Systems Thinking for Design

Session 9

https://sites.google.com/a/iiitdm.ac.in/sudhirvs/courses/systems-thinking-for-design

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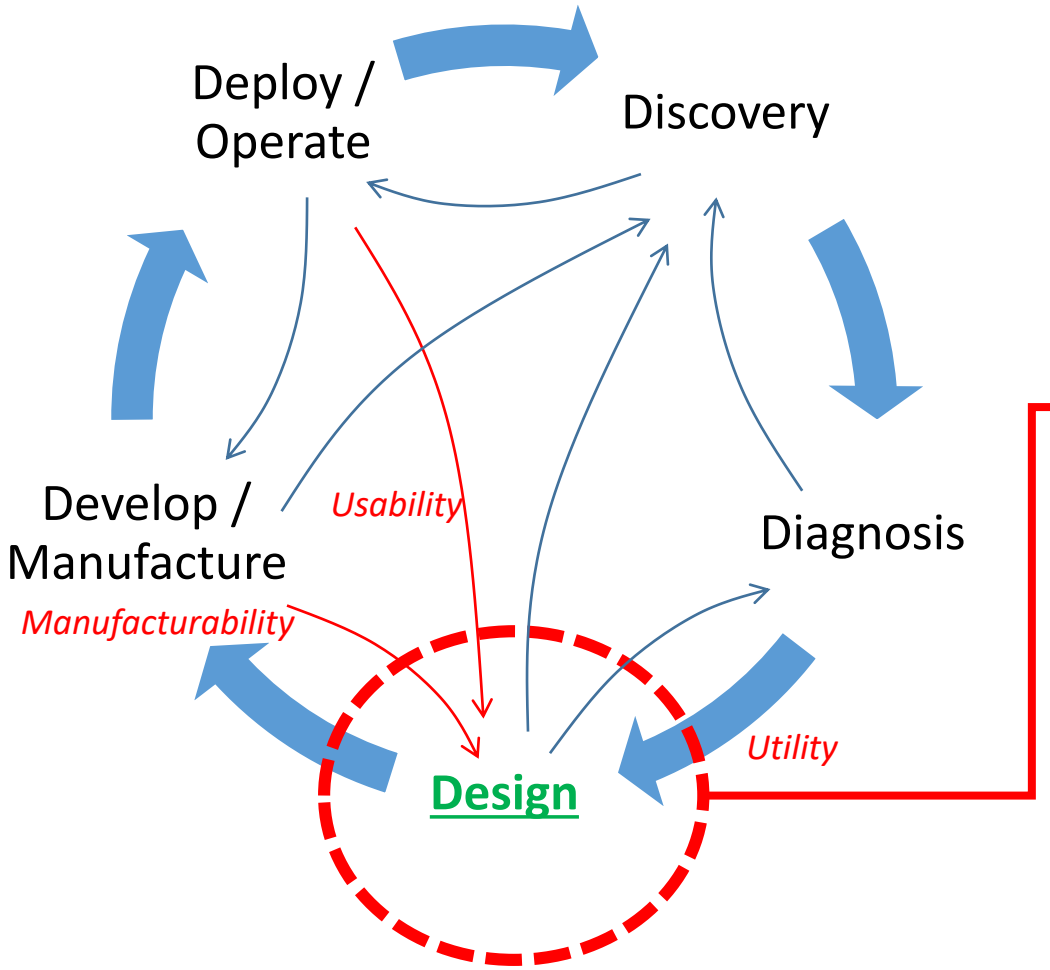
Session outline

- Moving from Diagnosis to Design
- Interpretive Structural Modeling for Design

Now, let us move into the design phase



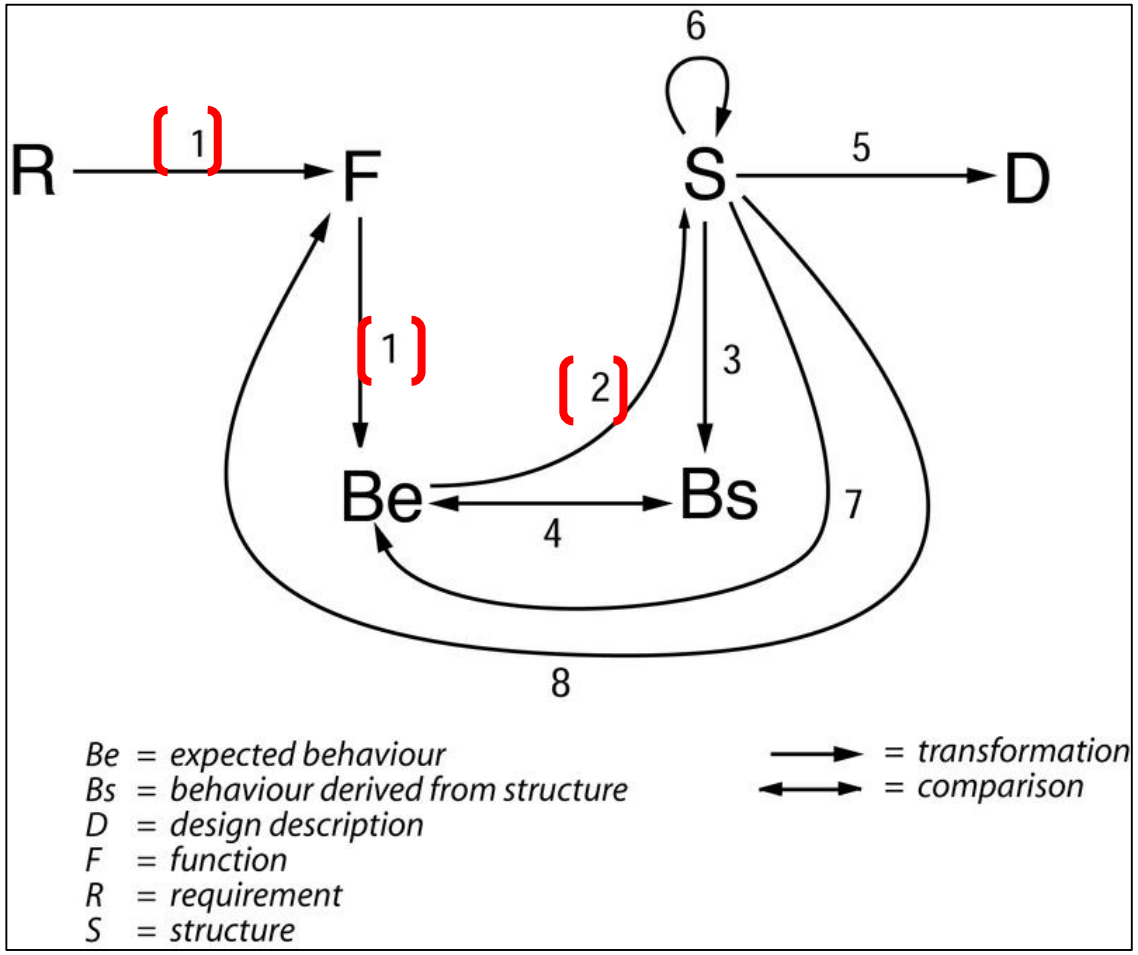
Distinguish between design as a noun (an artefact) and design as a verb (process)

Recognize differences between different stages in design: conceptual design versus detail design

Differences within conceptual design: functional design & structural/form design

The focus in Systems Thinking for Design is to improve effectiveness of the design process, and produce better conceptual designs (functional & structural)

Expected output of Concept Design = FBS



FBS is one of the popular models for capturing conceptual design specs

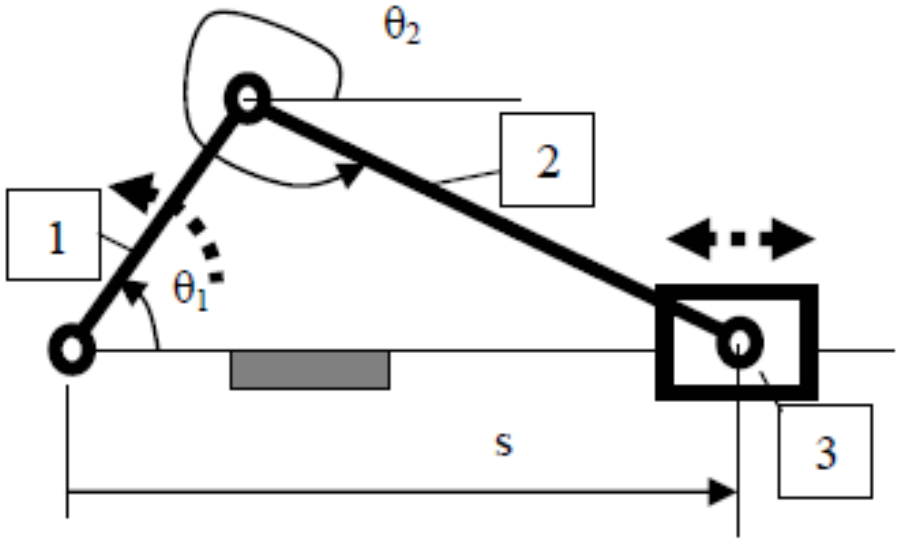
Function: the thing an artefact performs

Behavior: the manner in which an artefact acts under specified conditions

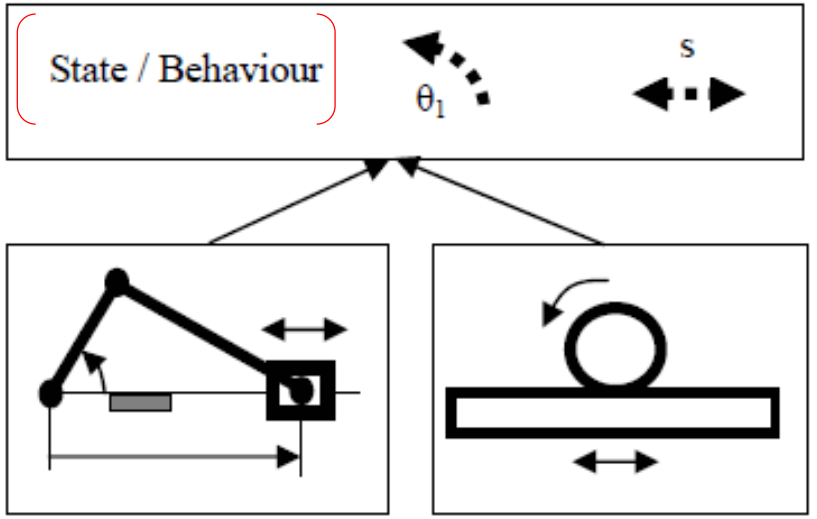
Structure: what constitutes an artefact (or defines its constitution)

Purpose: the reason why an artefact exists (specialized function)

Example of Function-Behavior-Structure

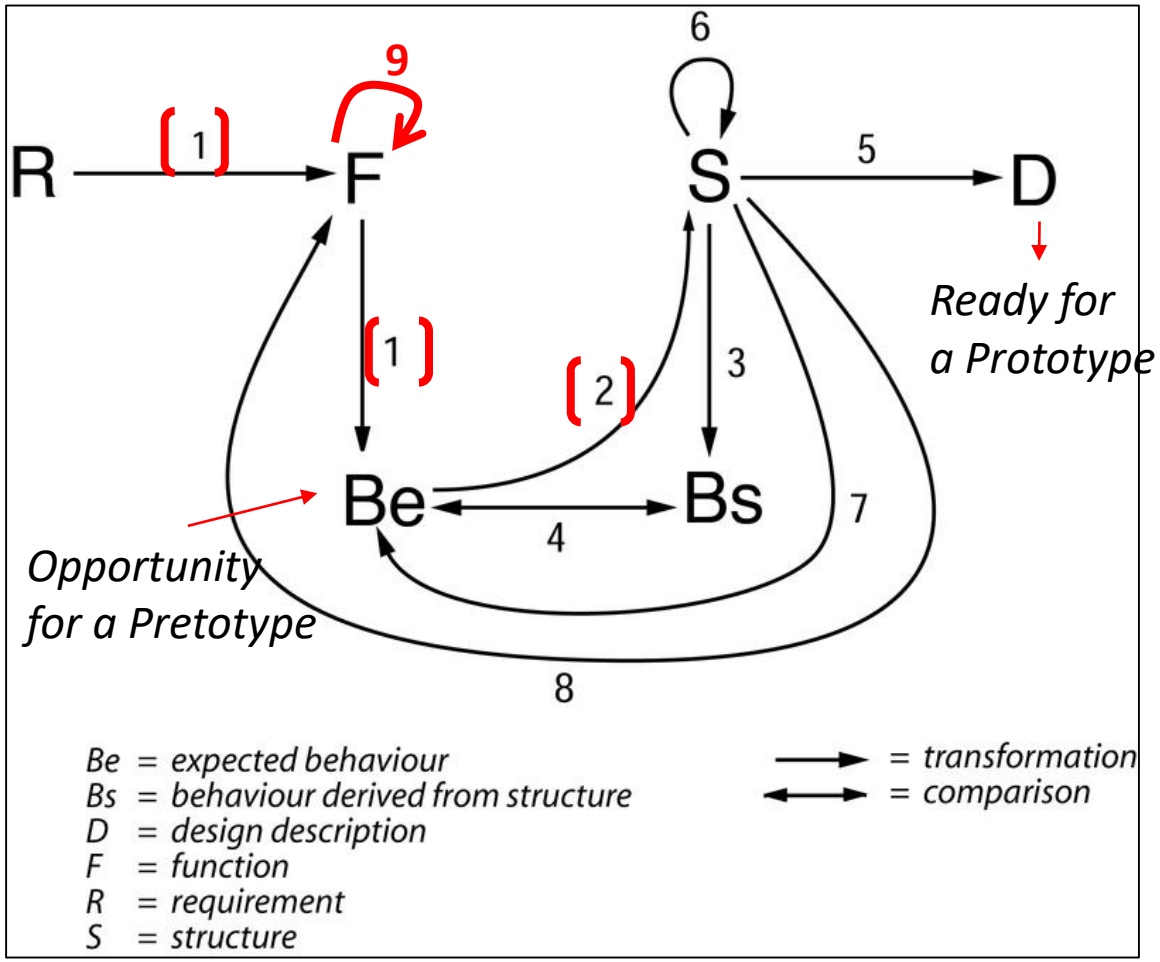


1: crank; 2: coupler; 3: slider



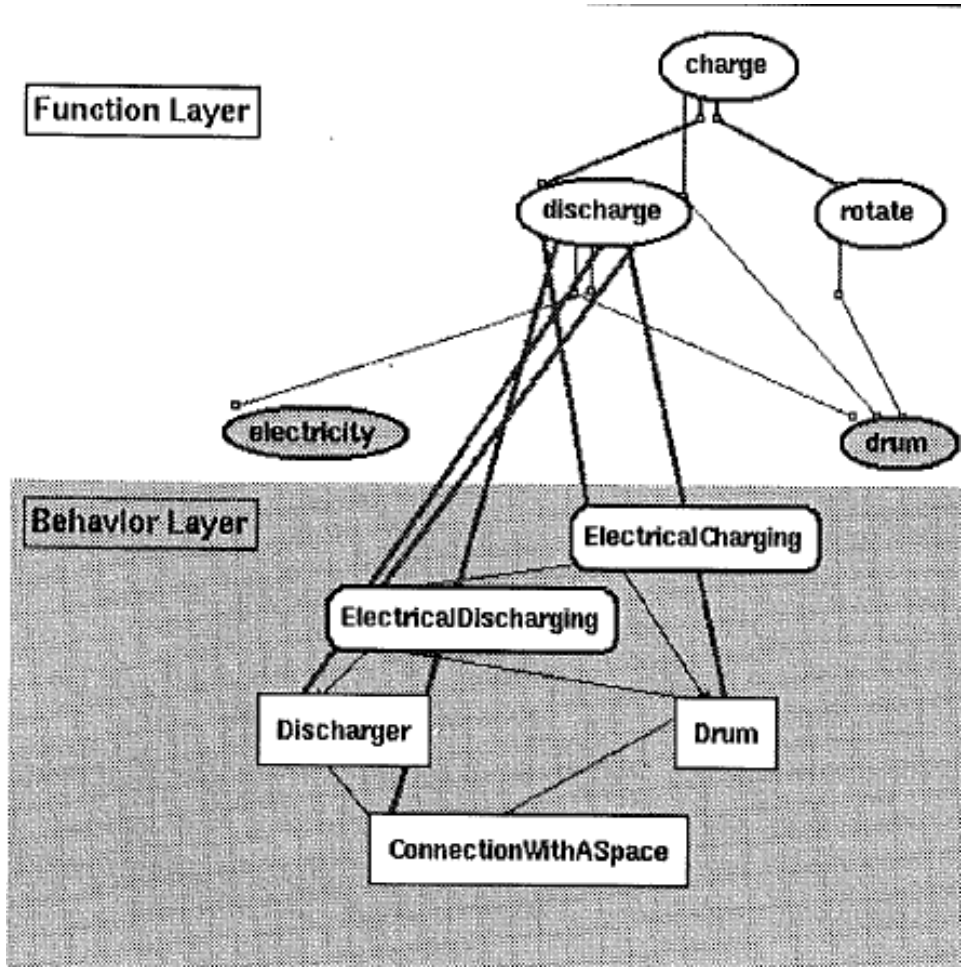
Two possible structures

Function-behavior-structure + (form, content, process..)



- In Systems Thinking for Design we are focusing on linkages [1] and [2] that represent key stages in the fuzzy front-end of product design & innovation
- Discovery-Diagnosis and Functional Design [9] can bring us to clarity on F and Be and their relationships
- Functional design can then be translated into [2] different structural designs
- [3,4,5] are part of detail design (core engineering design)
- [6] will be the component interaction matrix (will be enabled by ISM – to be discussed later)

Modeling interdependencies among FBS



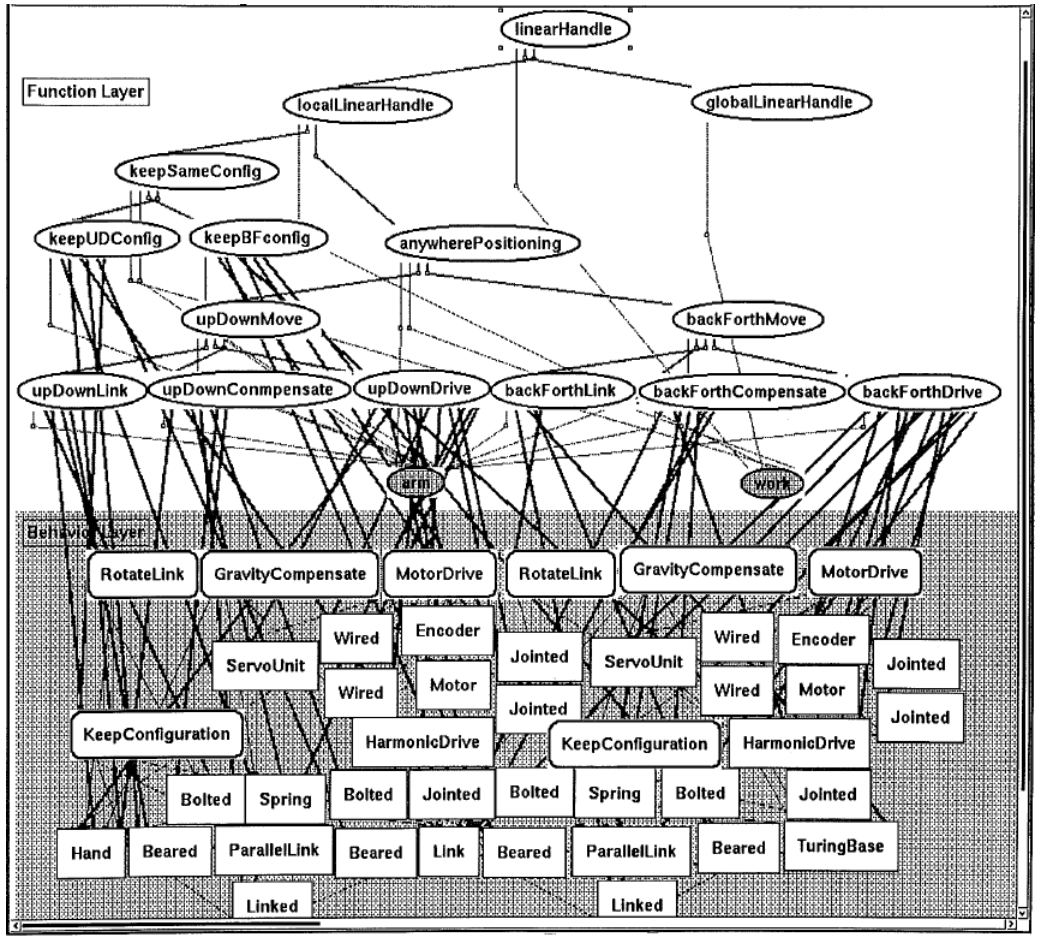


Fig. 12. The FBS model of a robot arm.

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Why functional hierarchy (or decomposition)? Why ISM?

Decomposition Method	Means Identified	Output	Required Expertise
Function Listing	None explicitly	Generic function list	Low
Black Box	None explicitly	Generic hierarchy	Medium
Axiomatic Design	One solution	A single solution	High
Reverse Engineering	Only existing ones	Existing solutions	Low
Benchmarking	Only existing ones	Existing solutions	Low
Function-Means Tree	Several	Several solutions	Medium

Introduction to Interpretive Structural Modeling (ISM)

- An approach to resolve complex problems requires
  - Application of many minds, understanding and support of stakeholders
  - Understanding the hidden hierarchy and alignment among different objectives
- A semi-mathematical approach
  - Combining a group's mental model and mathematical logic
  - A computer assisted learning process (one of the earliest human-machine interaction ideas)
- Developed by Prof. J.N.Warfield (GMU)
  - Leveraged developments in Group Techniques and Structural Modeling
  - Applied to a host of problem situations (engineering & management)
  - Tool available for download (ISM.ZIP for Windows 7)
  - More details at http://www.jnwarfield.com

Methodology of ISM (1/6)

- Define key elements
  - Ex.: Objectives, Issues, activities
  - Each element should convey only one idea/issue

1. To improve…
2. To reduce…
3. To change…
4. To introduce…

  - Ideas/Issues can be gathered from experts or through systemic analysis
  - For gathering data from experts, techniques like Nominal Group Technique or Brainstorming can be used to elicit views

Methodology of ISM (2/6)

- Define the contextual relationship
  - Ex.: facilitates, leads to, causes, precedes, succeeds, necessitates
  - Pair-wise comparison of elements. Every relationship should be read as ‘Does the realization of objective 1 facilitate the realization of objective 2’
  - Care should be taken to ensure that only one type of relationship is adopted. Different relationships may give different structures
  - It is useful to compare one element (preferably the one which is likely to appear in the middle of the hierarchy) with the rest of the elements for the first set of comparison
- Transitivity is assumed
  - E1--->E2, E2--->E3, implies E1-->E3
  - Strict relations would require extreme clarity, example, “is necessary”
  - A wider relationship is transitive. May result in feedback loops
- The degree of impact can be incorporated through weightage

Adjacency Matrix

A =

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

Methodology of ISM (3/6)

- Prepare the reachability matrix
  - Through implication identify the relations that can be inferred and those that need to be collected. Implication also reduces the effort involved in constructing a reachability matrix
  - Reachability matrix can be derived by multiplying the sum of adjacency matrix and identity matrix with itself until no further change in the reachability matrix can happen

$$R = (A+I)^n$$

R = (n=2)

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

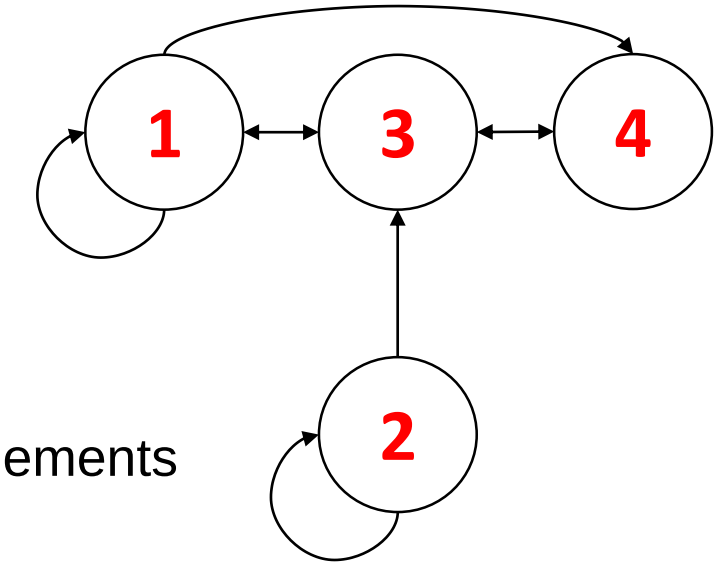
Methodology of ISM (4/6)

- Identify the hierarchical levels from the reachability matrix
  1. Identify the reachability set for each element (the row elements with 1s)
  2. Identify the antecedent set for each element (the column of that element with 1s)
  3. Find the intersection of the above two sets
  4. Those elements for whom the intersection = antecedent set represent the levels
  5. Remove these elements from the table and repeat step 3-4 until all elements are exhausted

	Reachability Set	Antecedent Set	Intersection Set	Level
1	1,3,4	1,2,3,4	1,3,4	2
2	1,2,3,4	2	2	1
3	1,3,4	1,2,3,4	1,3,4	2
4	1,3,4	1,2,3,4	1,3,4	2

Methodology of ism (5/6)

- Qualitative interpretation will be required to ensure appropriate position
  - Some elements without strong influence may be ignored or
  - Similar elements could be clubbed under one category
  - Long jumps may be corrected by introducing intermediate elements
  - Feedback from higher levels to lower levels could be avoided



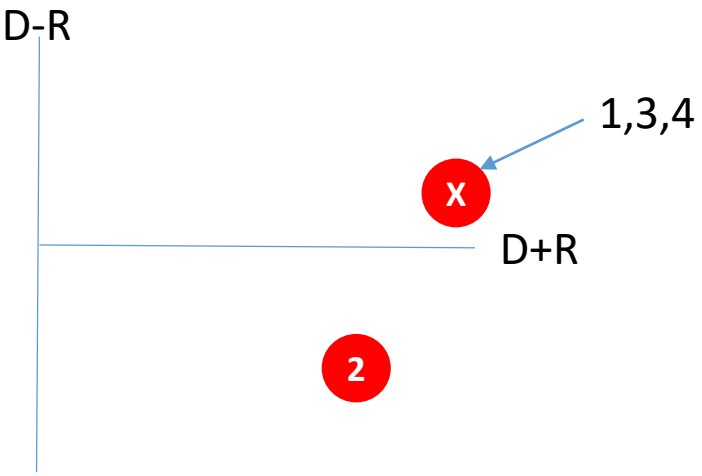
Methodology of ISM (6/6)

- Interpret the hierarchical model
- Look for patterns
- See what the structure is not saying
  - hidden or ignored dimensions
- The structure would reflect the nature of thinking
  - Too much cluttering or jumps or loops may indicate lack of clarity
- Use the model to assess key components and design strategies
- One could also segregate elements by the scores of Dependency and Reachability (D+R) vs (D-R)

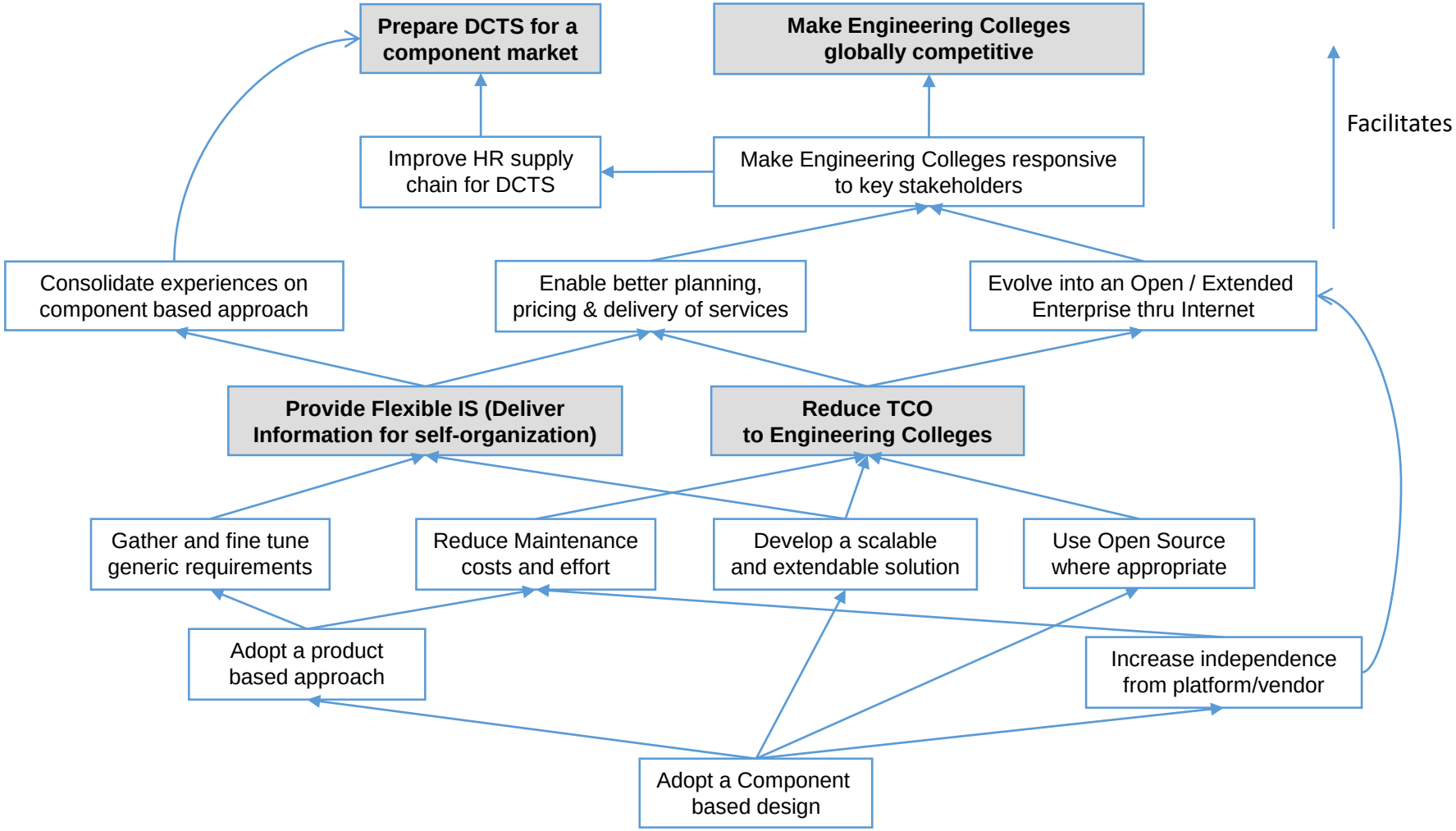
R =

(n=2)

	1	2	3	4	R	D+R	D-R
1	1	0	1	1	3	7	1
2	1	1	1	1	4	5	-3
3	1	0	1	1	3	7	1
4	1	0	1	1	3	7	1
D	4	1	4	4			



Example of Functional Hierarchy (solution design)



Business component architecture (software design)

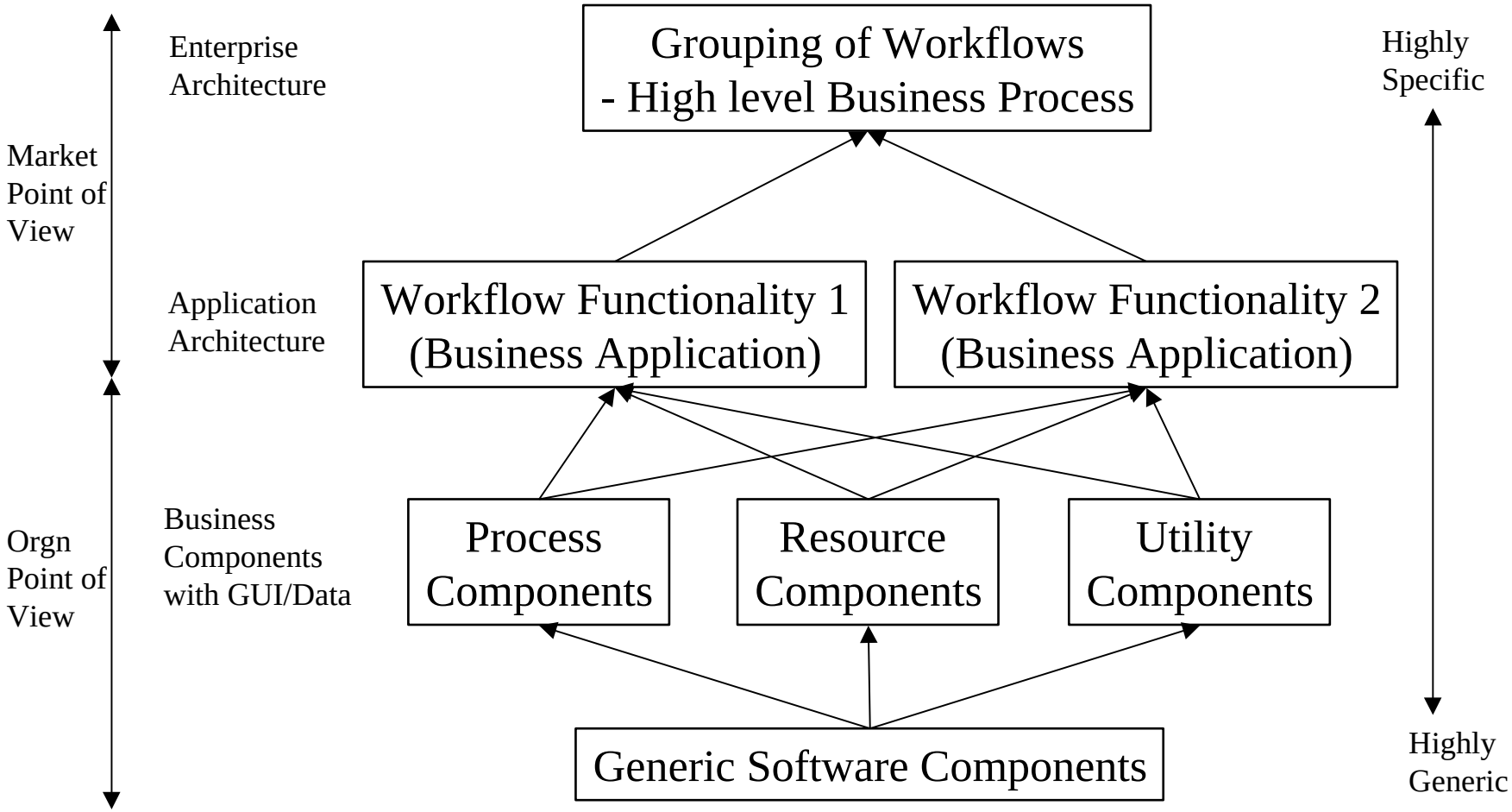
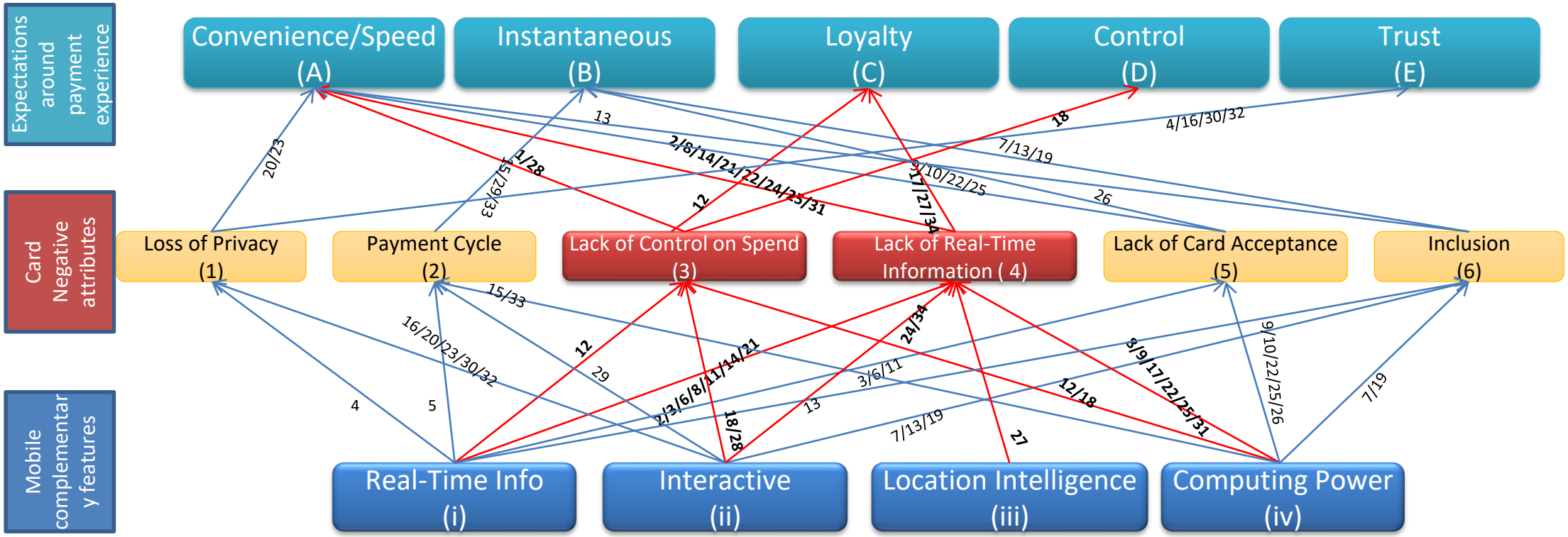
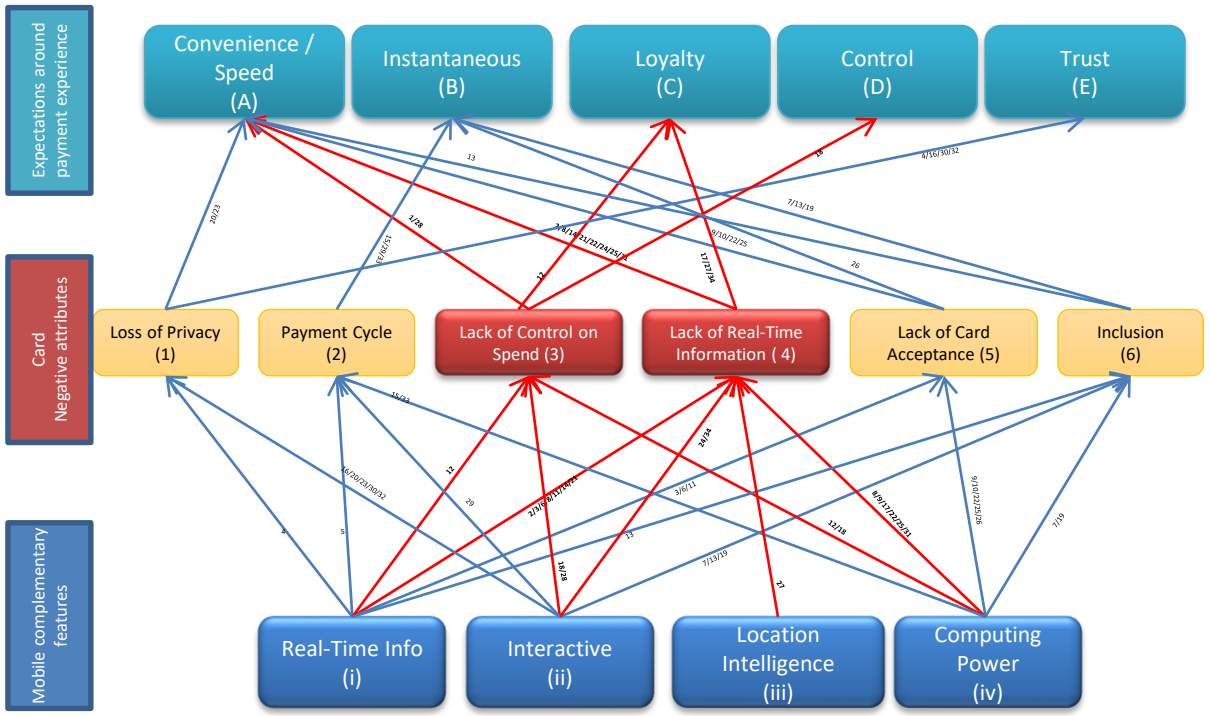


Illustration of ISM (1/3): Functional Architecture for Digital Payments



Mobile Payment Ideas that leverage power of mobility to address fundamental limitations of cards and reduce use of cash

Illustration of ISM (2/3): An example of Function-Behavior-Structure mapping



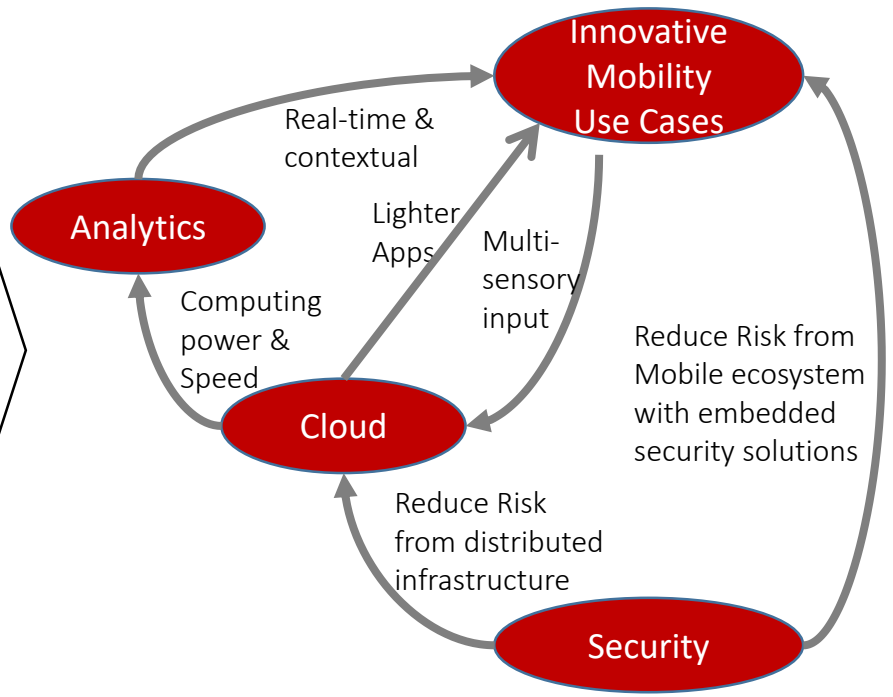
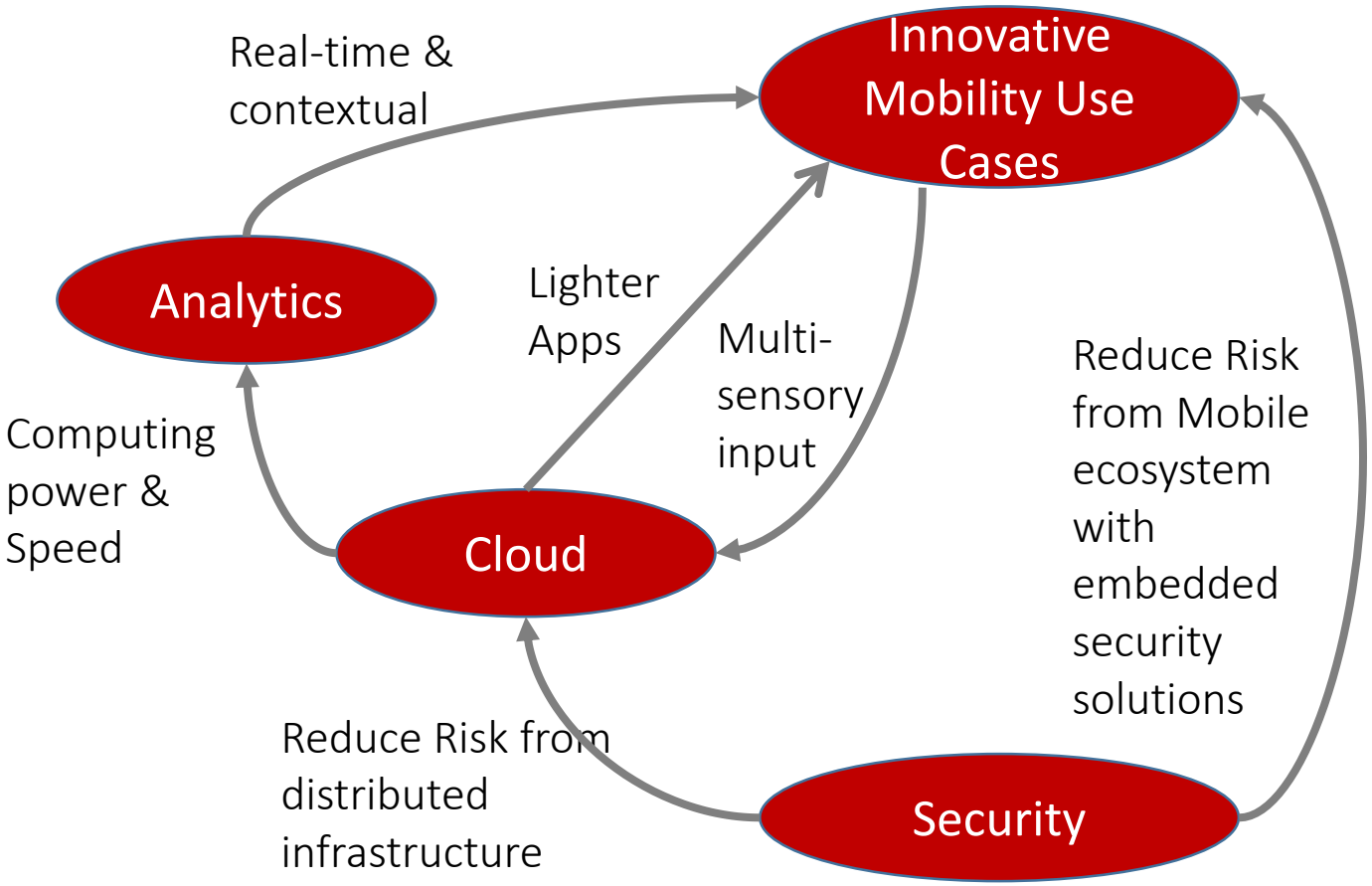


Illustration of ISM (3/3)
Architecture for digital technology platforms



And the truth behind SMAC…
SCAM >>> I-MACS >>> SMAC

Live demo of ISM software

- Let us take the challenge of
  - “Promoting design and innovation among IIITDM students and faculty”

Applications of ISM in engineering, product design and management

- Product Design
- Risk Management
- Technology Forecasting
- Large Program Management, ex: IT Infrastructure transformation program
- Accelerated learning, competency development & knowledge management
- Strategic planning and organization design

References

- W.J. Zhang et al. (2012), On the Function-Behavior-Structure Model for Design
- DAVID W. MALONE (1975), An Introduction to the Application of interpretive Structural Modeling, PROCEEDINGS OF THE IEEE, VOL. 63, NO. 3
- Ming-TangWang et al. (2013), An ISM Based Approach for Product Innovation Using a Synthesized Process, Mathematical Problems in Engineering, Volume 2014, Article ID 341614, http://dx.doi.org/10.1155/2014/341614

Identify & Exploit the hierarchical pattern among objectives