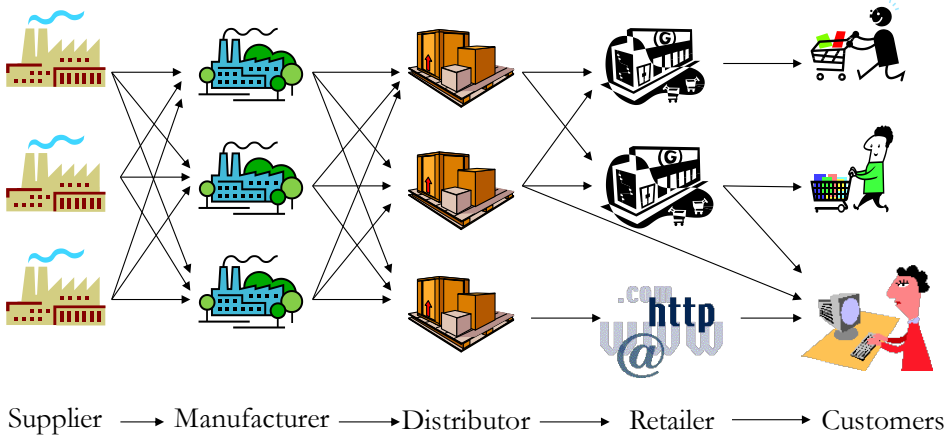
Supply Chain Management

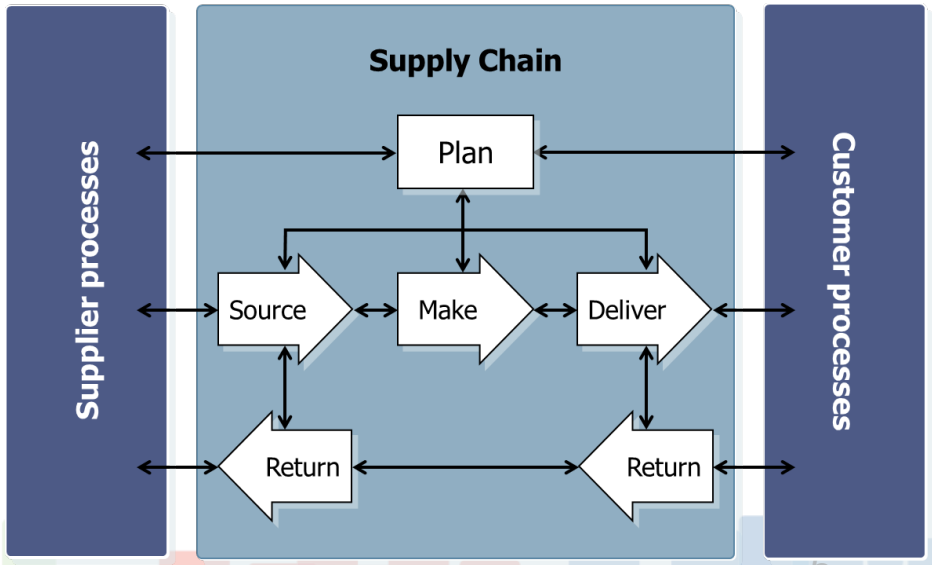
Supply Chain Management (SCM)

- A supply chain is not only a chain but a complex network that involves many system components from various fundamental facilities.
- These functional components are dependent and cooperate with each other through material, information and/or functional flows in and between stages.
- Management independently have some costly consequences.
- SCM exists for the management of various flows both in and between facilities.

Supply Chain Modelling

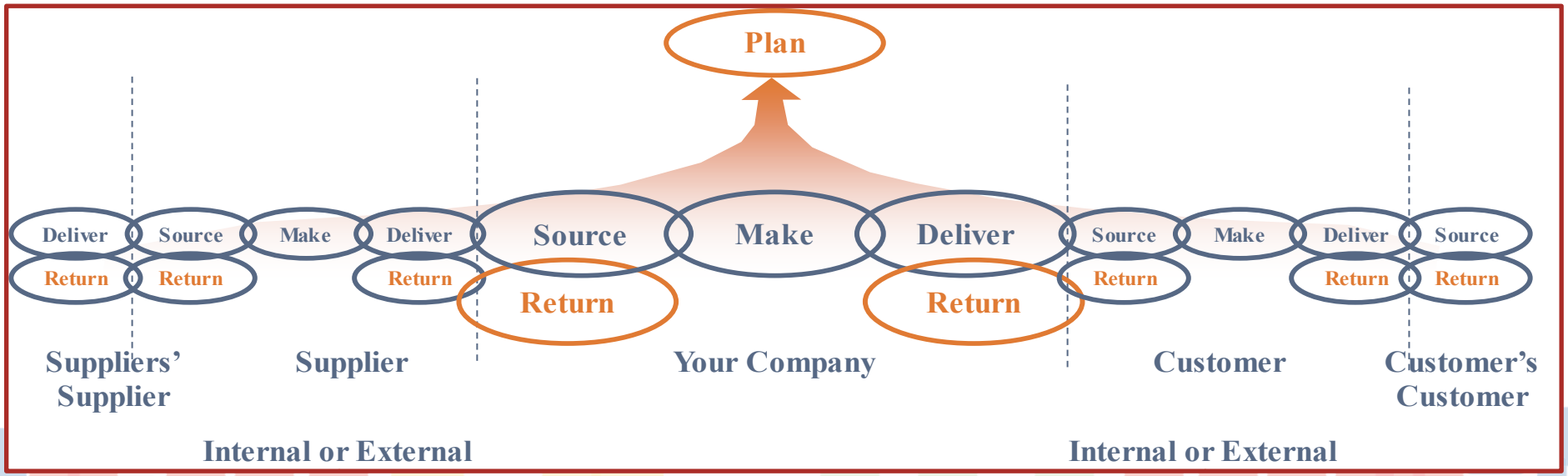
- An important current trend in supply chain modelling focuses on adding dimensions, stages or levels rather than discrete business functions.
  - Contains critical enterprises, distributors, retailers, as well as primary suppliers and secondary suppliers.
  - The supply chain operations reference (SCOR) model released by supply chain council (SCC) has distinct processes that are source, make, deliver, return and plan.



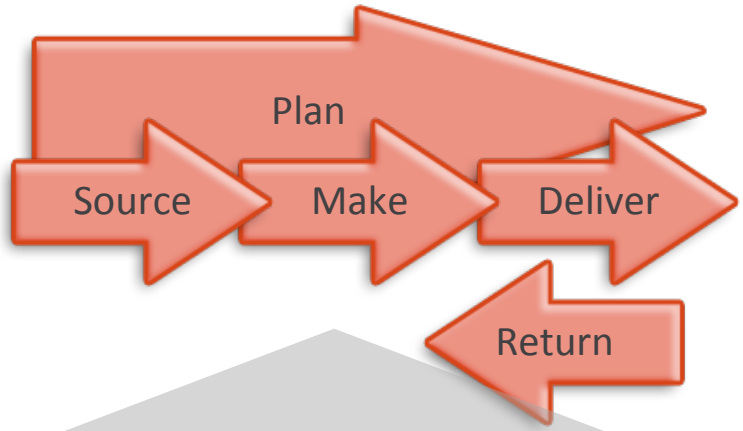


SCOR model

- The Supply-Chain Council (SCC) has developed and endorsed SCOR as the cross-industry standard for supply chain management.
- SCOR model can support the supply chain management operational, design and strategic research as it integrates a complete business process from various stages such as plan, source, produce, etc.



SCOR Framework Levels*



SCOR is a hierarchical model

Level-1 Sets **Scope** and Context, Geographies, Segments and Products

M1
Make
Build to Stock

M2
Make
Build to Order

M3
Make
Engineer to Order

Level-2 Identifies Major **Configurations** within Geographies, Segments and Products

M2.01
Schedule Production Activities

M2.02
Issue Product

M2.03
Produce & Test

M2.04
Package

M2.05
Stage Product

M2.06
Release Product to Deliver

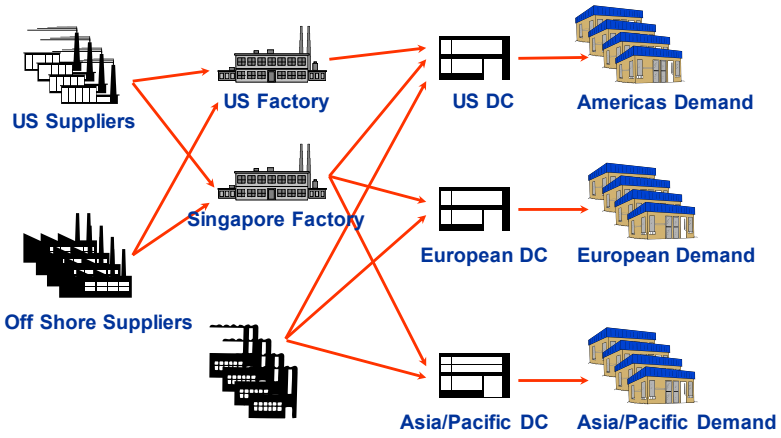
Level-3 Identifies key **business activities** within a configuration

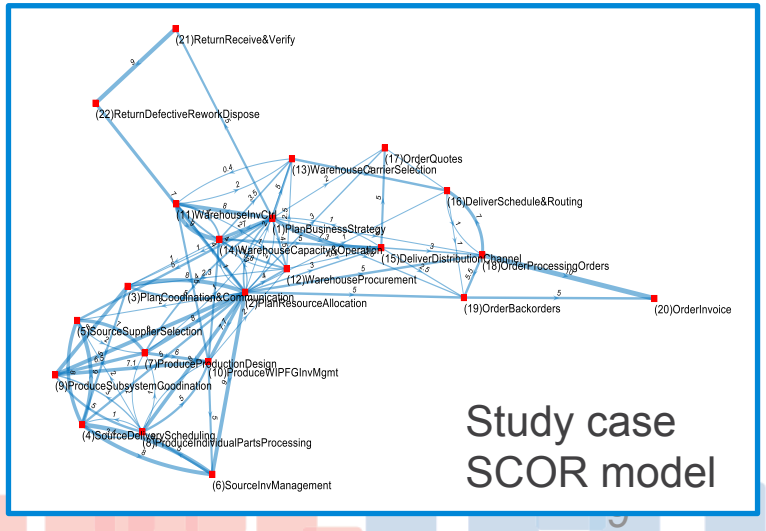
*E. Camerinelli Introduction to SCOR, Aite Group, 2012

Network Analysis

A supply chain viewed as a social network

- The supply chain system under the background of global economic integration has a characteristic of complex network.
- The research community has spent effort on modelling supply chain network and systematic approaches for SCM. Social network analysis methods are considered useful.
- Its success depends on the systematic integration of business processes and collaborative performance of supply chain entities.

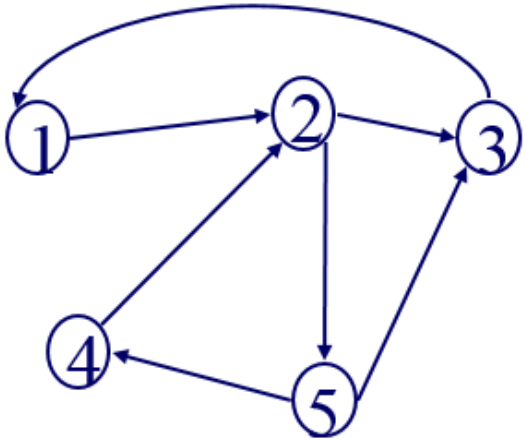




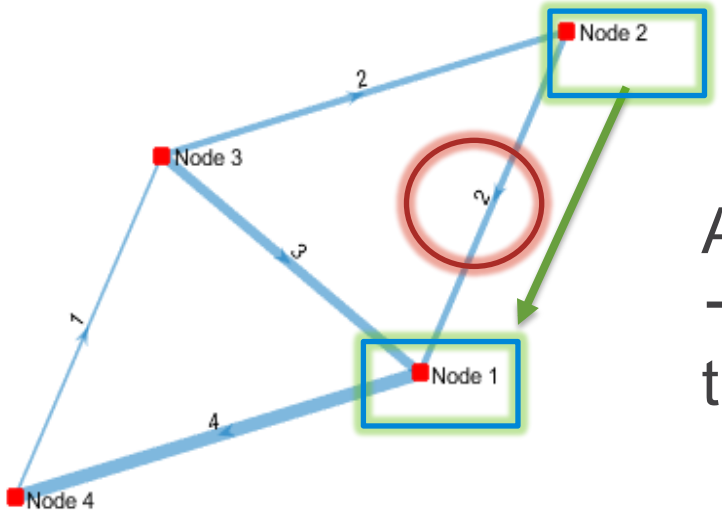
Network analysis

- Derived from graph theory.
- Study the characteristics of a whole network and the position of individuals in the network structure.
- Applies quantitative techniques to produce relevant indicators.
- Identify the "important" nodes in the network.
- One reflection of **importance** is indicators of **centrality**.
- *The idea is to use the centrality of individuals in their network to acquire the positional features of individual nodes within networks.*

Which are the most "important" nodes in the directed graph?



Notation for Graphs and Matrices

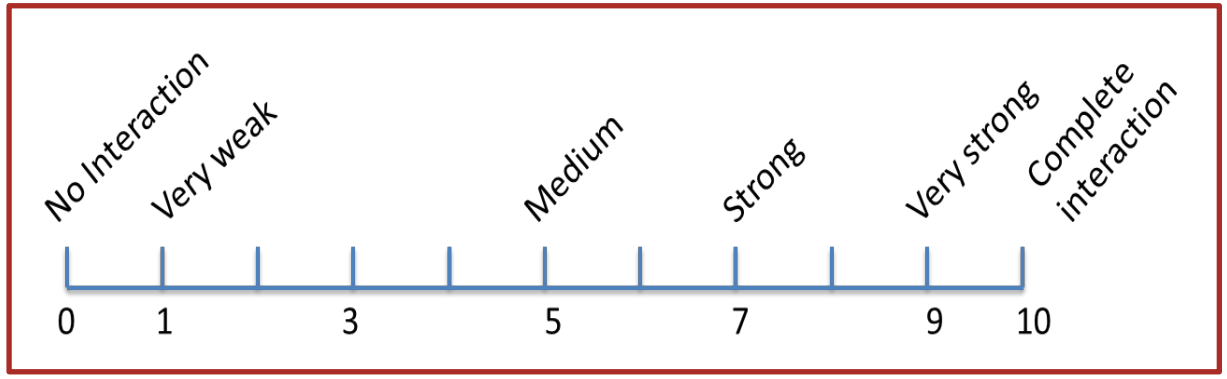


A directed flow from *i* to *j*
→ A positive integer in the the cell (row *i*, column *j*).

	1	2	3	4
1		0	0	4
2	2		0	0
3	3	2		0
4	0	0	1	

Network graph (a directed graph)

Network adjacency matrix



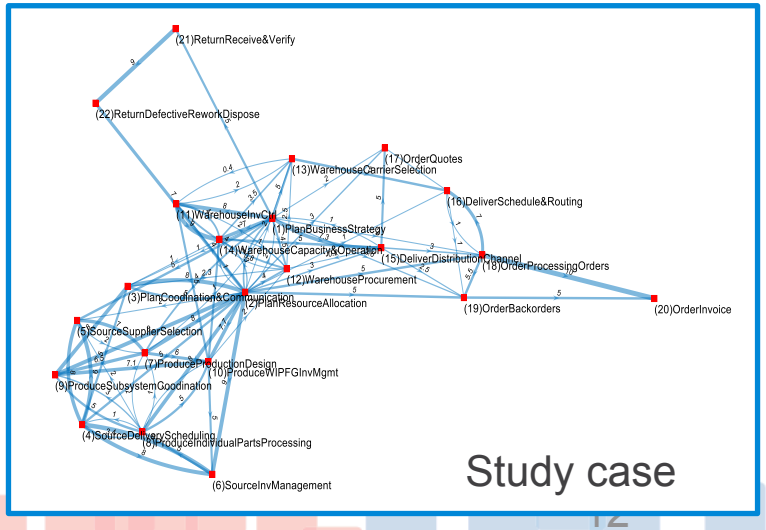
Scales for determine the interaction/flow strength

Each interaction is assigned a strength ranging by managers and/or experts based on their experience and expertise of the related elements

Indicators of network analysis: Centralities

- Network centrality
  - Degree
    - In-degree
    - Out-degree
  - Closeness
    - In- closeness
    - Out-closeness
  - Betweenness
  - PageRank

Characterizing network：who are the most “important” nodes in the network?

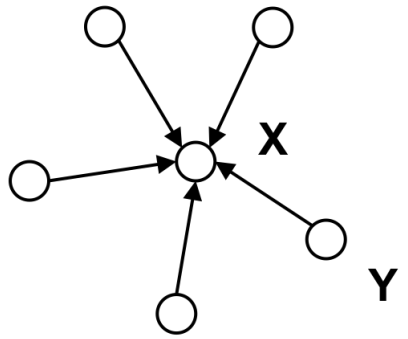


Degree Centrality(in-/out-degree)

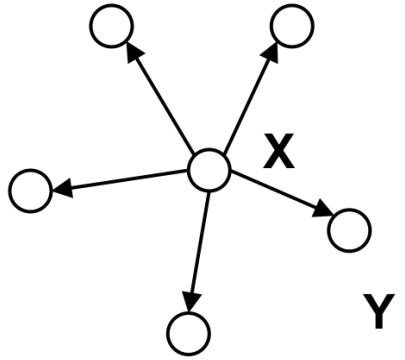
- The number of connections an node has
  - Number of ties sent (**out-degree**) and received (**in-degree**）
- Degree centrality does not take into account indirect ties an node has.

$$C_{Degree,in}(V_i) = \sum_{j=1}^{n} r_{ij,in}$$

$$C_{Degree,out}(V_i) = \sum_{j=1}^{n} r_{ij,out}$$



In-degree （X>Y）

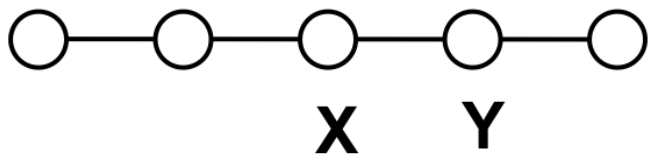


Out-degree（X>Y）

Closeness Centrality (In-/Out-closeness)

- A measure of the degree to which an individual is near all other individuals in a network.
- It is the inverse of the sum of the shortest distances between each node and every other node in the network.
- Reveals the extent to which a particular node is reachable from and to other nodes.
- High closeness node is important/central as it can quickly interact with all other

$$C_{Closeness}(V_i) = \frac{1}{\sum_{j=1}^{n} d(V_i, V_j)}$$



Closeness (X>Y)

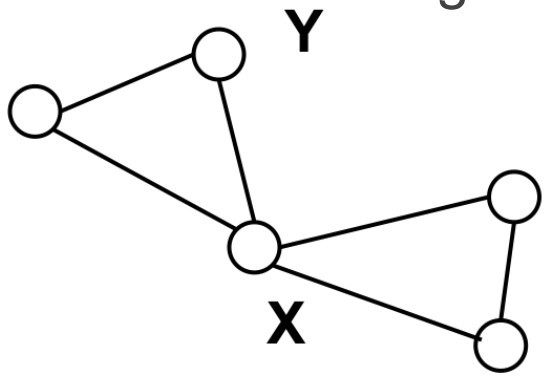
Degree centrality measures one's local position, while closeness centrality measures position globally.

Betweenness

- The extent to which a node lies on the paths between others.
- A measure of the degree to which a node serves as a bridge/broker.
- Another global measurement that elaborates the ability of a given node to control interactions between pairs of other nodes in the network.
- High betweenness centrality means that it is a highly critical intermediary between pairs of other nodes, since most flows will pass through this node while traveling between other various nodes.

$$C_{Betweenness}(V_i) = \sum_{j}^{l} \sum_{k}^{l} \frac{g_{jk}(V_i)}{g_{jk}} \qquad j \neq k \neq i$$

The number of short distance linking the two nodes that contain node i.
The number of distance between node j and k.

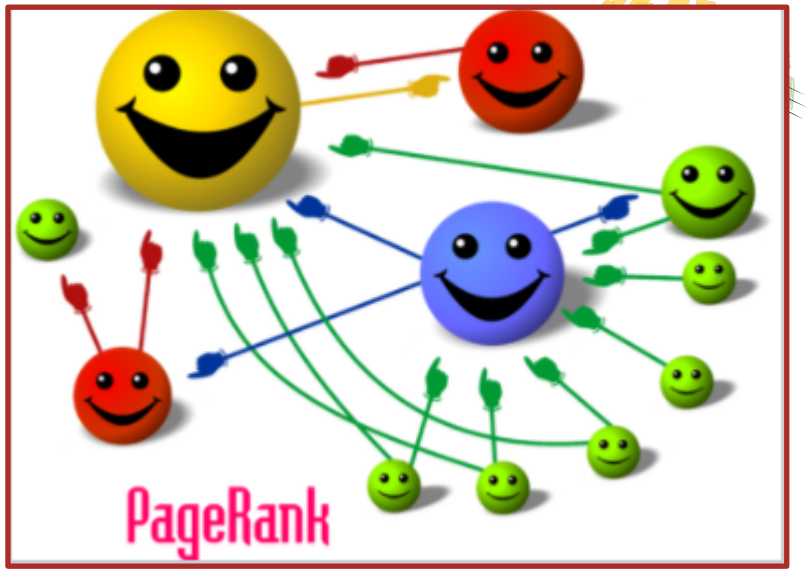


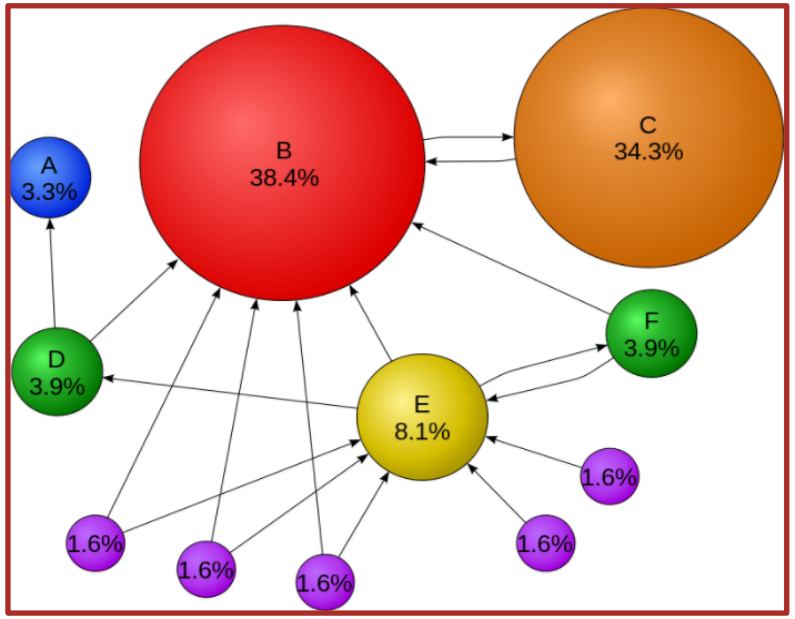
Betweenness (X>Y)

PageRank

- Measure the importance of website pages. Used by google to rank websites. Estimates a page's authority by taking into account the link structure of the web.
- When one vertex links to another, it casts a vote for that other vertex. The higher the number of votes that are cast for a vertex, the higher the importance of the vertex.
- An enhanced version of in-degree centrality.

$$C_{PageRank}(V_i) = (1-d) + d \times \sum_{j \in In(V_i)} \frac{C_{PageRank}(V_j)}{|r_{ij,out}|}$$





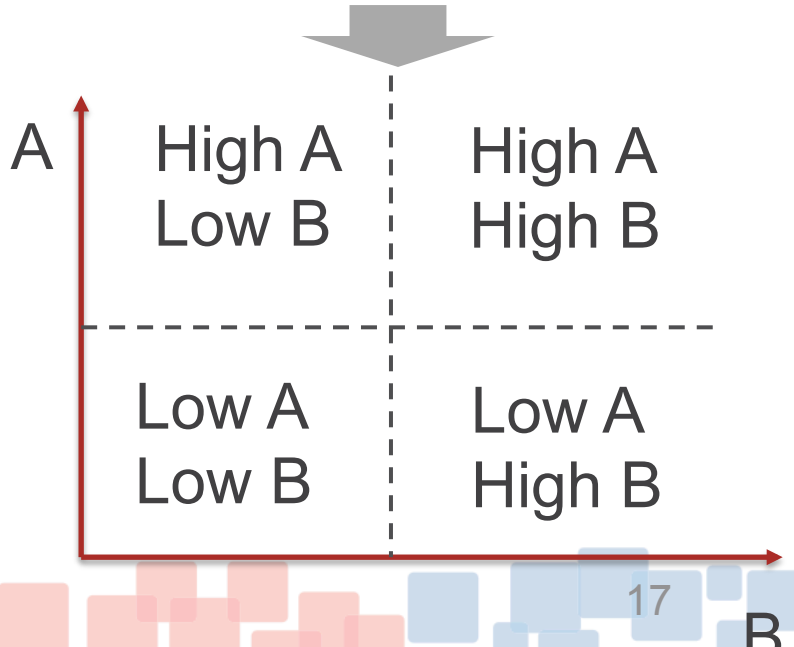
Mathematical **PageRanks** for a simple network, expressed as percentages.

Cluster Analysis with Centralities

- Overall, the centralities were strongly correlated.
- When they are not or weakly correlated, there is likely something interesting about the network.
  - E.g. nodes with high betweenness and low degree are crucial for network flow.
- Employ cluster analysis to classify the nodes according to their centrality scores.
  - Given two centrality values, A and B
  - Group the nodes to four clusters using k-means clustering algorithm.
  - The resulting four groups are nodes with high A and high B, high A and low B, low A and high B, low A and low B.

Component	Degree		Closeness		Betweenness	PageRank
	In-degree	Out-degree	In-closeness	Out-closeness		
1	4.0	57.4	0.0073	0.0087	104.0	0.0255
2	10.0	94.7	0.0056	0.0115	85.0	0.0221
3	10.0	20.3	0.0078	0.0068	26.0	0.0190
4	28.0	20.4	0.0056	0.0055	6.0	0.0832
5	25.0	10.0	0.0065	0.0069	10.5	0.0677
6	22.0	14.0	0.0029	0.0047	0	0.0434
7	15.0	21.5	0.0060	0.0094	96.0	0.0623
8	23.4	12.0	0.0057	0.0086	83.0	0.1189
9	32.6	5.0	0.0040	0.0046	0	0.0547
10	23.7	20.1	0.0040	0.0101	5.5	0.0482
11	23.4	15.0	0.0055	0.0053	15.0	0.0644
12	17.4	5.50	0.005	0.0090	79.0	0.0527
13	1.0	5.4	0.054	0.0055	3.5	0.0522
14	20.0	20.3	0.0057	0.0106	71.0	0.0466
15	15.3	11.7	0.0037	0.0106	1.0	0.0190
16	13.0	3.0	0.0059	0.0040	25.0	0.0420
17	11.0	0.0	0.0076	0	0	0.0285
18	11.0	22.5	0.0075	0.0012	0	0.0285
19	16.6	5.0	0.0075	0.0005	16.0	0.0366
20	15.0	0.0	0.0042	0	0	0.0499
21	5.0	9.0	0.0037	0.0003	0	0.0124
22	16.0	0.0	0.0030	0	0	0.0222

A B

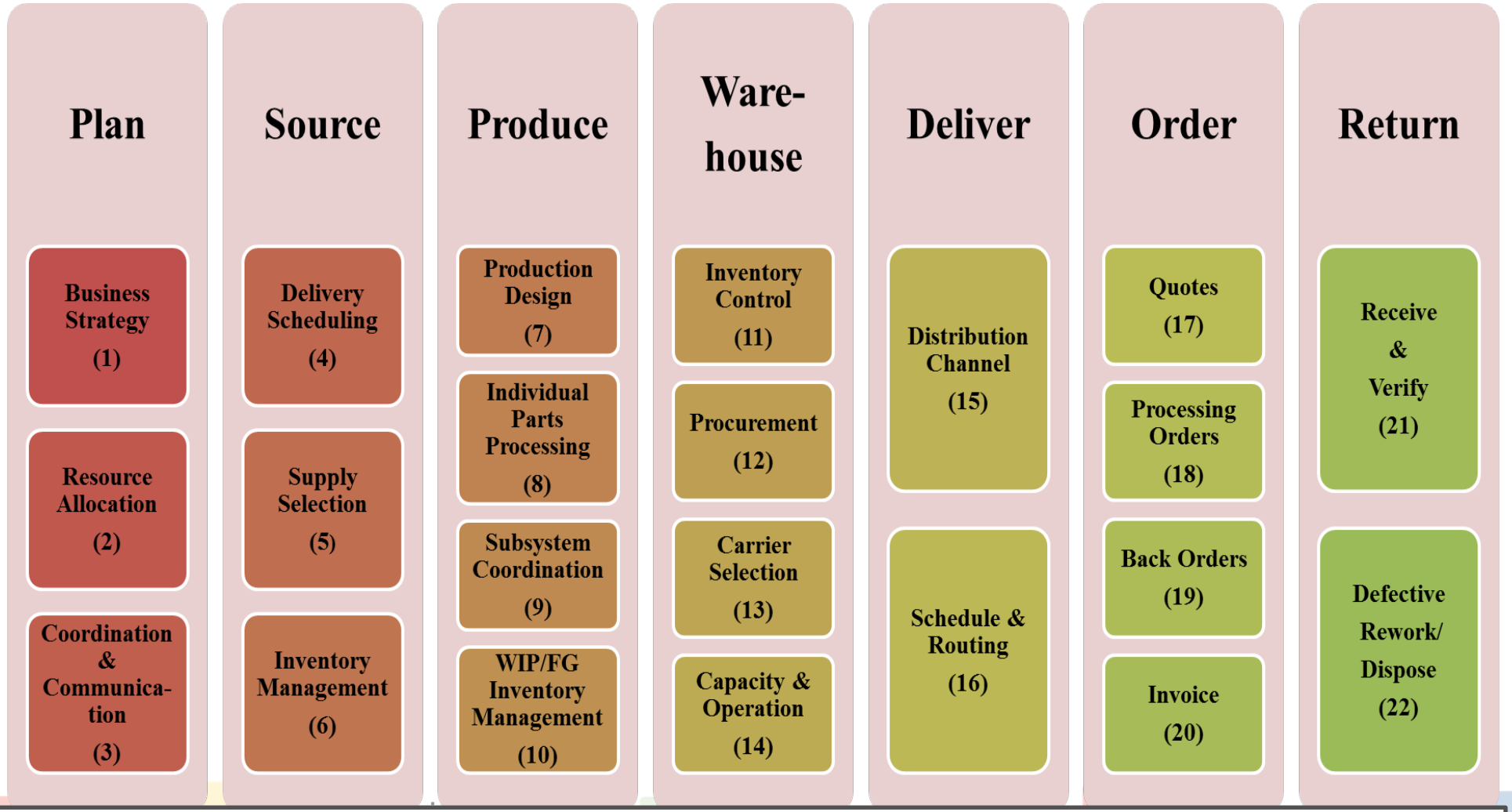


Study Case

A functional structure constructed with SCOR models

22 functional components spread across 7 stages.

Each stage has several sub-level functional components

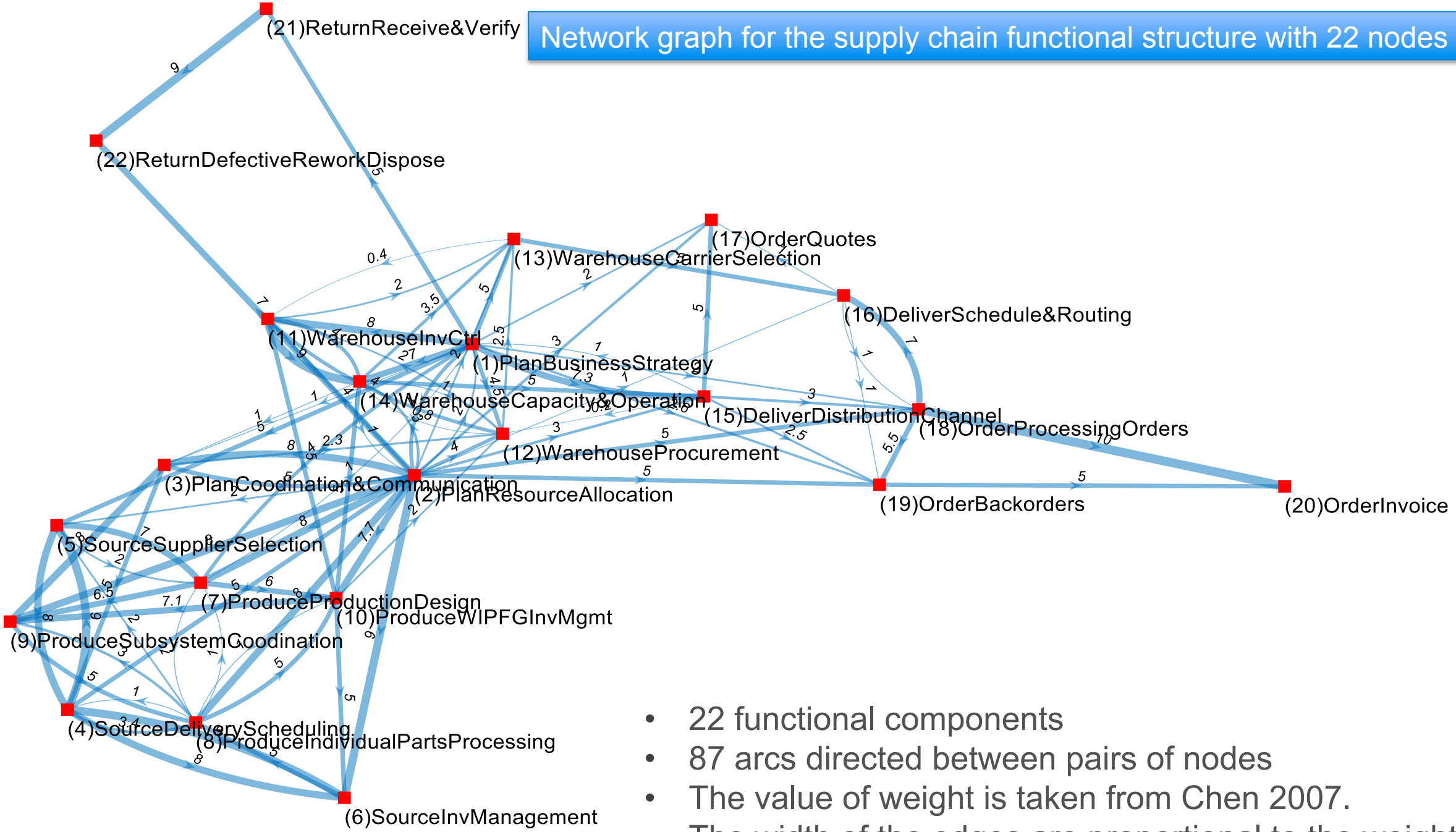


Chen, S.-J. G. and E. Huang, 2007. A systematic approach for supply chain improvement using design structure matrix. *Journal of Intelligent Manufacturing*, 18(2), 285-299.

Three important types of flows

- Information flows specify customer needs, pricing information, system status, and/or other information that is required to maintain the functionality of a supply chain element.
- Material flows are the physical flows and processes from raw materials to finished parts/products.
- Functional flows are the communication and coordination flows among different functional departments (e.g., to determine or change task due date, supplier, quality requirements, product design, material usage or other specifications).

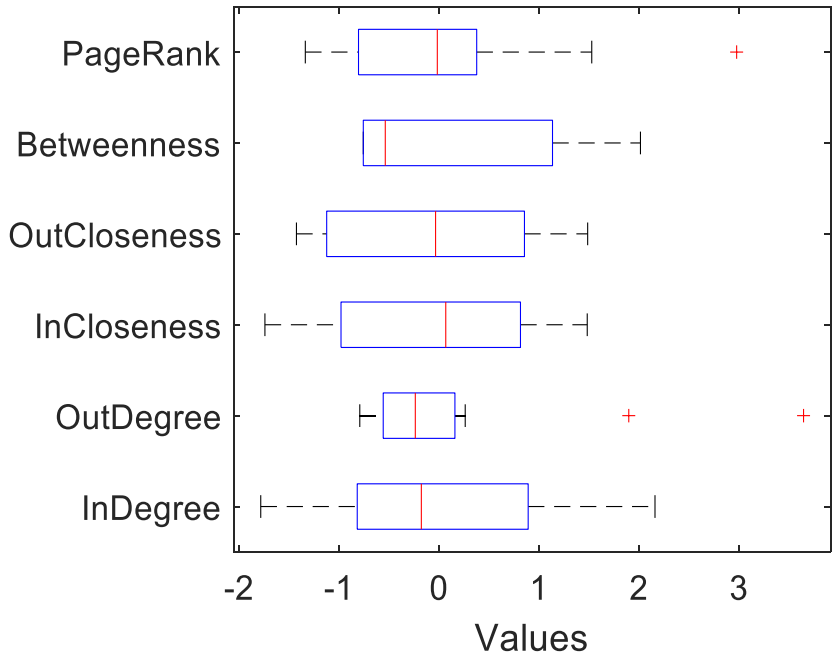
Network graph for the supply chain functional structure with 22 nodes



- 22 functional components
- 87 arcs directed between pairs of nodes
- The value of weight is taken from Chen 2007.
- The width of the edges are proportional to the weights

Results

Centrality values of the supply chain network



Different centralities distribution

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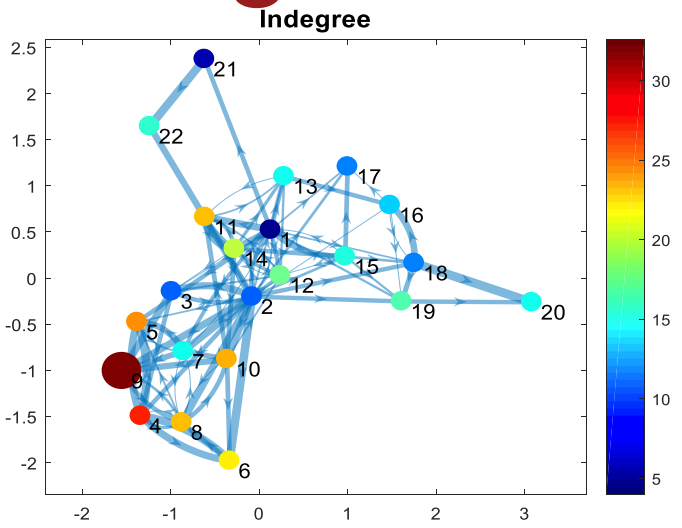
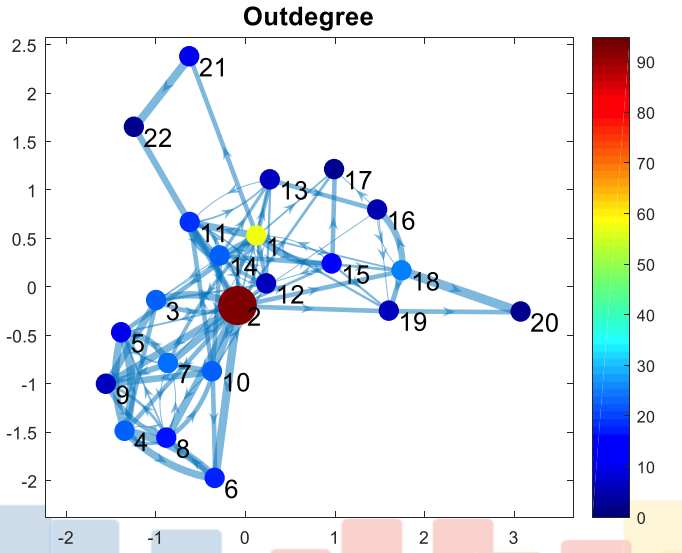
19	16.6	5.0	0.0075	0.0005	16.0	0.0366
20	15.0	0.0	0.0042	0	0	0.0499
21	5.0	9.0	0.0037	0.0003	0	0.0124
22	16.0	0.0	0.0030	0	0	0.0222
Mean	16.9	16.9	0.0055	0.0056	28.5	0.0454
STD	7.3	21.3	0.0015	0.0039	37.5	0.0247
Min	4	0	0.0029	0.0000	0.0	0.0124
Max	32.6	96.7	0.0078	0.0114	104.0	0.1189

If the distribution of the nodes is not even which suggests the existence of something interesting.

In-degree, out-degree

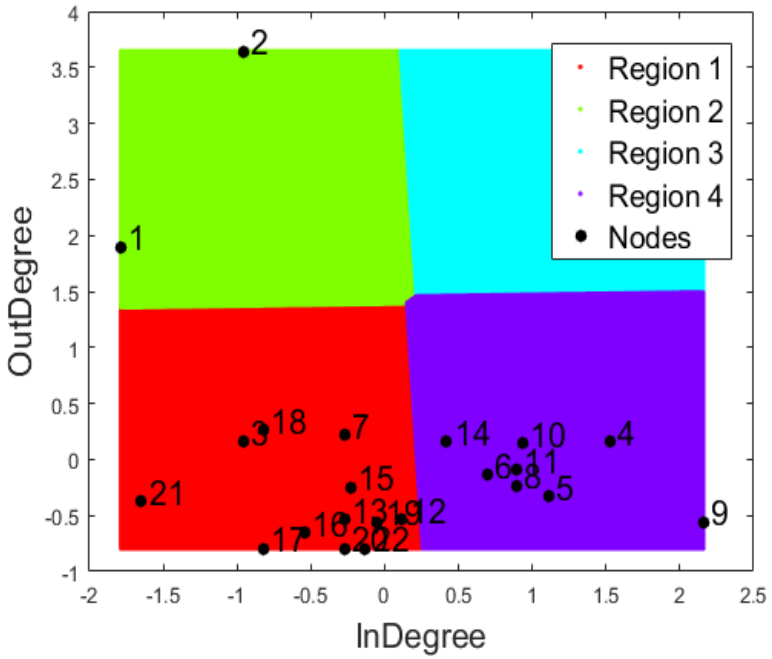




- Higher out-degree is more central/conductive.
- Higher in-degree is more prestigious/dependent.
- A highest degree indicates the most vulnerable nodes, as its failure will inactivate the maximum number of links, such as Node 2 and 9.

- Node 9 (Produce Subsystem coordination) has the highest in-degree, which suggests it receives the most choices and gets the most support from other nodes. Node 4 (Source Delivery scheduling), 5 (Source Supplier Selection), 10 (Produce WIP/ FG Inventory Management), 8 (Produce Individual Parts Processing), 11 (Warehouse Capacity and Operation) also have high in-degree. These nodes belong to Source, Produce and Warehouse stages.
- Node 2 (Plan Resource Allocation) is the highest out-degree node, which implies it plays the role of choice maker.

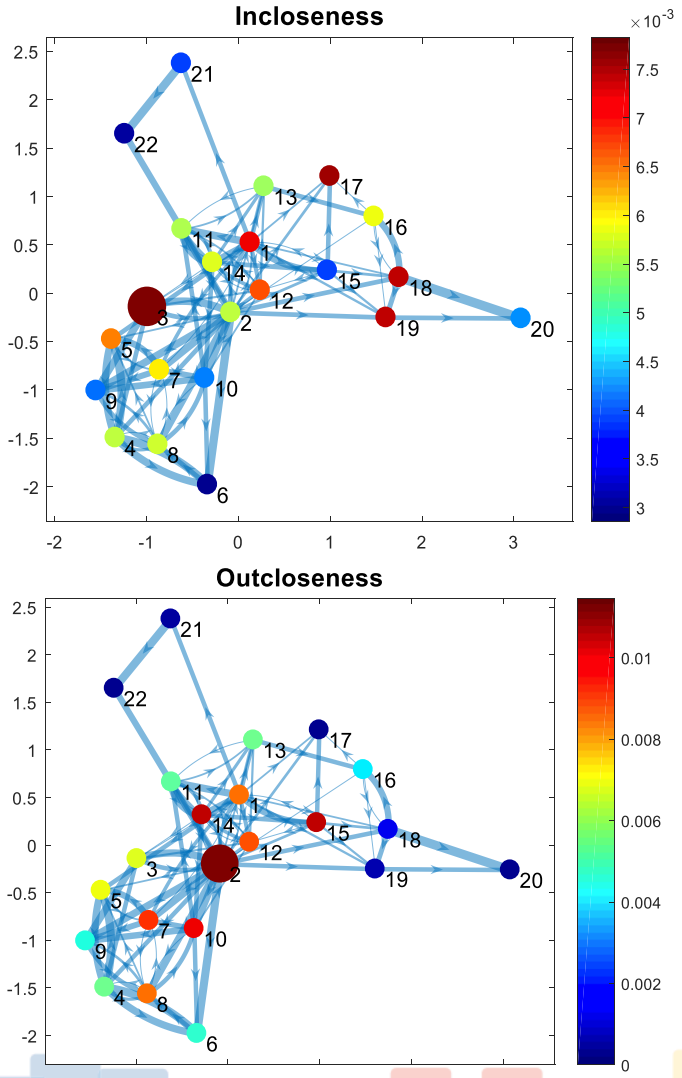
Compare in-degree and out-degree



- Reveals nodes that function as beginning or terminal node

- Node 1(Plan Business Strategy) is low in-degree but high out-degree, which means Node 1 is the typical beginning nodes of the entire network. The beginning nodes should be provided with appropriate introductory resources, such as sales related information (e.g. customer survey, market investigation) for making right business strategy.
- Node 9 (Subsystem coordination) is low out-degree and high in-degree, which is typical terminal node.

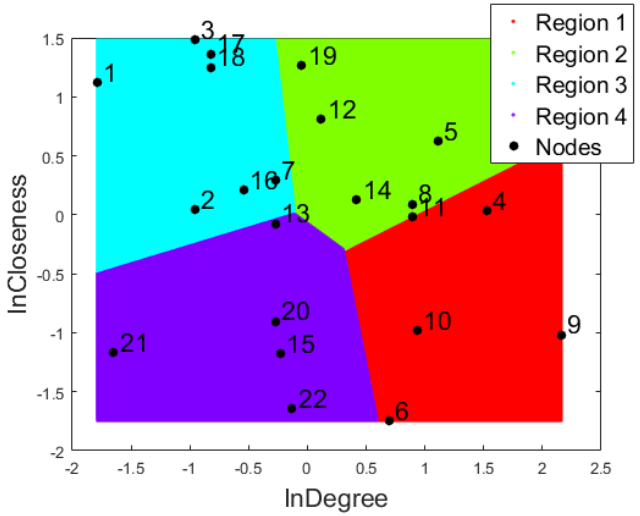
In-closeness, out-closeness

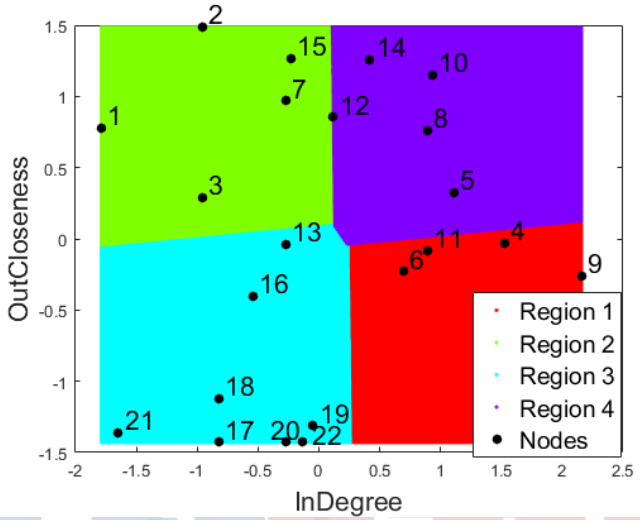


- Reveal accessible and popular nodes that many flows always include these nodes

- Node 3 (Plan Coordination & Communication) has the highest in-closeness. Node 17 (Order Quotes), 18 (Order Processing Orders), and 19 (Order Back Orders) also have high in-closeness, and all of them belongs to Order Department. The resources that can improve the responsiveness of the supply chain to meet the customers' requirement are proper for these nodes. E.g. build-to-order strategy in Dell.
- Node 2 (Plan Resource Allocation) has the highest rating which means it is a gateway. Resources to facilitate the downstream flows are proper for these nodes

Compare closeness and degree

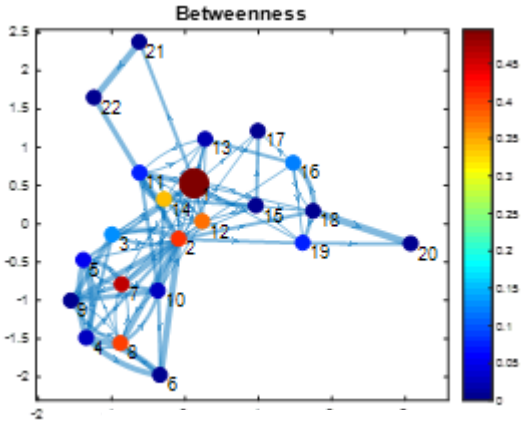


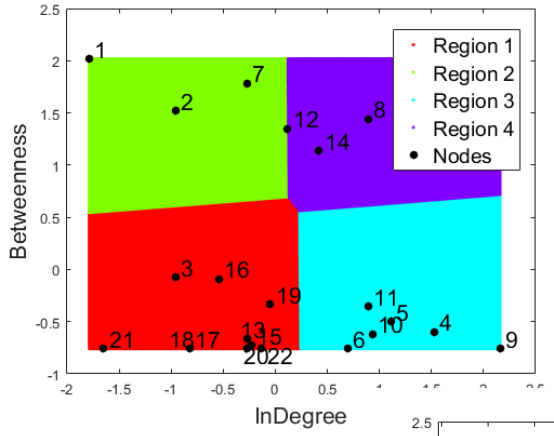


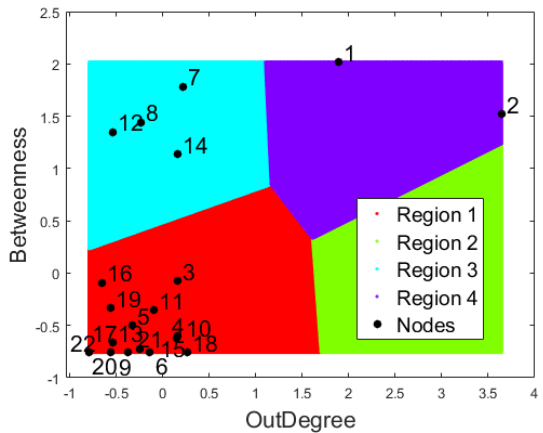
- Nodes with high closeness and low degree, normally are key players tied to important nodes.
- Reveal nodes far from the rest of the network

- High closeness and low degree: Node 1, 2, 3 belong to Plan; Node 17, 18 and 19 belong to Order.
- Node 6 (Source Inventory Management) is low in-closeness and high in-degree. If the designers plan to increase the importance of inventory management, they must check and adjust the flows connected to Node 6. This node brings the opportunities for improvement. E.g. new inventory management models to increase the network competitiveness

Betweenness







- High betweenness nodes act as critical intermediates.
- Have the potential to influence others near them, through both direct and indirect pathways.
- The nodes with high betweenness and low degree mean their few ties are crucial for network flow.

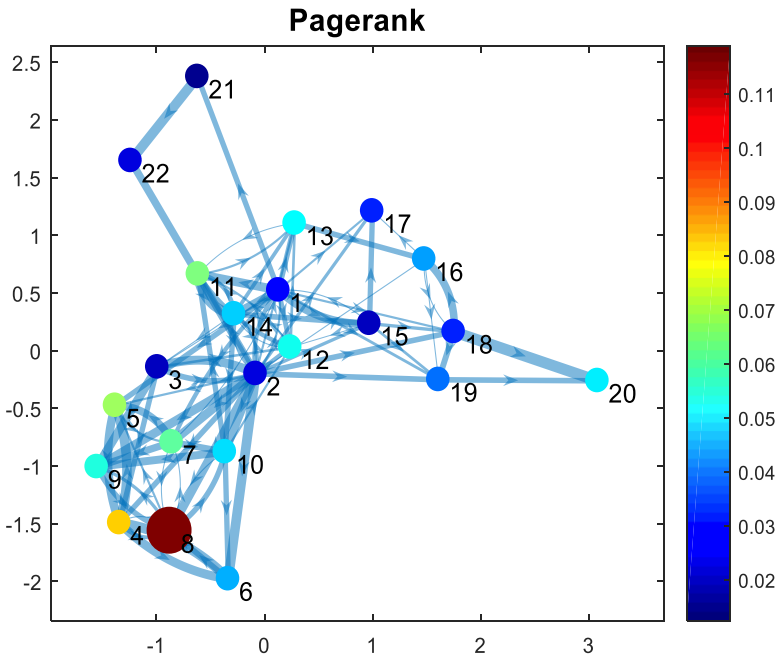
- Node 1 (Plan Business strategy), 2 (Plan Resource Allocation), 7 (Produce Production design), 8 (Produce Individual parts processing), 12 (Warehouse Procurement), and 14 (Warehouse capacity and Operation) are high betweenness nodes. Services to control the flows are appropriate for these nodes.
- Intermediates need resources that can mitigate the negative influence happed in these intermediates. E.g. mitigating warehouse explosion related service should be placed on Node 12 and 14.
- Comparison: Node 1, 2, 7, 8, 12, 14, belong to Plan, Produce and Warehouse stages.

Low degree, betweenness, closeness nodes

- Few connections with adjacent nodes, are relatively inaccessible, and act less as intermediates between other nodes due to being located near the border of the network.
- The position of border provides opportunities to bring potentially valuable information from outside the network.

- Node 20 (Order Invoice), 21 (Return Receive and Verify), 22 (Return Defective Rework/ Dispose), 17 (Order Quotes), 18 (Order Processing orders)
- These nodes belong to Order and Return stages, which connect to real customers.
- Develop promotion-related information in these border nodes.
- E.g. for Node 20 (Order Invoice), information such as “goods that you might be also interested” should be put here to attract the customers return to the network again.

PageRank



- Nodes with high PageRank scores are most frequently crossed in the network.
- Nodes that have high in-degrees tend to have high PageRank values.

- Node 8 (Produce Individual Parts Processing) has the highest PageRank centrality. Node 4 (Source Delivery Scheduling) and 5 (Source Supply Selection) have high PageRank centrality.
- Node 8 belong to Produce strategy and Node 4 and 5 belong to Source strategy. These two strategies are vital for high quality product.
- Customer fulfilment related resources are proper here.

Network characteristics, interpretation, resources recommendations and example nodes

Network characteristics	Network interpretation	Resource recommendations	Example nodes
High in-degree	Prestigious/dependent, critical and vulnerable	Upstream information alignment and sharing service	9, 4, 5,10,8,11
High out-degree	Conductive, critical and vulnerable	Downstream information alignment and sharing service	2, 1,18,7
High out-degree, low in-degree	A beginning	Introductory resources, such as sales oriented information	1
High in-closeness	Highly accessible from all other nodes	Regulation to improve the access efficiency, such as new coordination and communication model	3,17,19,18,1
High out-closeness	Highly accessible to all other nodes, outbound, gateway	Resources to facilitate the downstream flows	2,15,14,10,7,12,
High betweenness	Critical intermediate	Service to control the flows across the network Service to mitigate negative effects	1,7,2,8,12,14
Low closeness, high in-degree	Far from the rest of the network	Opportunities for improvement	6
Low degree, low closeness, low betweenness	Border	Promotion-related information	20,21,22,17,18
High PageRank	Influential nodes	Customer fulfilment related information	8,4,5,11,7,9

Conclusion

Conclusion

- Propose a systematic and analytical tool to gain important insights into the supply chain network. Offer an illustration of this investigation with the help of network analysis and clustering.
- Used the supply chain network example constructed with SCOR model as a case study.
- The advantage of network analysis is that it offers numerous techniques and indicators by measuring the importance of nodes to demonstrate the structural patterns of connected network.
- The practical implication of the study is that this network analysis would assist the supply chain planners to make decision such as locating resources.
- In industry, we can use these to build a catalogue of behaviours, which would serve as a guide for resource allocation for different business processes.

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