Cognitive Maps

I would like to acknowledge
Emel Aktaş
who has a great influence on
the organization
of these slides

Introduction

- **Cognitive mapping** is the task of mapping a person’s thinking about a problem or issue (Tolman, 1948).
- A cognitive map is the representation of thinking about a problem that follows from the process of **mapping**.
- **Cognition** can be used to refer to the mental models, or belief systems, that people use to perceive, contextualize, simplify, and make sense of otherwise complex problems.

Definition

- A cognitive map is an image of cognitive processes and an attempt to utilize expert(s) opinion and cognition about ill-structured social relationships (Axelrod, 1976; Lee *et al.*, 1992)
- Cognitive maps are *cause-effect networks*, with nodes representing concepts articulated by individuals, and directional linkages capturing causal dependencies (Srinivas and Shekar, 1997).

Why?

- Cognitive mapping is a tool which enables a group of experts and/or specialists to negotiate a definition of the problem that is visualized in the form of a model amenable to further elaboration and to the analysis of complexity (Eden, 1988)
- One of the practical aims of cognitive mapping is to attain an appropriate and powerful link between the qualitative aspects of a problem definition and the role of quantitative analysis (Eden et al., 1986)

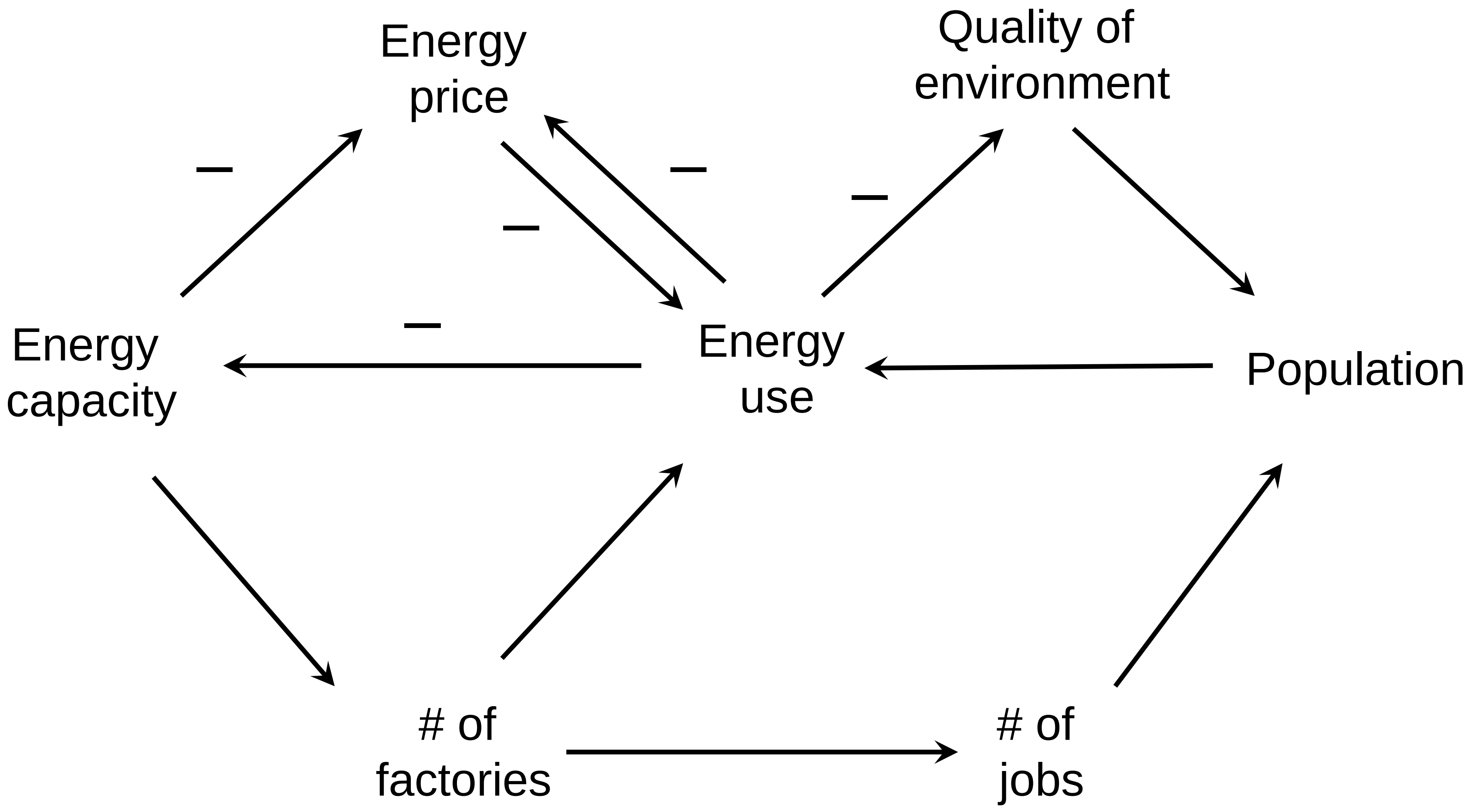
Where?

- Cognitive maps have been studied in various fields of science, such as
  - psychology
  - planning
  - geography
  - management

Directed Graph

- The problem is represented by a **signed digraph** (directed graph) of basic elements where
  - A concept variable is symbolized as a point, and
  - The causal assertion (belief) of how one concept variable affects another (relationship between the variables) is symbolized as an arrow
  - A plus sign is attached to the arrows that show positive relationships (changes occur in the same direction)
  - A minus sign is attached to the arrows that show negative relationships (changes occur in the opposite direction)

Signed Digraph for Energy Demand



Deriving Cognitive Map

- There are three basic ways of deriving a cognitive map of the expert opinion (Hwang & Lin, 1987):
  - questionnaire survey,
  - documentary coding, and
  - interviews.
- A questionnaire survey can be divided into three phases (Roberts, 1976):
  - identifying potentially relevant variables,
  - limiting the number of variables by rating their importance, and
  - the choice of arrows and signs

Analysing Cognitive Map

- Decision Explorer software package (Banxia Software, 1996)
  - Domain analysis (centrality)
  - Head-Tail analysis”
  - Cluster analysis
  - ... ...

Centrality

- The total number of concept variables directly affected by concept *i* is

  outdegree of variable *i*

- The total number of concept variables directly affects concept *i* is

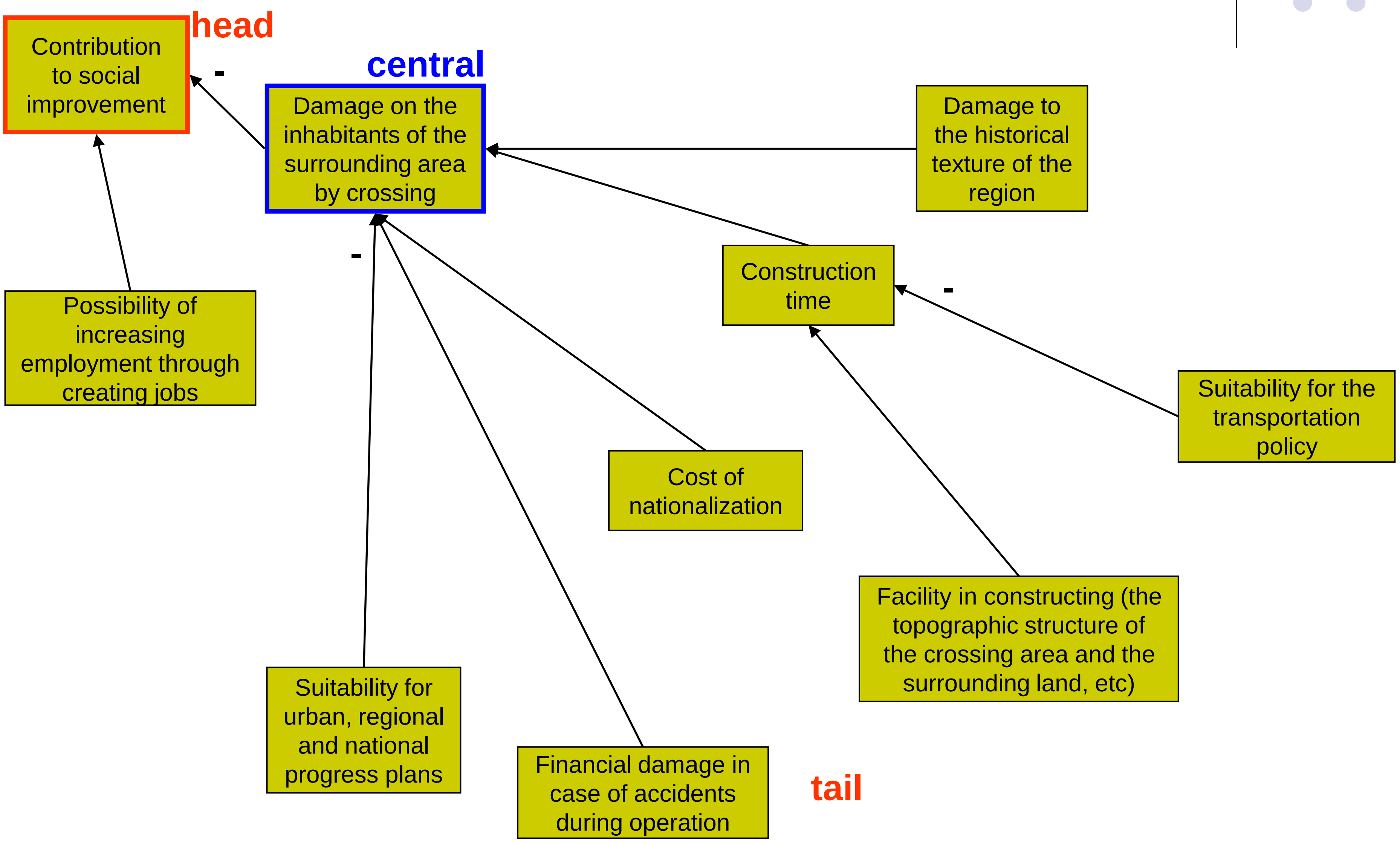
  indegree of variable *i*

- outdegree + indegree = total degree (centrality)

Heads and tails

- Typically a node which has no implication (outgoing arrows) is referred to as a “head”, and a node which has no in-arrows is referred to as a “tail”.
- The node which has the highest total of incoming and outgoing arrows is the most central element of the map.

Example

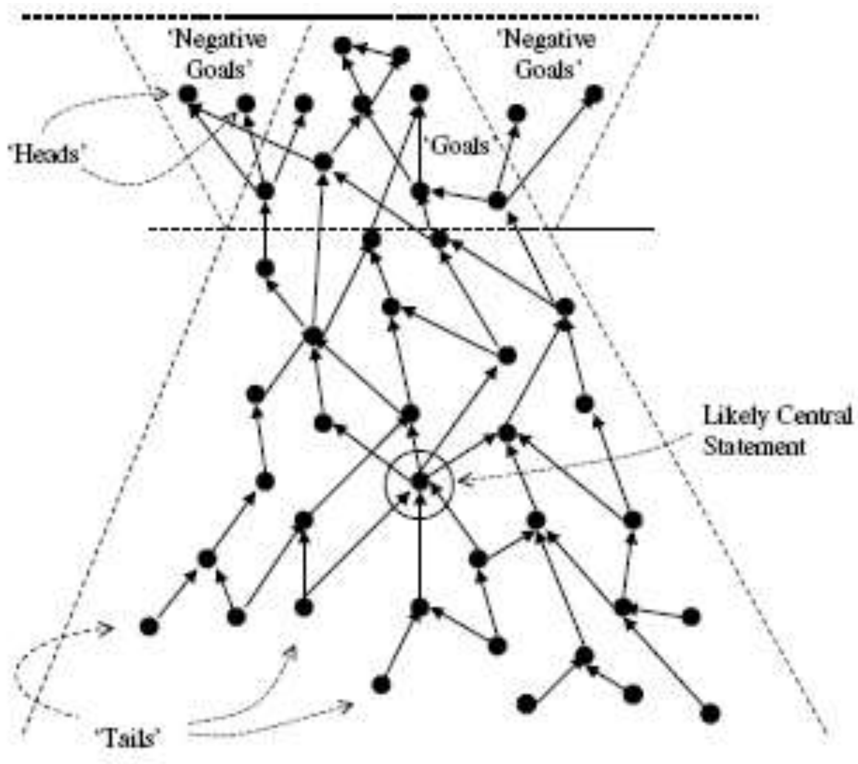

head
Contribution to social improvement
-
central
Damage on the inhabitants of the surrounding area by crossing
Damage to the historical texture of the region
Possibility of increasing employment through creating jobs
-
Construction time
-
Suitability for the transportation policy
Cost of nationalization
Facility in constructing (the topographic structure of the crossing area and the surrounding land, etc)
Suitability for urban, regional and national progress plans
Financial damage in case of accidents during operation
tail

Heads and tails

- Heads will usually be “goal” type statements: expressions of desired or not-desired outcomes,
- Tails will be “options”.
- When goals are expressed as not-desired outcomes, sometimes indicating disasters to be avoided at all costs, they are referred to as “negative-goals”.
- Usually the map will contain more goal statements than those shown by heads, and more options than those shown by tails.

Structural properties

- When a cognitive map is pictured in graph form it is then relatively easy to see how each of the concepts and causal relationships relate to each other, and to see the overall structure of the whole set of portrayed assertions'' (Axelrod, 1976).



Problem/issue complexity

- Both cognitive scientists and organizational scientists have been fond of simple analyses of cognitive maps.
- These analyses are supposed to indicate the central features of a directed graph.
  - The first of these simple analyses explores the total number of nodes and the total number of arrows;
  - The second is concerned with “cognitive centrality” of particular nodes.

The extent of the map

- The more nodes (or concepts) are there in a map, the more complex is the map and the issue.
- The map, as model, acts as a device for establishing a mutual understanding of the issue.
- The number of concepts elicited during an interview is dependent upon the length of the interview and the skills of the interviewer.

The complexity of the map as a network

- An alternative analysis of issue complexity is to determine the ratio of arrows to concepts. A higher ratio indicates a densely connected map and supposedly a higher level of complexity.
- Ratios of 1.15 to 1.20 is fine for maps elicited from interviews.

Representation

- Graph
  - Helps to see the causal relationships between variables better
- Matrix
  - Allows mathematical analysis in en effective way.

Example: How can we motivate employees?

- Variables
  - Motivation
  - Salaries
  - Problems in the work environment
  - Good attitude of the employer
  - Good attitude of the colleagues
  - Career possibilities

Causal relationships between the variables

- positive (+)

  salary ⟶ motivation

- negative (-)

  problems in the work environment $\xrightarrow{-}$ motivation

- no relationship

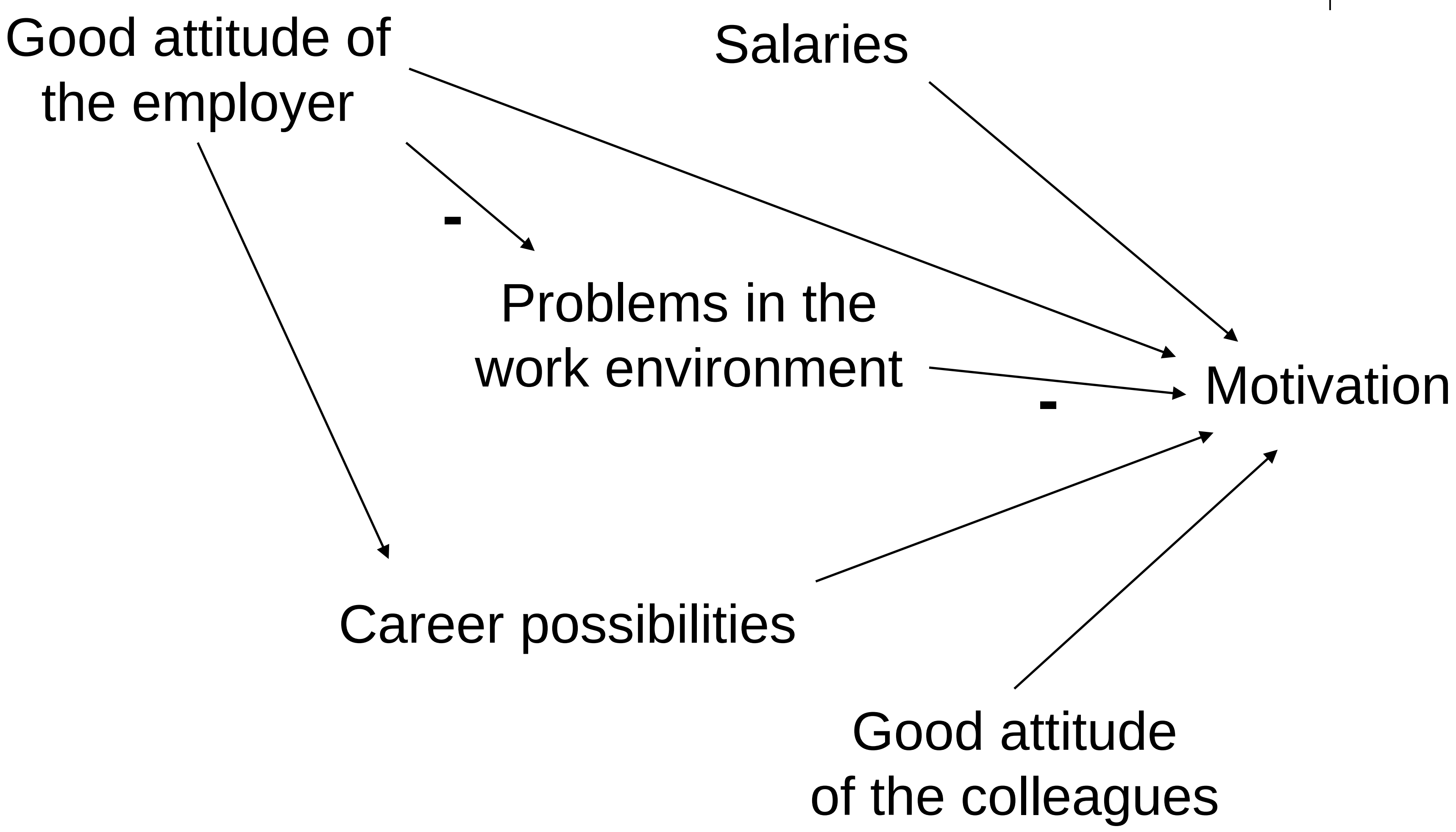
  attitude of colleagues salary

How can we motivate employees?

	mtv.	sal.	env.	emp.	col.	car.
mtv.	0	0	0	0	0	0
sal.	+	0	0	0	0	0
env.	-	0	0	0	0	0
emp.	+	0	-	0	0	+
col.	+	0	0	0	0	0
car.	+	0	0	0	0	0

Motivation; Salaries; Problems in the work environment;
Good attitude of the employer; Good attitude of the colleagues;
Career possibilities

How can we motivate employees?

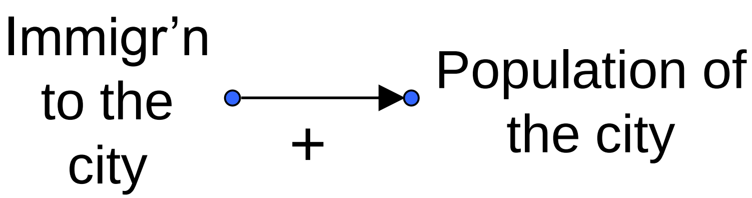


Matrix Algebra

- Valency Matrix
- Centrality
- Reachability Matrix

Valency Matrix

- The adjacency matrix
- V is a square matrix of n*n, where *n* is the total number of concept variables
- Entry displays the <u>direct</u> effect of the column variable on the row variable



	poc
ic	+1

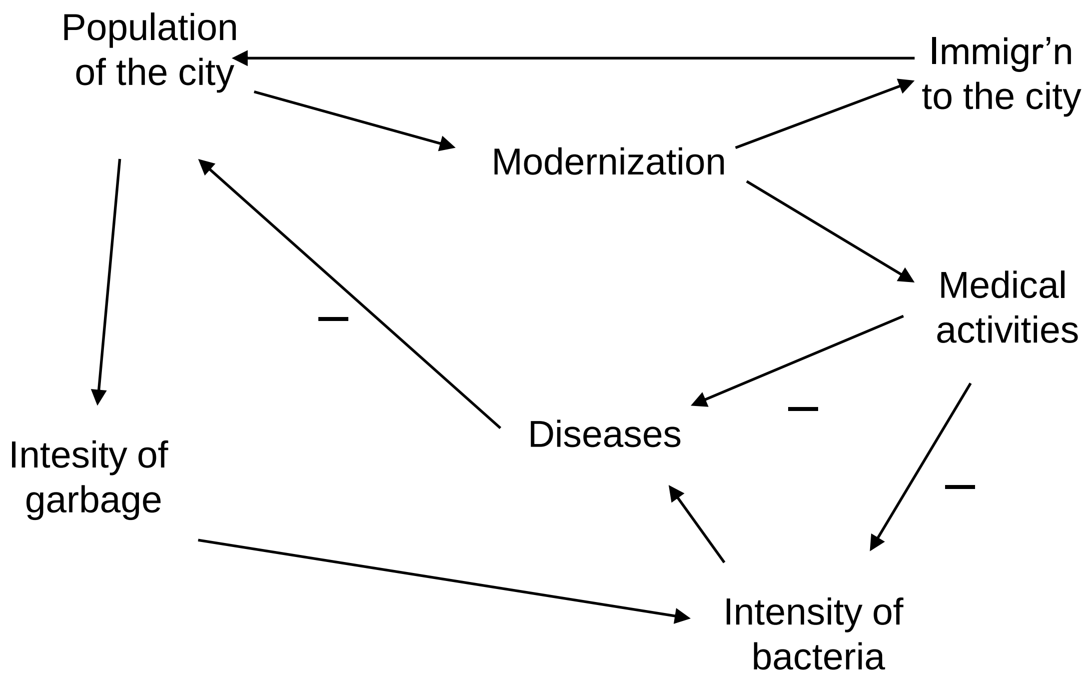
- The valency matrix indicates only direct relations between concept variables, that is, concept linkage paths of length 1

Centrality

- The row sum of the absolute values of the elements of V for row *i* gives the **<u>outdegree</u>** (od) of variable *i*.
- The column sum of the absolute values of the elements of V for column *i* gives the **<u>indegree</u>** (id) of variable *i*.
- The sum of od_i and id_i gives the **<u>total degree</u>** of *i* (td_i) which is a useful operational measure of that variable's **<u>cognitive centrality</u>** in the opinion structure of the experts

Indirect effect

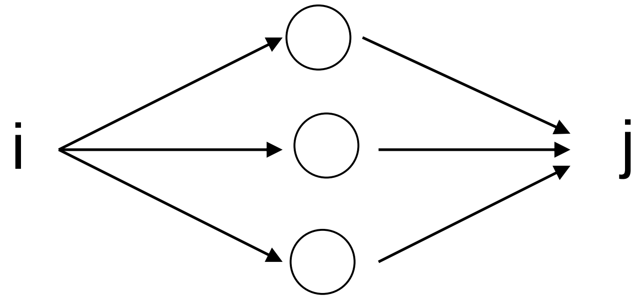
V_{ij}^{n}: for the path of length *n*, indirect effect of variable *i* on variable *j*



$V_{pop,pop}^{3}$=1 (loop exists) $V_{pop,dis}^{3}$=0 (two alternative paths)

Indirect effect

Reachability of variable *i* on variable *j*



For the path of length 2, the cumulative indirect effects of variable *i* on variable *j*

$V_{i,j}^2 = +3$ (Three paths +)

$V_{i,j}^2 = +1$ (Two paths +, one path -)

$V_{i,j}^2 = -1$ (Two paths -, one path +)

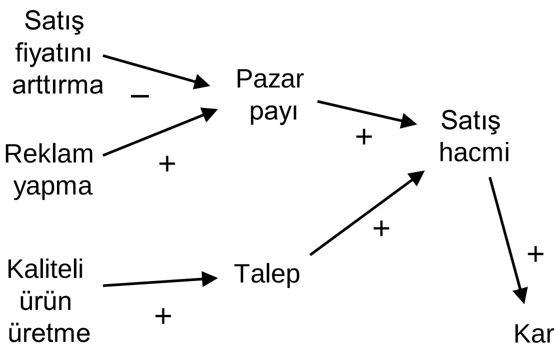
$V_{i,j}^2 = -3$ (Three paths -)

Reachability Matrix

- R reflects the existence of indirect relations
- If the adjacency matrix contains no feedback loops, the cumulative indirect effects (R) are calculated as: $R = V + V^2 \ldots + V^{n-1}$

- The sum of the absolute values for row *i* of R shows the total number of variables reachable from variable *i*
- The sum of the absolute values for column *i* of R shows the total number of variables reaching variable *i*

Example



V

	sf	r	k	pp	t	sh	kar	
sf	0	0	0	-1	0	0	0	1
r	0	0	0	1	0	0	0	1
k	0	0	0	0	1	0	0	1
pp	0	0	0	0	0	1	0	1
t	0	0	0	0	0	1	0	1
sh	0	0	0	0	0	0	1	1
kar	0	0	0	0	0	0	0	0
	0	0	0	2	1	2	1	6

V^2

	sf	r	k	pp	t	sh	kar
sf	0	0	0	0	0	-1	0
r	0	0	0	0	0	1	0
k	0	0	0	0	0	1	0
pp	0	0	0	0	0	0	1
t	0	0	0	0	0	0	1
sh	0	0	0	0	0	0	0
kar	0	0	0	0	0	0	0

V^4

	sf	r	k	pp	t	sh	kar
sf	0	0	0	0	0	0	0
r	0	0	0	0	0	0	0
k	0	0	0	0	0	0	0
pp	0	0	0	0	0	0	0
t	0	0	0	0	0	0	0
sh	0	0	0	0	0	0	0
kar	0	0	0	0	0	0	0

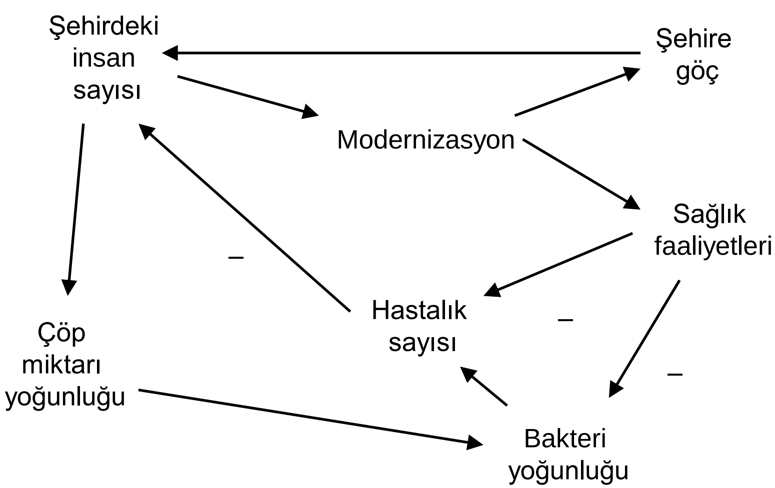
V^3

	sf	r	k	pp	t	sh	kar
sf	0	0	0	0	0	0	-1
r	0	0	0	0	0	0	1
k	0	0	0	0	0	0	1
pp	0	0	0	0	0	0	0
t	0	0	0	0	0	0	0
sh	0	0	0	0	0	0	0
kar	0	0	0	0	0	0	0

R

	sf	r	k	pp	t	sh	kar	
sf	0	0	0	-1	0	-1	-1	3
r	0	0	0	1	0	1	1	3
k	0	0	0	0	1	1	1	3
pp	0	0	0	0	0	1	1	2
t	0	0	0	0	0	1	1	2
sh	0	0	0	0	0	0	1	1
kar	0	0	0	0	0	0	0	0
	0	0	0	2	1	5	6	14

Example



V

	sis	sg	m	sf	hs	by	çmy	
sis	0	0	1	0	0	0	1	2
sg	1	0	0	0	0	0	0	1
m	0	1	0	1	0	0	0	2
sf	0	0	0	0	-1	-1	0	2
hs	-1	0	0	0	0	0	0	1
by	0	0	0	0	1	0	0	1
çmy	0	0	0	0	0	1	0	1
	2	1	1	1	2	2	1	

V^4

	sis	sg	m	sf	hs	by	çmy
sis	0	0	1	0	-1	0	1
sg	1	0	0	0	0	-1	0
m	1	1	1	1	0	1	1
sf	0	1	1	1	0	1	1
hs	-1	0	0	0	0	1	0
by	0	-1	0	-1	0	-1	0
çmy	0	0	-1	0	0	0	-1

V^2

	sis	sg	m	sf	hs	by	çmy
sis	0	1	0	1	0	1	0
sg	0	0	1	0	0	0	1
m	1	0	0	0	-1	-1	0
sf	1	0	0	0	-1	0	0
hs	0	0	-1	0	0	0	-1
by	-1	0	0	0	0	0	0
çmy	0	0	0	0	1	0	0

V^5

	sis	sg	m	sf	hs	by	çmy
sis	1	1	0	1	0	1	0
sg	0	0	1	0	-1	0	1
m	1	1	1	1	0	0	1
sf	1	1	0	1	0	0	0
hs	0	0	-1	0	1	0	-1
by	-1	0	0	0	0	1	0
çmy	0	-1	0	-1	0	-1	0

V^3

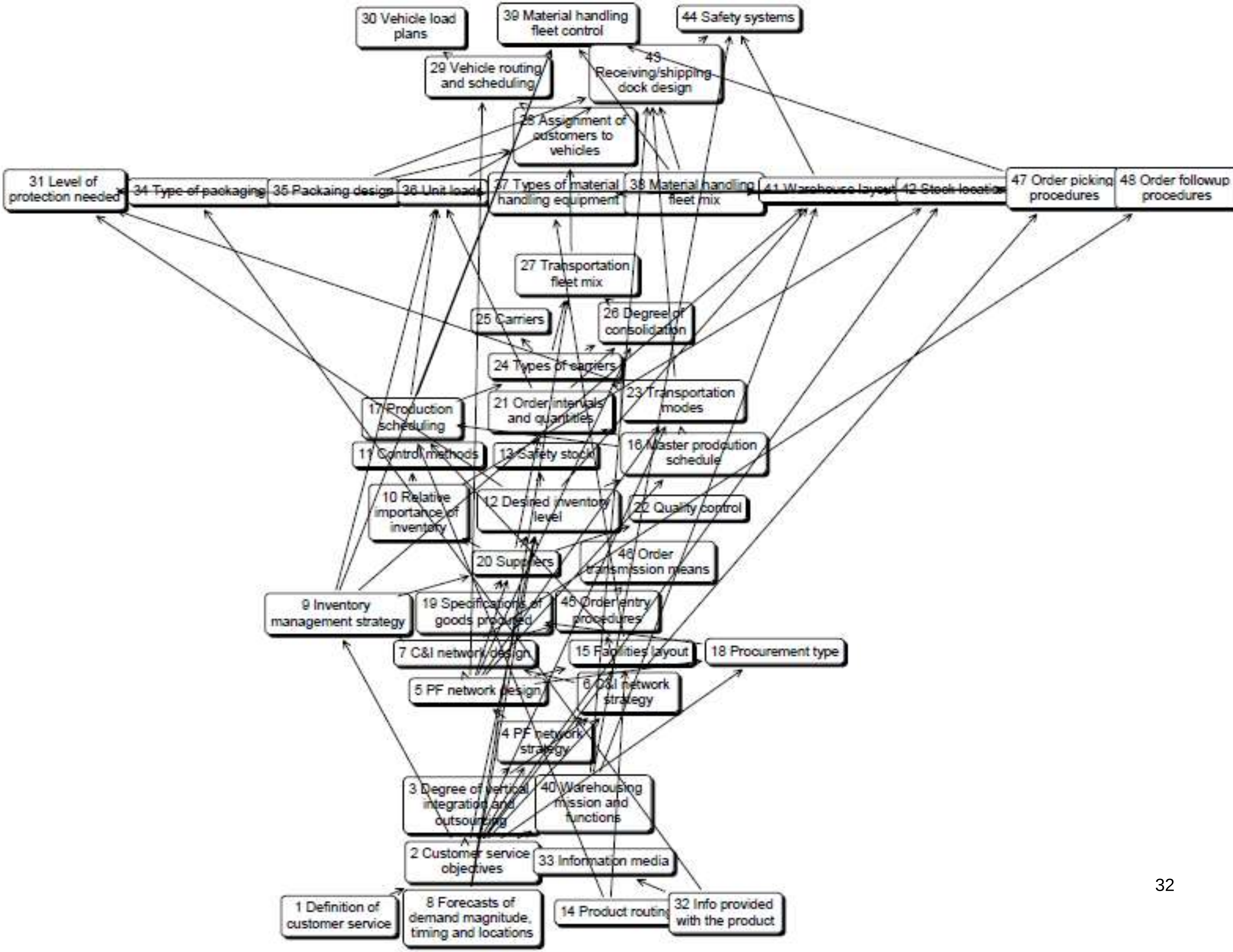
	sis	sg	m	sf	hs	by	çmy
sis	1	0	0	0	0	-1	0
sg	0	1	0	1	0	1	0
m	1	0	1	0	-1	0	1
sf	1	0	1	0	0	0	1
hs	0	-1	0	-1	0	-1	0
by	0	0	-1	0	0	0	-1
çmy	-1	0	0	0	0	0	0

V^6

	sis	sg	m	sf	hs	by	çmy
sis	1	0	1	0	0	-1	1
sg	1	1	0	1	0	1	0
m	1	1	1	1	-1	0	1
sf	1	0	1	0	-1	-1	1
hs	-1	-1	0	-1	0	-1	0
by	0	0	-1	0	1	0	-1
çmy	-1	0	0	0	0	1	0

Construction of the Group Cognitive Map

- Gathering a list of related concepts about the issue on hand from different persons
- Preparing a collective list of concepts
- Persons’ judgments to reveal the relationships between the concepts
- Construction of personal cognitive maps
- Aggregating personal cognitive maps
  - Single number of experts
  - Taking experts’ opinions again about the doubtful relations
- Size
  - Over 100 nodes on the map


30 Vehicle load plans
39 Material handling fleet control
44 Safety systems
29 Vehicle routing and scheduling
43 Receiving/shipping dock design
28 Assignment of customers to vehicles
31 Level of protection needed
34 Type of packaging
35 Packaing design
36 Unit loads
37 Types of material handling equipment
38 Material handling fleet mix
41 Warehouse layout
42 Stock location
47 Order picking procedures
48 Order followup procedures
27 Transportation fleet mix
25 Carriers
26 Degree of consolidation
24 Types of carriers
17 Production scheduling
21 Order intervals and quantities
23 Transportation modes
11 Control methods
13 Safety stock
16 Master prodcution schedule
10 Relative importance of inventory
12 Desired inventory level
22 Quality control
20 Suppliers
46 Order transmission means
9 Inventory management strategy
19 Specifications of goods procured
45 Order entry procedures
7 C&I network design
15 Facilities layout
18 Procurement type
5 PF network design
6 C&I network strategy
4 PF network strategy
3 Degree of vertical integration and outsourcing
40 Warehousing mission and functions
2 Customer service objectives
33 Information media
1 Definition of customer service
8 Forecasts of demand magnitude, timing and locations
14 Product routing
32 Info provided with the product

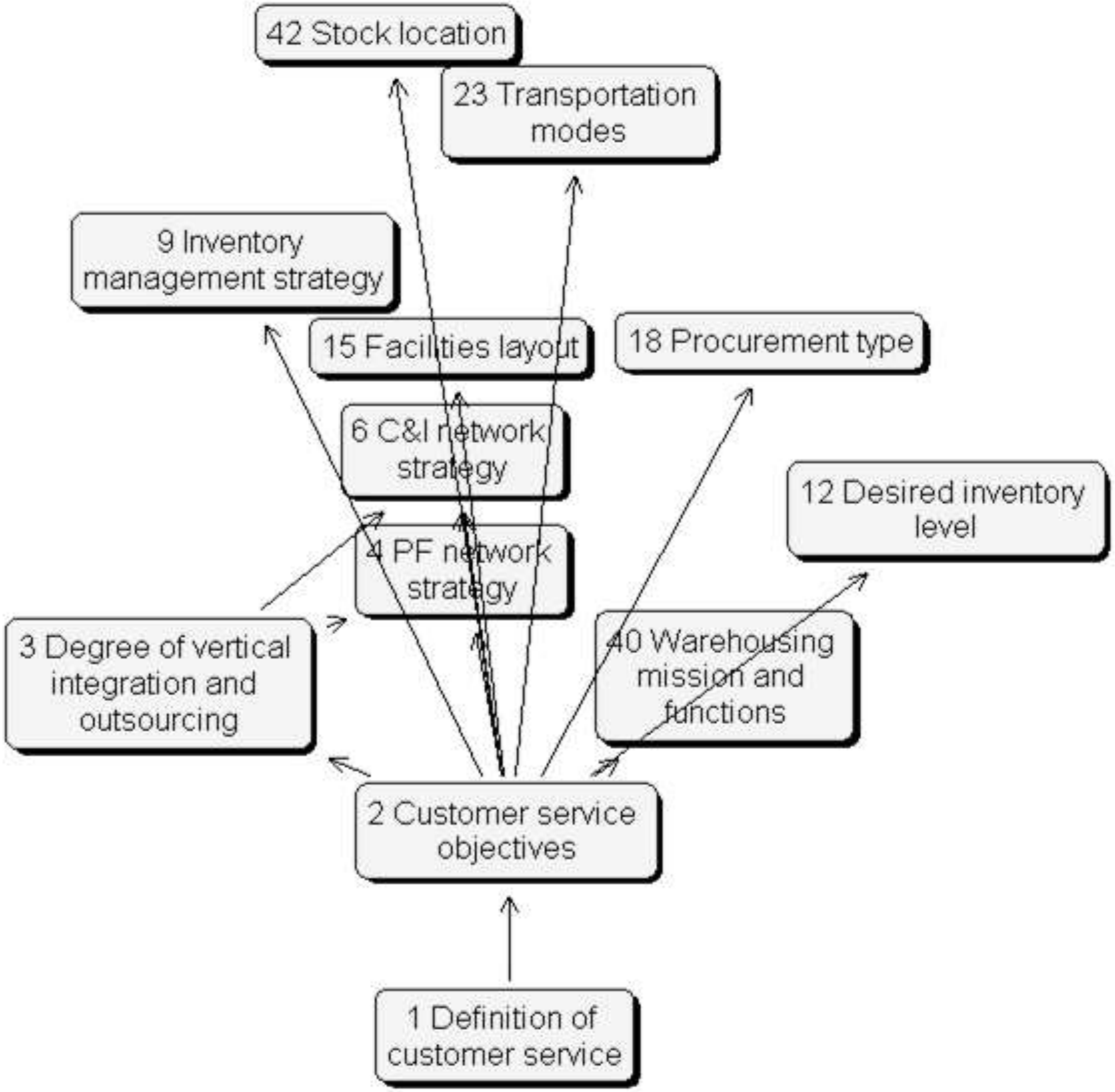
Hierarchy of decisions

- The most fundamental decisions are
  - Definition of customer service (1)
  - Forecasts of demand (8)
  - Product routing (14)
  - Information to be provided with the product (32)

- The rest of the decisions cannot be taken unless these 4 decisions are given

Definition of customer service

The 'view' of the part of the cognitive map showing the fundamental decision 'definition of customer service'



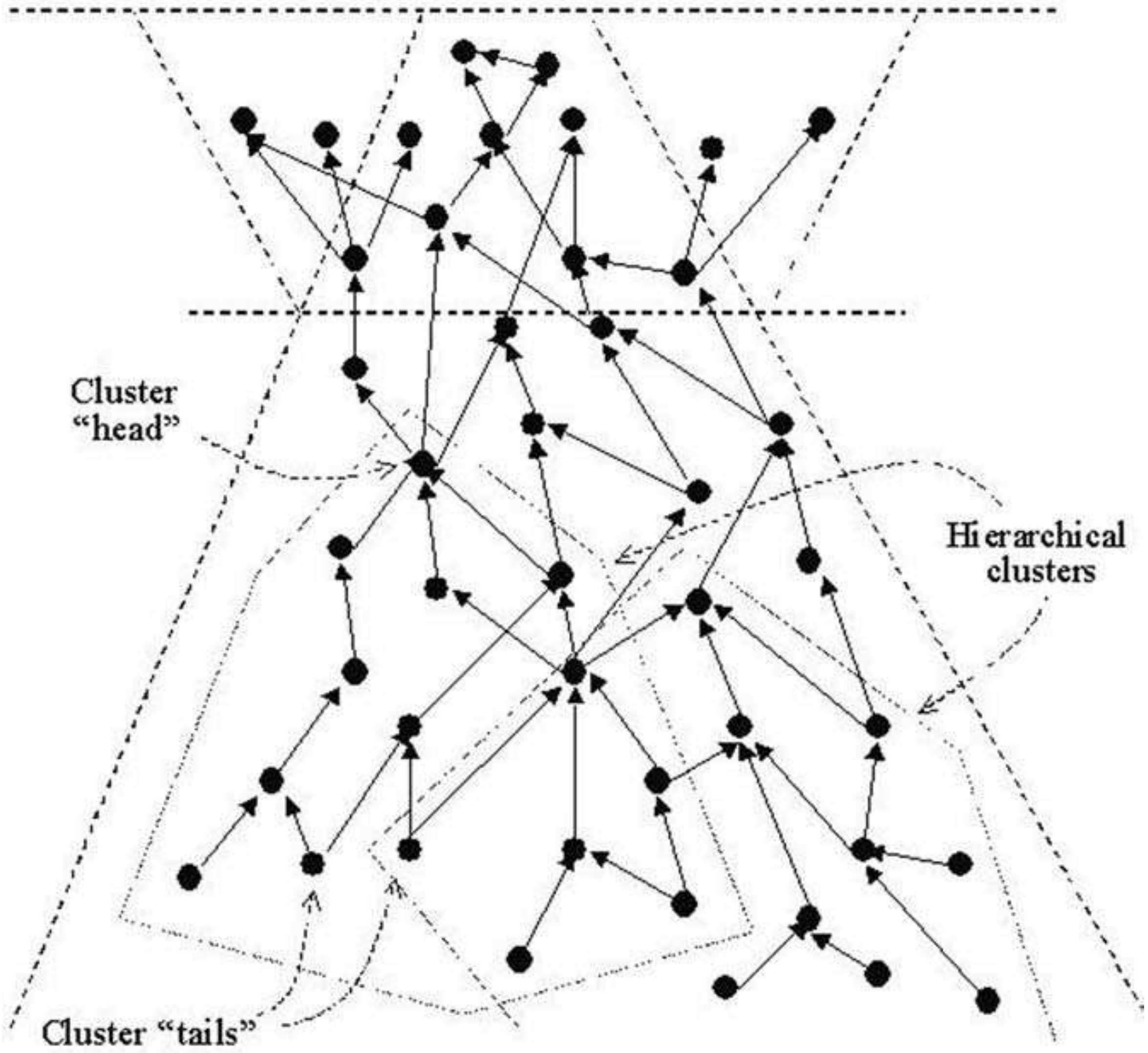
Domain Analysis (Centrality)

Centrality score	Decision
11	2 Customer service objectives
9	5 PF network design
8	41 Warehouse layout
7	12 Desired inventory level 20 Suppliers 36 Unit loads 37 Types of material handling equipment 47 Order picking procedures
6	6 C&I network strategy 9 Inventory management strategy 17 Production scheduling 23 Transportation modes 35 Packaing design 43 Receiving/shipping dock design

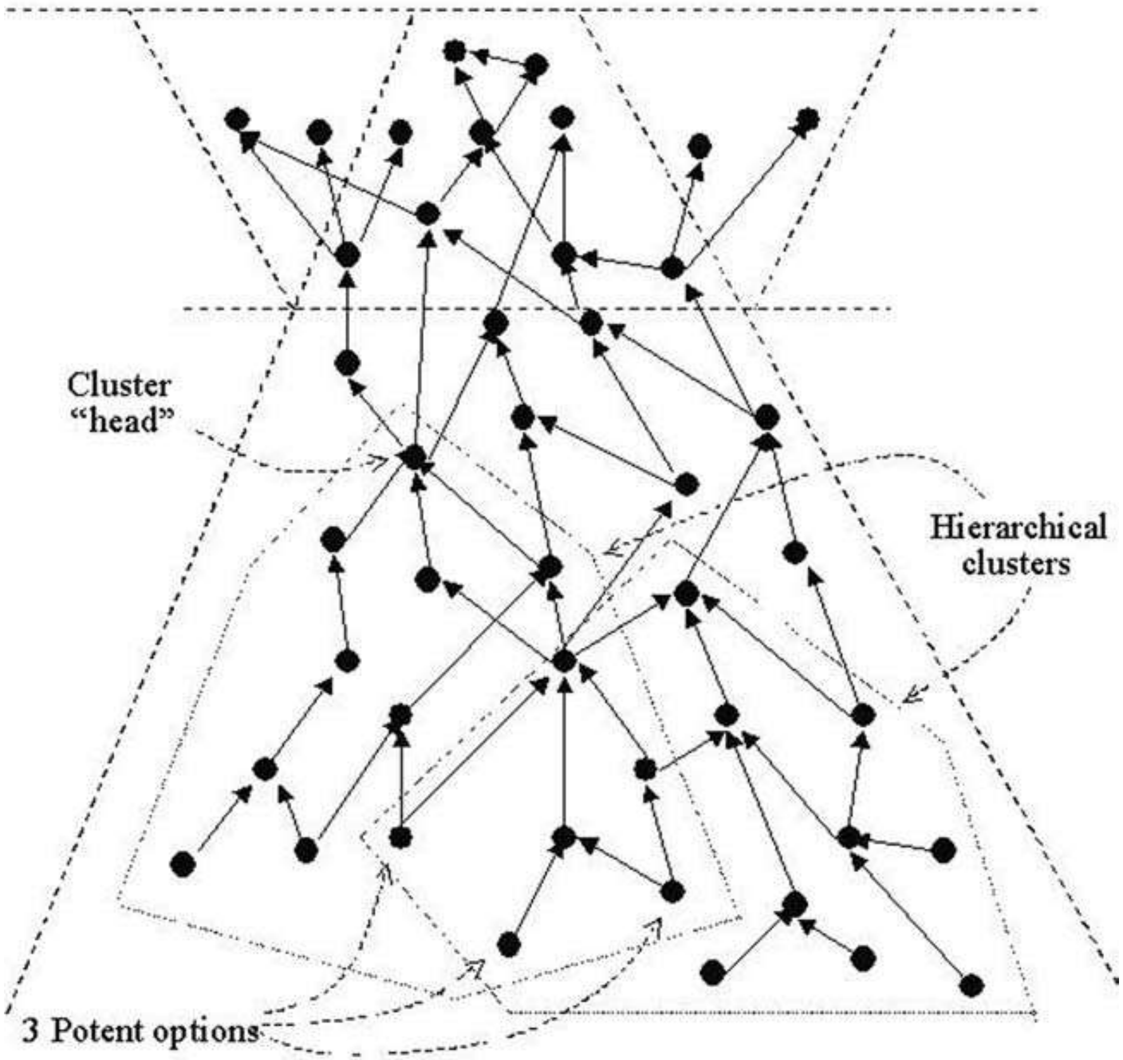
Cluster Analysis

- *Islands of themes*
  - without accounting for hierarchy
- Nodes in each cluster → tightly linked
- Bridges with other clusters → minimized

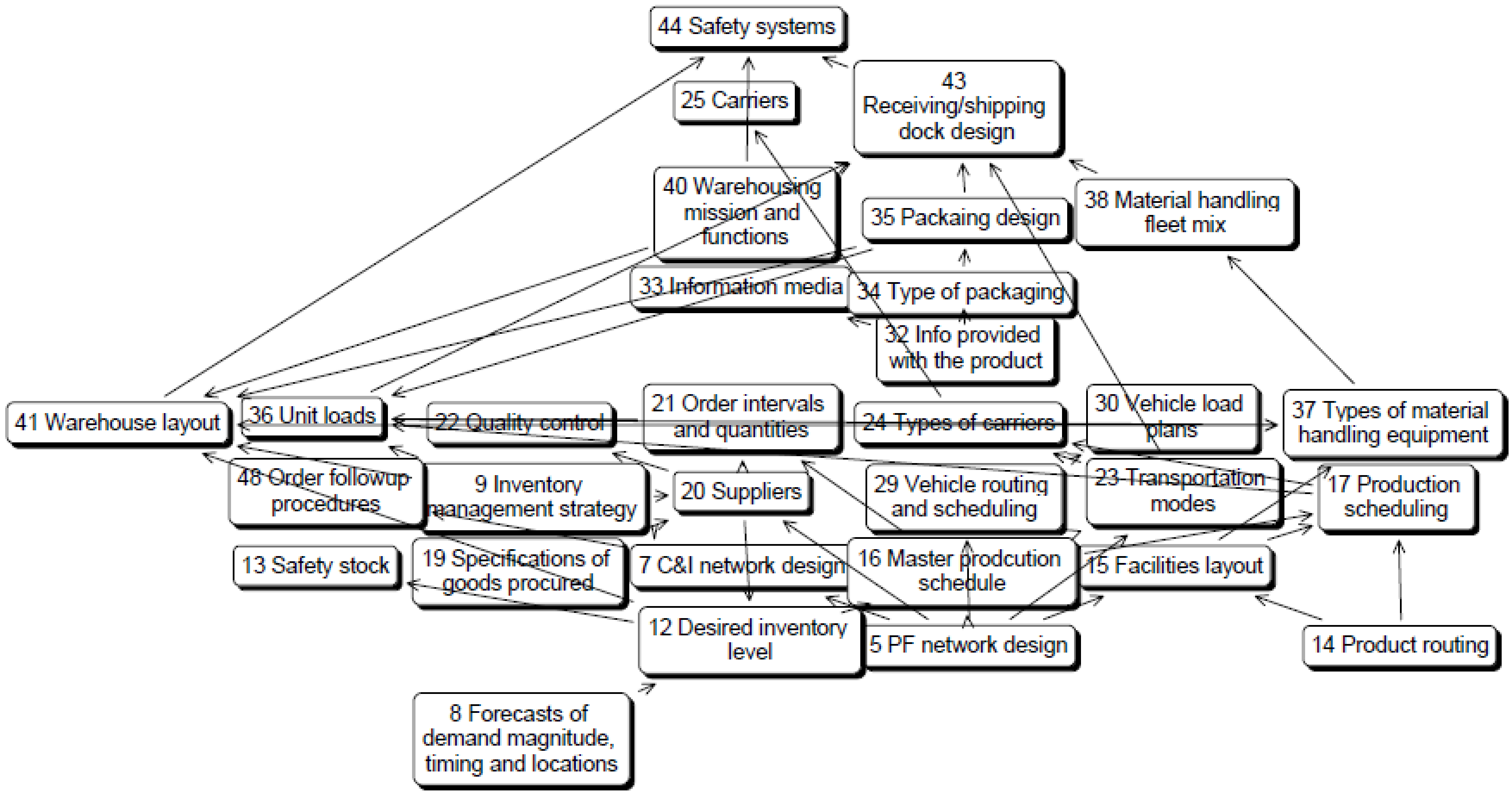
Hierarchical Clusters



Potent Options



Cluster Analysis (Cluster I)



Cluster Analysis (Cluster II)