Artificial Intelligence & CPPS :

An Holistic View of the link between IS and CPPS

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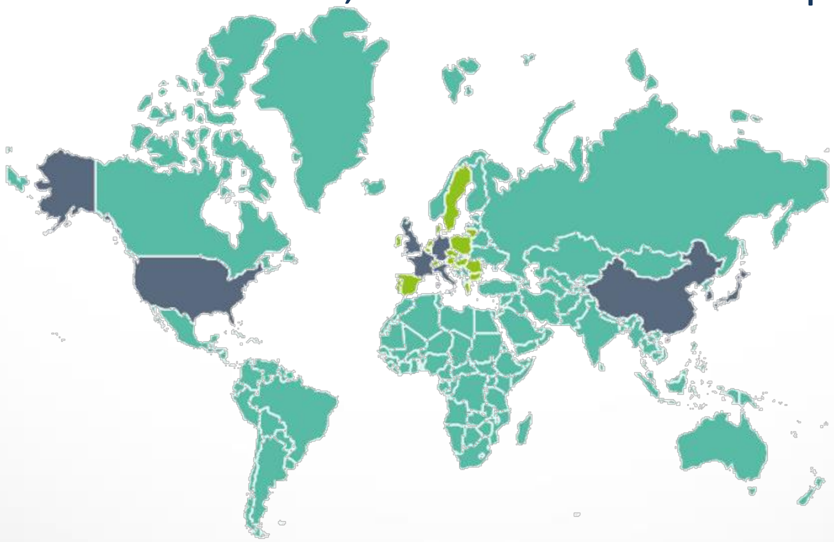
Presentation Outline

- Context and main concepts
- The integrative link between EIS and CPPS
- Holistic Performance Management
- Discussion

Context

The Future of Industry

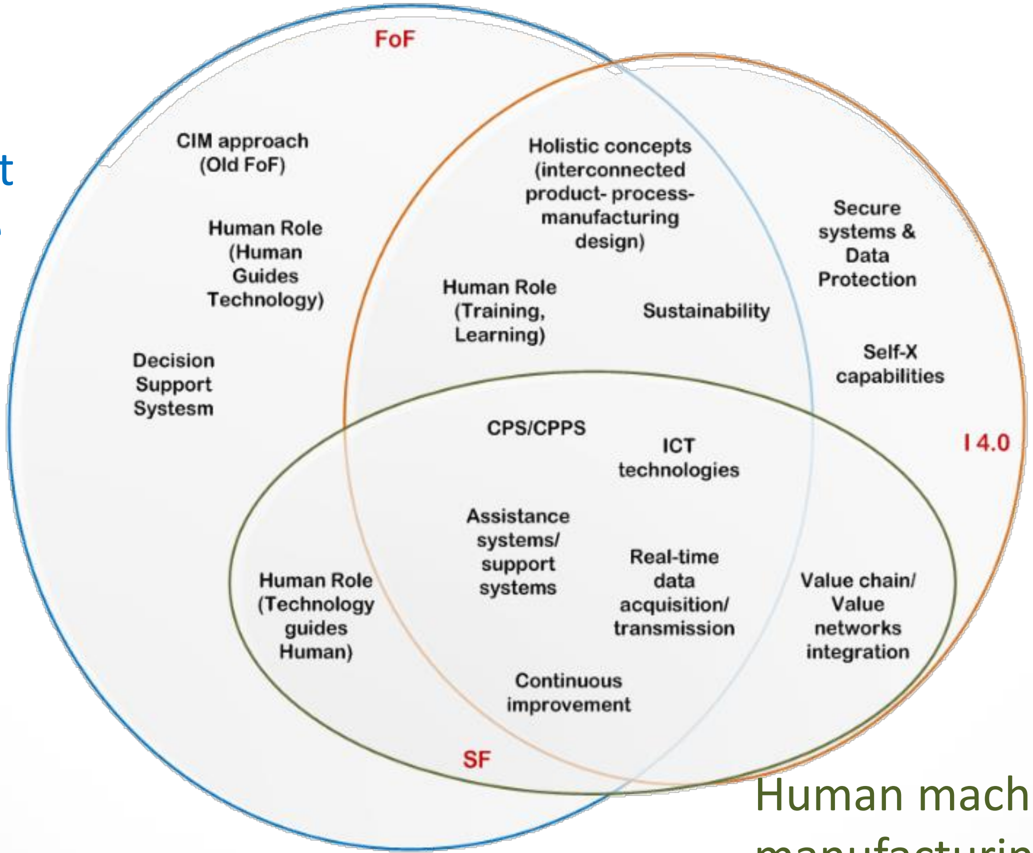
- **Plenty of research agendas for the future of industry :**
  - **Europe** : Germany – «High-Tec Strategy 2020». (2012), Italy – «La Fabbrica del Futuro». (2012), France – «La Nouvelle France Industrielle» (2013), UK – «The Future of Manufacturing». (2013)
  - **America** : USA – «Advanced Manufacturing Partnership». (2011)
  - **Asia** : China- « Made in China 2025 ». (2015), South Korea – « Innovation in Manufacturing 3.0 ». (2014), Japan- « 5th Science and Technology Basic Plan » (2015), Singapore – "Research, Innovation and Enterprise 2020" (2016)



Context

Factory of the Future, Smart Factory & I4.0

Key-features that evolve over time



4th Industrial Revolution

Human machine connection and manufacturing data feedback

IT are crucial for performance
Manufacturing systems are based on CPS

Concepts

IS Alignment

"Put two or more things into a straight line"

IT alignment

fitness

bridge

IS alignment

congruence

fusion

strategic alignment

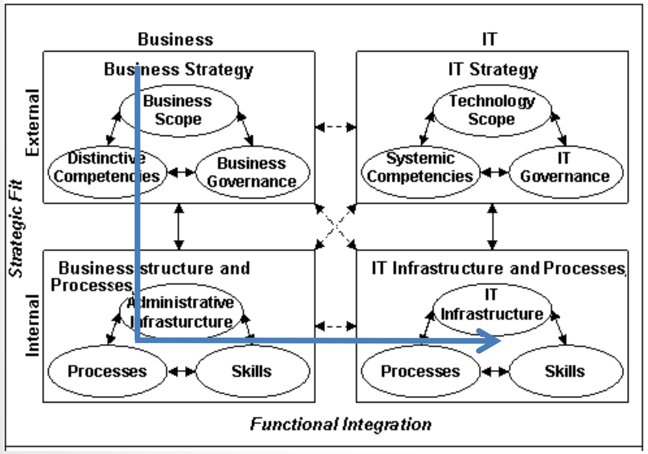
BITA

Consistency between business and IT on both operational and strategic levels

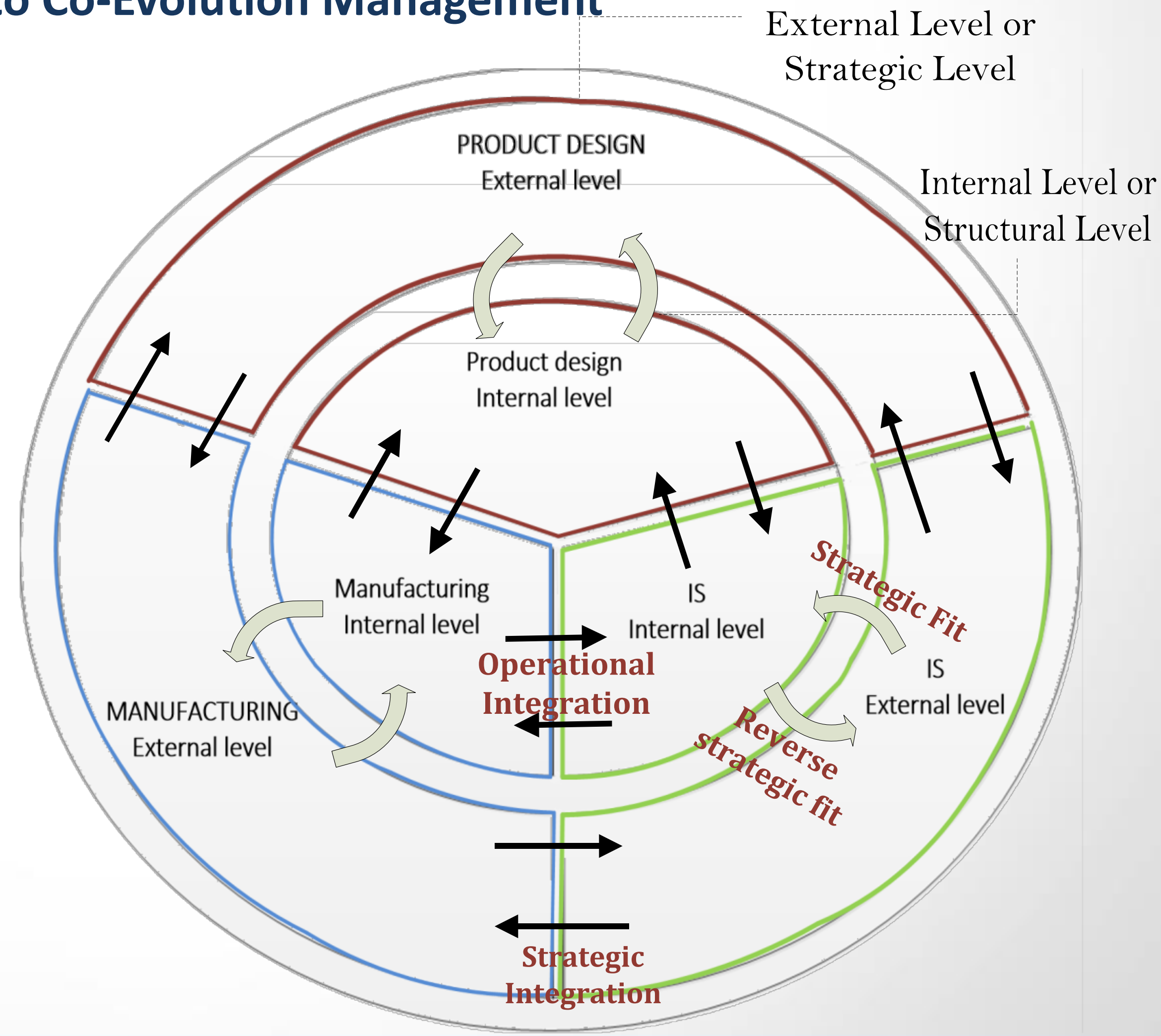
Concepts

IS Alignment

- **From Strategic Alignment Model to Co-Evolution Management**



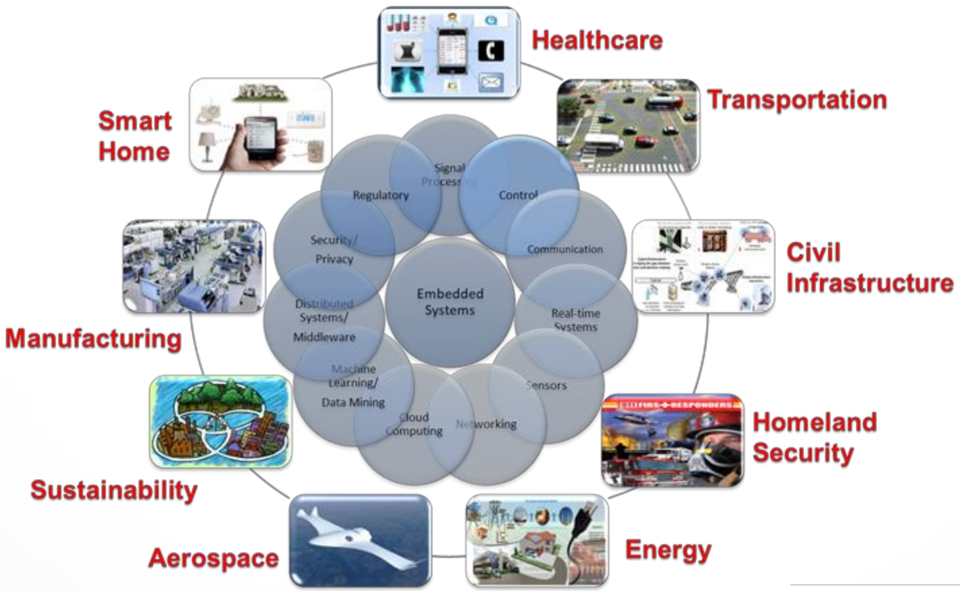
[Henderson, Venkatraman 1993]



Concepts

CPS

- CPSs: systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on-going processes, providing and using, at the same time, data-accessing and data-processing services available on the internet. [Hellinger, A. et al., 2011]



Application domains in CPSs

The application of CPSs in the manufacturing domains leads to Cyber Physical Production Systems (CPPSs).

Concepts

CPPS

- CPPSs consist of **autonomous and cooperative elements and sub-systems** that are getting into **connection** with each other in situation dependent ways, **on and across all levels of production**, from processes through machines up to production and logistics networks. [L. Monostori et al. 2016]

- A CPPS is a composition of human resources, production equipment and aggregated products towards which it establishes one or several cyber-physically formulated interaction interfaces. These interfaces are used for **monitoring and control of the CPPS operations** as well as **to tap into the knowledge generated both by the human resources, and the equipment, during the production process as well as knowledge generated by its aggregated products throughout their life-cycle** [Silva et al. 2017].

From the Concepts to the Problem

- **How to manage the link between CPPS and IS ?**
    - Definition of the link
    - State of the art
    - Research gap
    - Conceptualization of the link

The integrative link between IS and CPPS

EIS Dimensions [Reix et al. 2019]

EIS

- **Informational dimension**: Representation of environment through a set of data
- **Technological dimension**: Technological means that enable data collecting, storing and processing.
- **Organizational dimension**:
  - Function perspective:
    - EIS meets the specific internal needs of each BP
    - EIS meets the need for inter-BP communications
  - Structure perspective:
    - IS structures the way of functioning within an enterprise

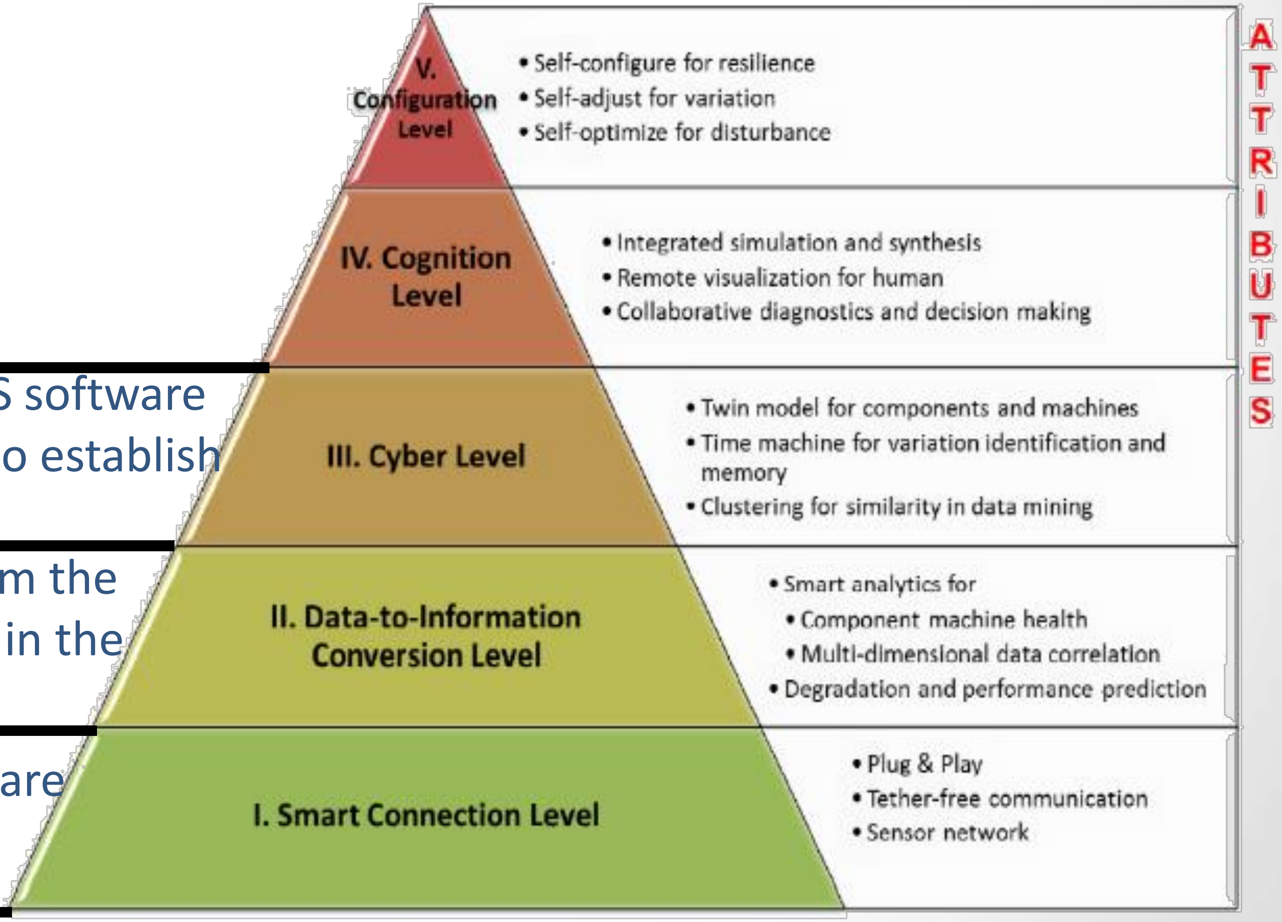
The integrative link between IS and CPPS

Definition of the link between EIS and CPPS

Informational dimension	Exchange of data and information between EISs software and CPPSs
Technological link	EISs use the information technologies to achieve data collecting, storing and processing in CPPSs
Organizational dimension	The way CPPSs impacts business processes and decision making processes supported by EISs.

The integrative link is the integration of all elements including data, information technologies (IT), people and business processes to achieve the optimal fulfilment of the business mission.

State of the Art : The informational link IS/CPPS



Information is being pushed to EIS software from every source and compiled to establish a cyber space

Infers meaningful information from the large amount of data and show it in the EIS software

Acquires data from EISs software such as ERP and MES

5C architecture for implementation of CPSs

(Lee, J., Bagheri, B., Kao, H. A. 2015. A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing letters, 3, pp 18-23.)

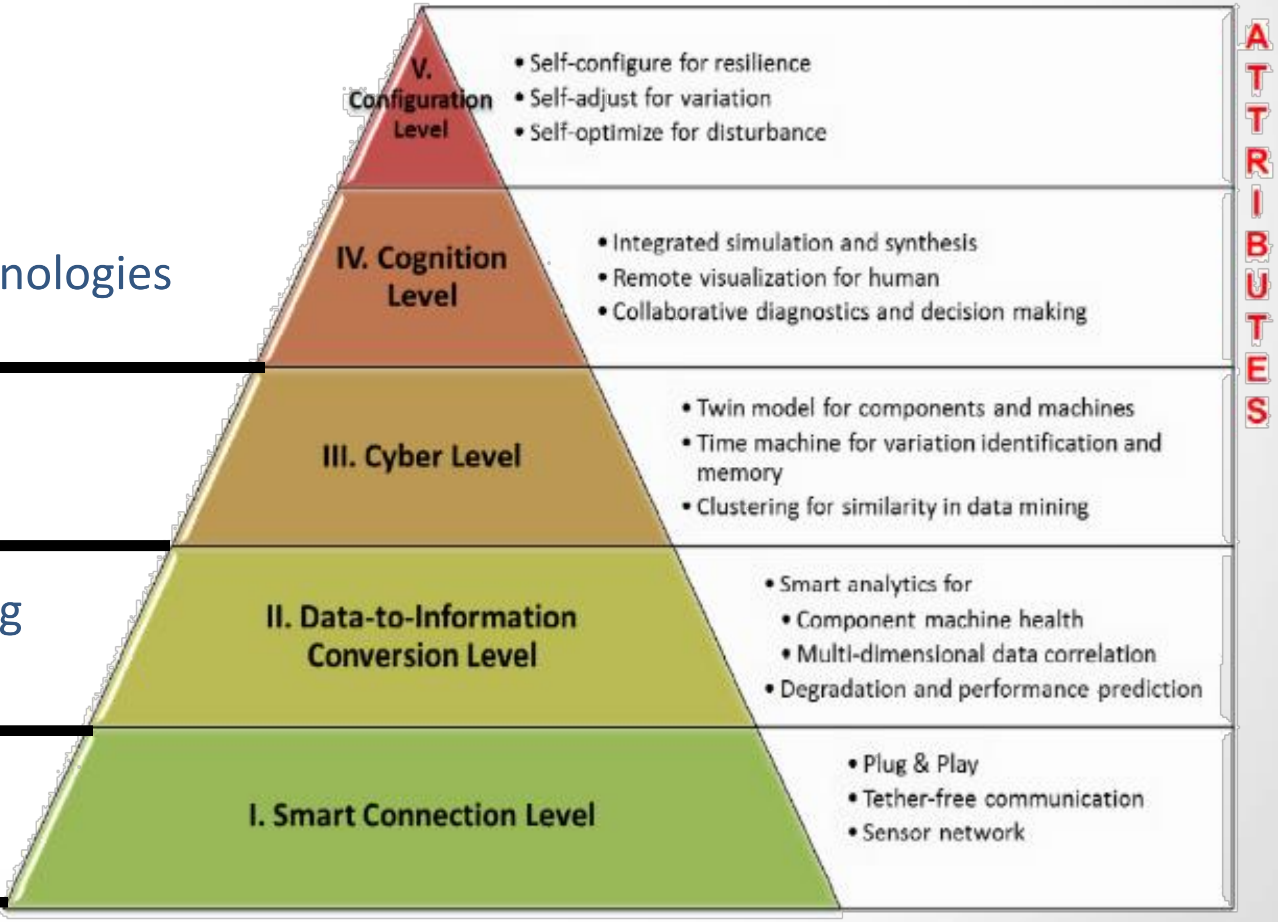
State of the Art : The technological link IS/CPPS

Information presentation technologies

Information processing and security technologies

Data converting and processing technologies

Data acquisition and storage technologies

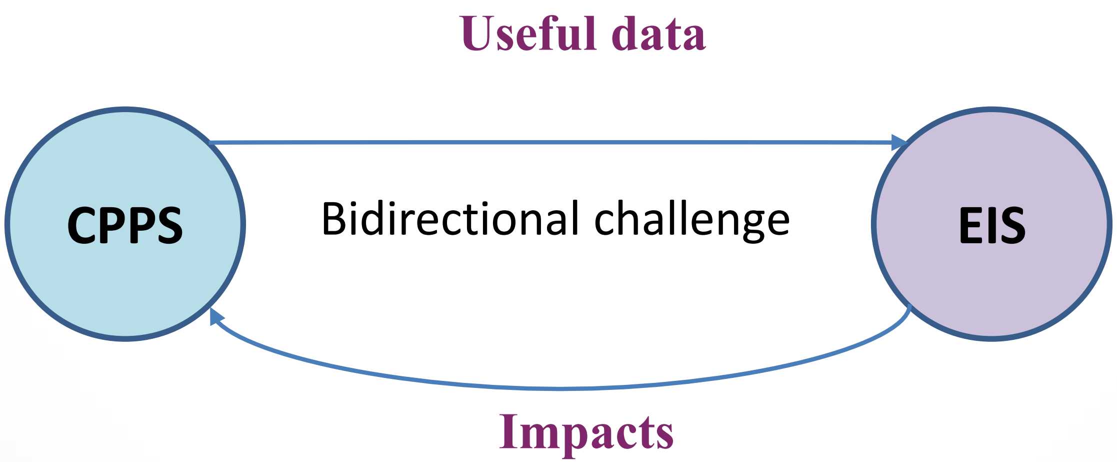


5C architecture for implementation of CPSs

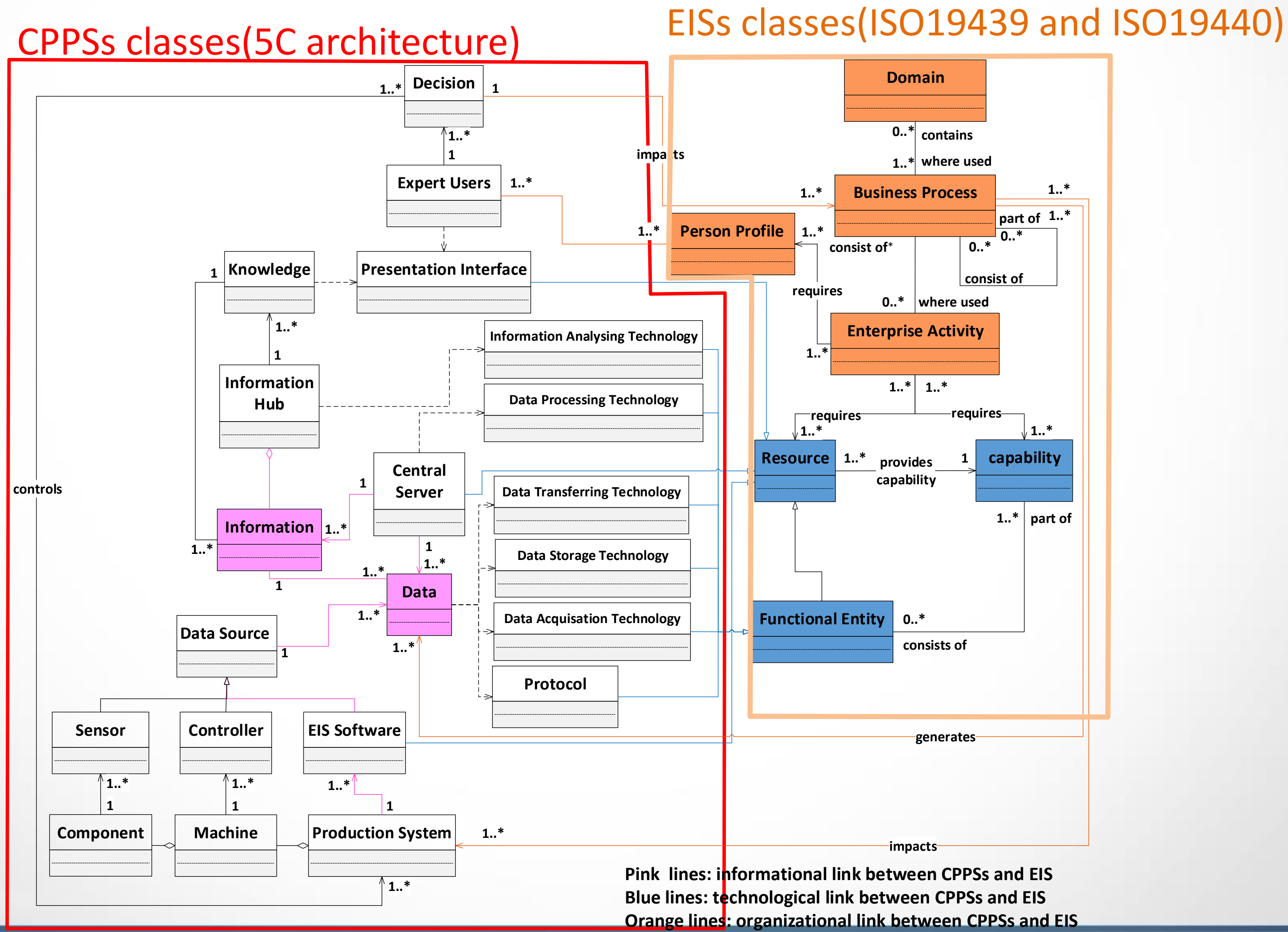
(Lee, J., Bagheri, B., Kao, H. A. 2015. A cyber-physical systems architecture for industry 4.0-based manufacturing systems. Manufacturing letters, 3, pp 18-23.)

Research gap

- **Implement the organizational link between CPPSs and EISs**



Conceptualization of the link : Meta-model Overview



Pink lines: informational link between CPPSs and EIS
Blue lines: technological link between CPPSs and EIS
Orange lines: organizational link between CPPSs and EIS

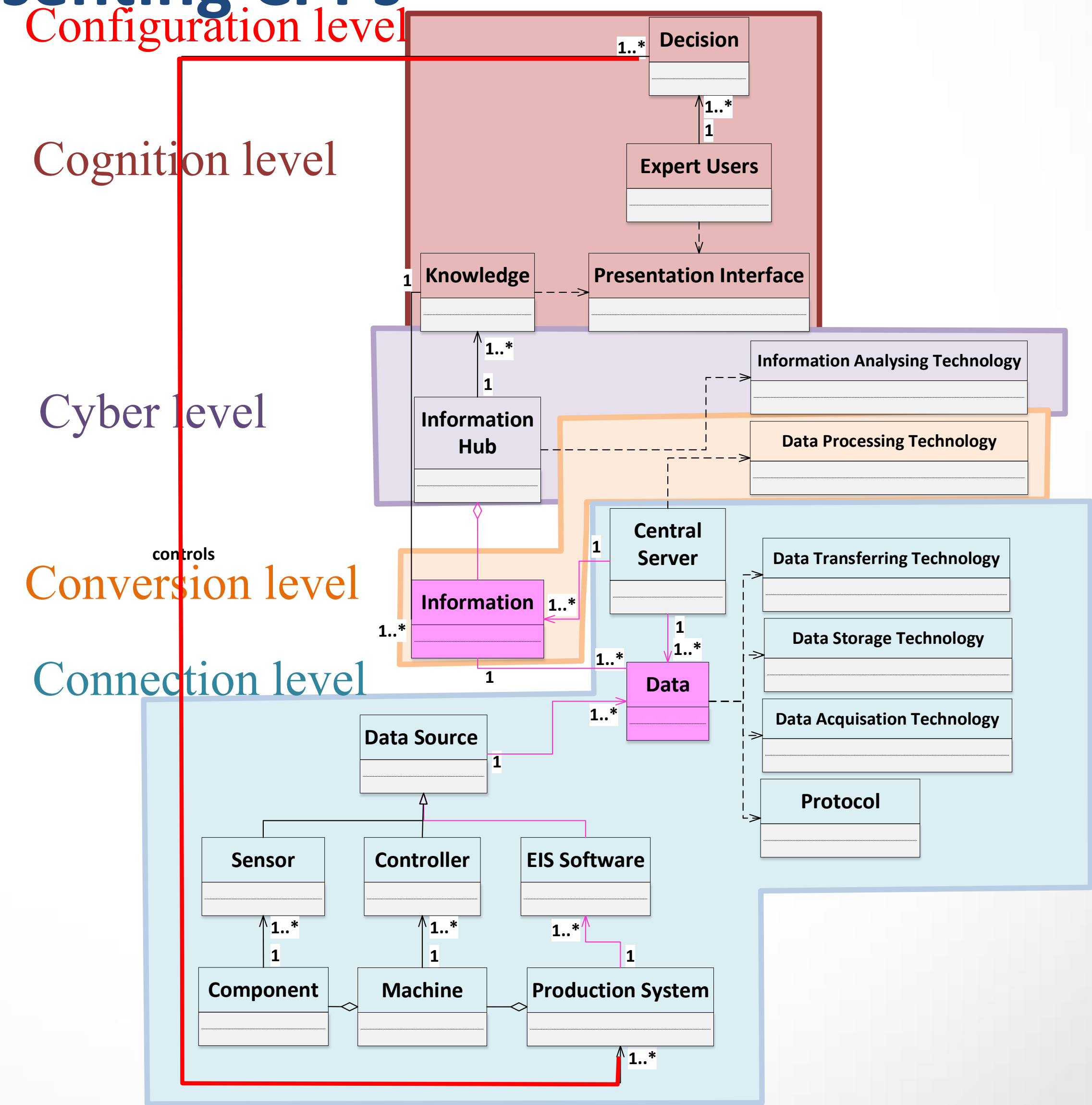
The classes representing CPPs

Cognition level:

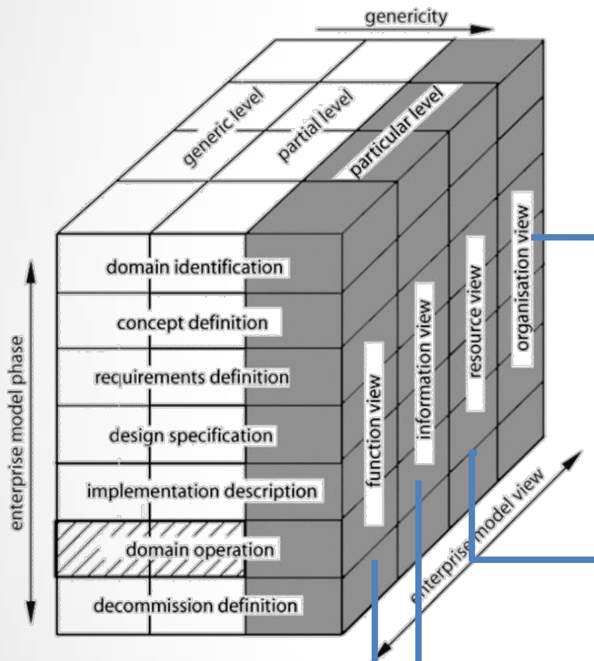
"Implementing CPS upon this level generates a thorough ***knowledge*** *of the monitored system. Proper* ***presentation*** *of the acquired knowledge to* ***expert users*** *supports the correct* ***decision*** *to be taken" (Jay Lee, 2016)*

⇩

Knowledge
Presentation interface
Expert users
Decision



The classes representing EIS



Enterprise Modelling Cube

represents the organization, organizational relationships and the decision-making responsibilities in an enterprise

Organizational dimension

represents the enterprise assets (e.g. human and technological components) that are needed for carrying out enterprise operations

Technological dimension

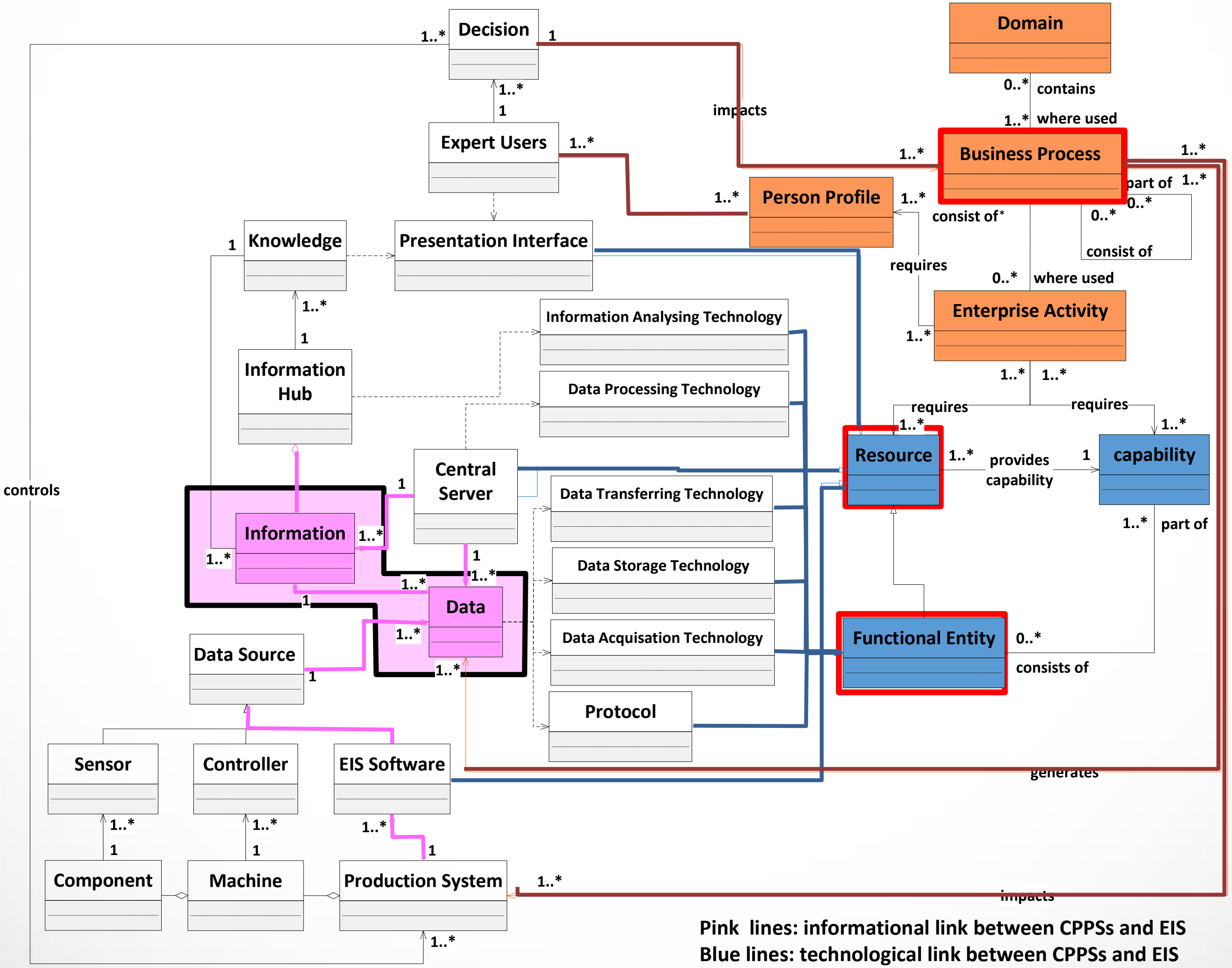
represents the information used in an enterprise

Informational dimension

represents the business processes in an enterprise

Organizational dimension

The integrative link between EIS and CPPS



Pink lines: informational link between CPPSs and EIS
Blue lines: technological link between CPPSs and EIS
Orange lines: organizational link between CPPSs and EIS

What's next ?

- Operationalize the link for a specific EIS software like MES
- Set up a dynamic link
- Evaluate the performance of the link with an holistic view

Introduction

«You can't manage

what you can't measure»

Paradigm shift (over the 20th century):

- Cost measurement → Cost management, and then
- Perf. measurement → Perf. management

Industrial Performance

Performance

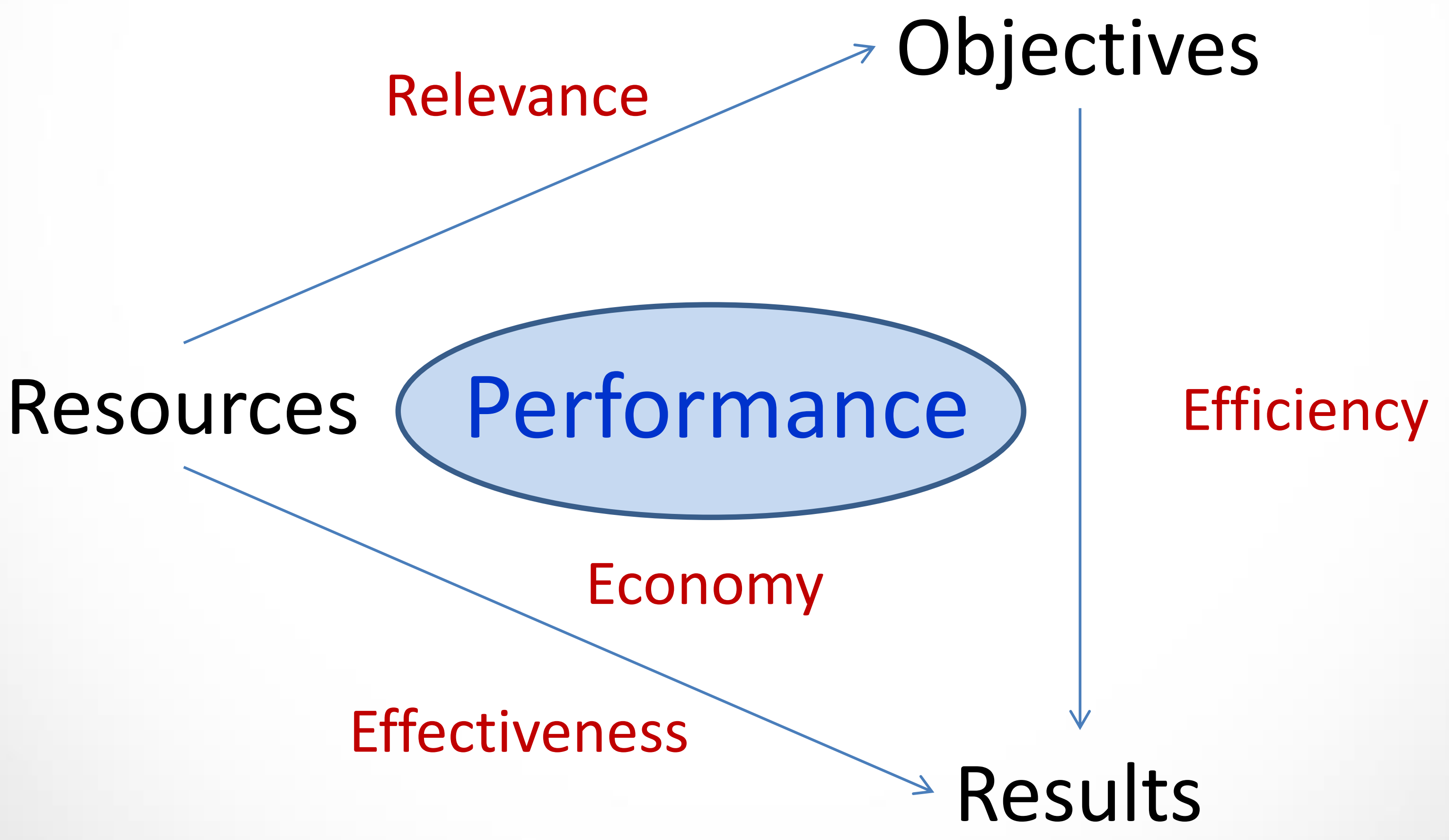
- Is about the degree of satisfaction of a goal/objective/requirement/need

- Is a relative concept:
  - Depends on the objective
  - Varies over time
- Is a multi-criteria concept
- Financial vs. non-financial criteria

About Performance

- Performance (European Court of Auditors)
  - Efficiency
  - Effectiveness
  - Economy
- Industrial Performance (QCD paradigm)
  - Quality
  - Cost
  - Delay

About Industrial Performance



(From Bescot, 1995 and Jacot, 1996)

About Industrial Performance

- Performance Evaluation: is about how an objective has been (or is) achieved/fulfiled

requires

- Performance Indicators (PIs): Evaluation of performance elements / measures

aggregated into a

- Global Performance: A measure of the achievement of the global objective(s)

About Industrial Performance

Two Types of Performance Indicators:

- Result Indicators (*a posteriori* evaluation)

  After the fact (measures, statements…)

  (nb of parts made, nb of scraps, availability rate, prod cost…)

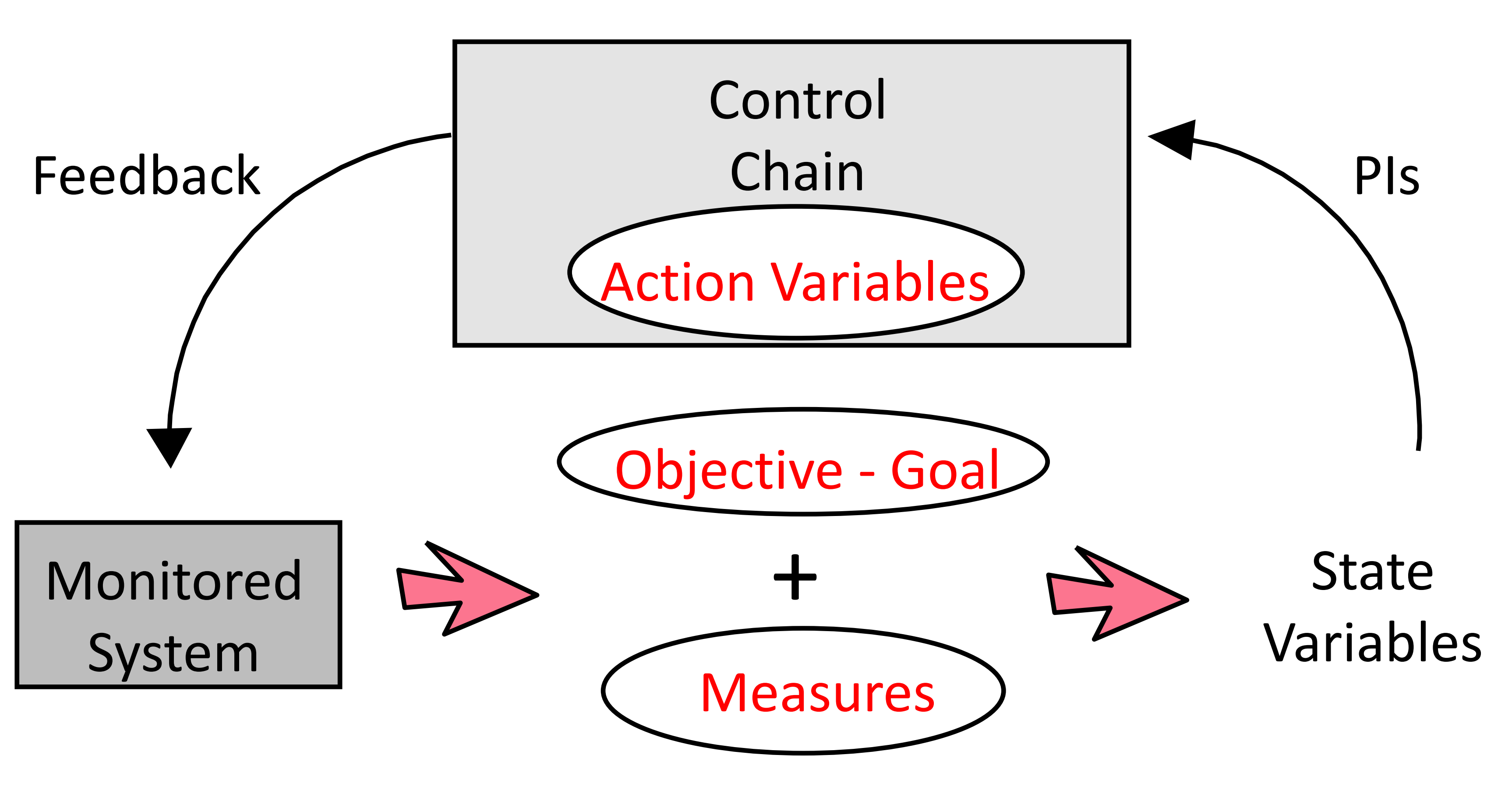
- Process Indicators (*on-line* evaluation)

  During the fact (trends, thresholds…)

  Are part of the decision-making process

  (increase rate of scraps per hour, reach 5% below limit threshold…)

About Industrial Performance



Controlability: (objective, measure, (action) variable)

(Berrah & Vernadat, 2002)

Performance Management

- Fundamental questions:
  - How to define the PI's (to be RACER)? Where?
  - How many? Performance dashboard or PMS?
  - How to aggregate performance elements in PMS?
  - How to handle the multicriteria dimension of performance?
  - When should PI's be questioned/revised?

(RACER: Relevant, Accepted, Credible, Easy, Robust)

Performance Management

- Global vs. elementary objectives
- Global vs. elementary performance
- Performance measurement & aggregation

Objective analysis is fundamental

Elementary objective <-> Performance indicator

Global objective <-> Global performance

PI and Elementary Performance

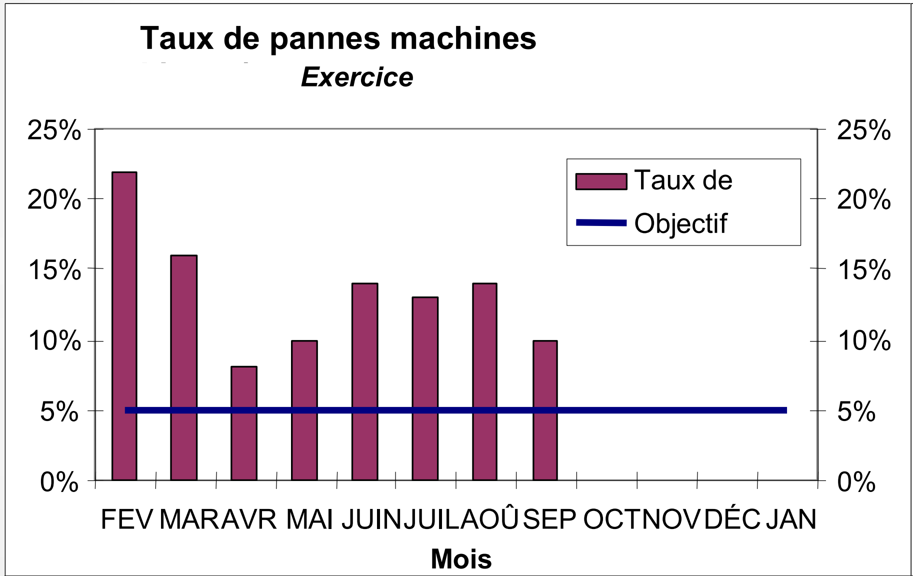
- Elementary performance expression is the result of the comparison between a measure and an elementary objective

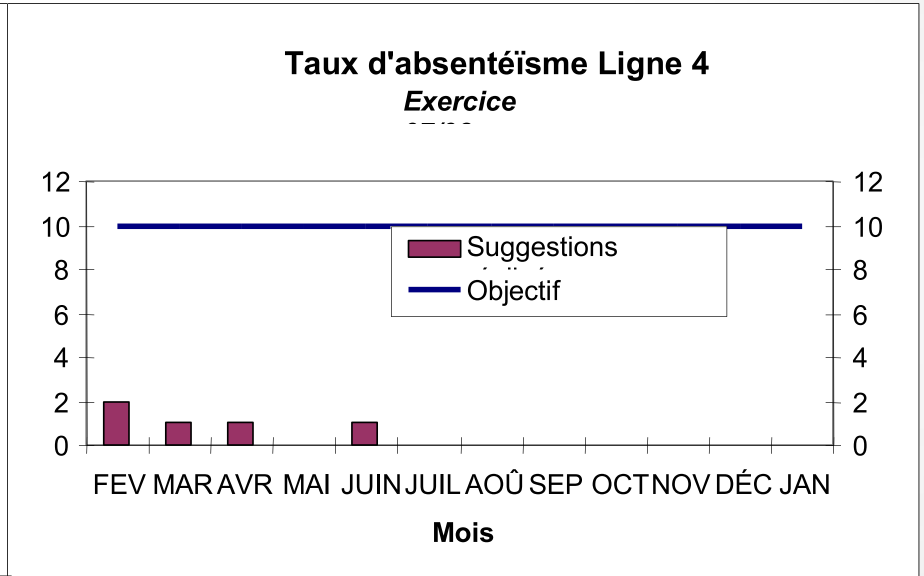
- Global performance expression is the result of the aggregation of elementary expressions of sub-objectives

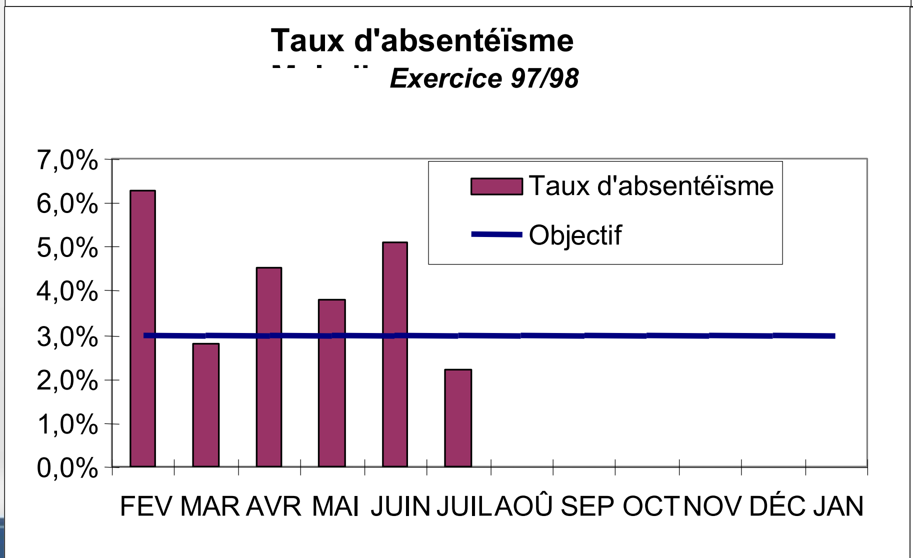
Examples of PIs

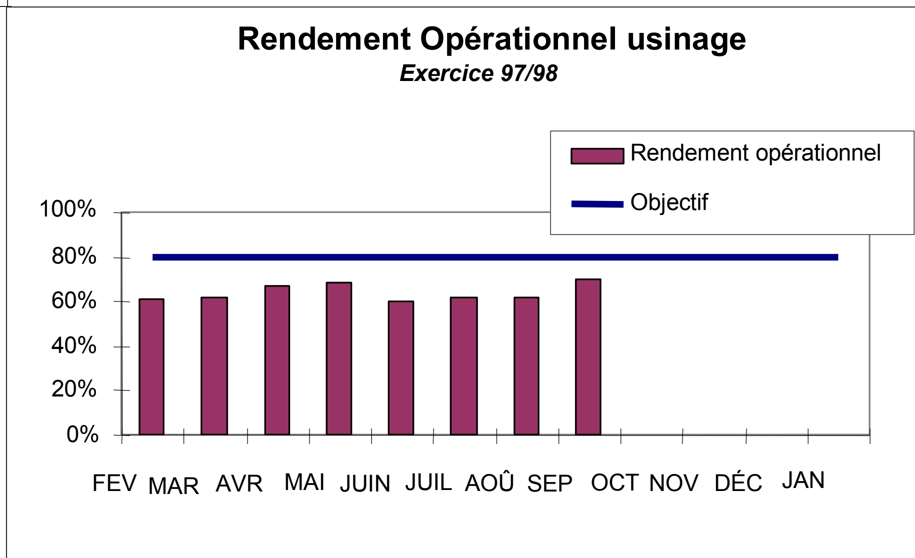
Cost / Volume	$Productivity = \frac{number\ of\ parts\ made}{number\ of\ hours\ spent}$ $Efficiency = \frac{quantity\ made \times allocated\ time}{elapsed\ time}$ $Costs\_Purchase = \frac{amount\ of\ purchase}{annual\ sales}$
Quality	$\mathrm{Re}\,turn\_Ratio = \frac{number\ of\ returned\ deliveries}{total\ number\ of\ deliveries}$ $\mathrm{Re}\,works = \frac{number\ of\ hours\ of\ rework}{number\ of\ hours\ worked}$ $Scrap\ rate = \frac{number\ of\ scrap\ parts}{number\ of\ parts\ made}$
Delay	*Delivery date/customer due date* $\mathrm{Pr}\,oduction\ throughput = production\ start\ date - end\ date$ $Customer\ service = \frac{orders\ delivered\ in\ time}{delivered\ orders}$

Tableaux de bord or PMS example





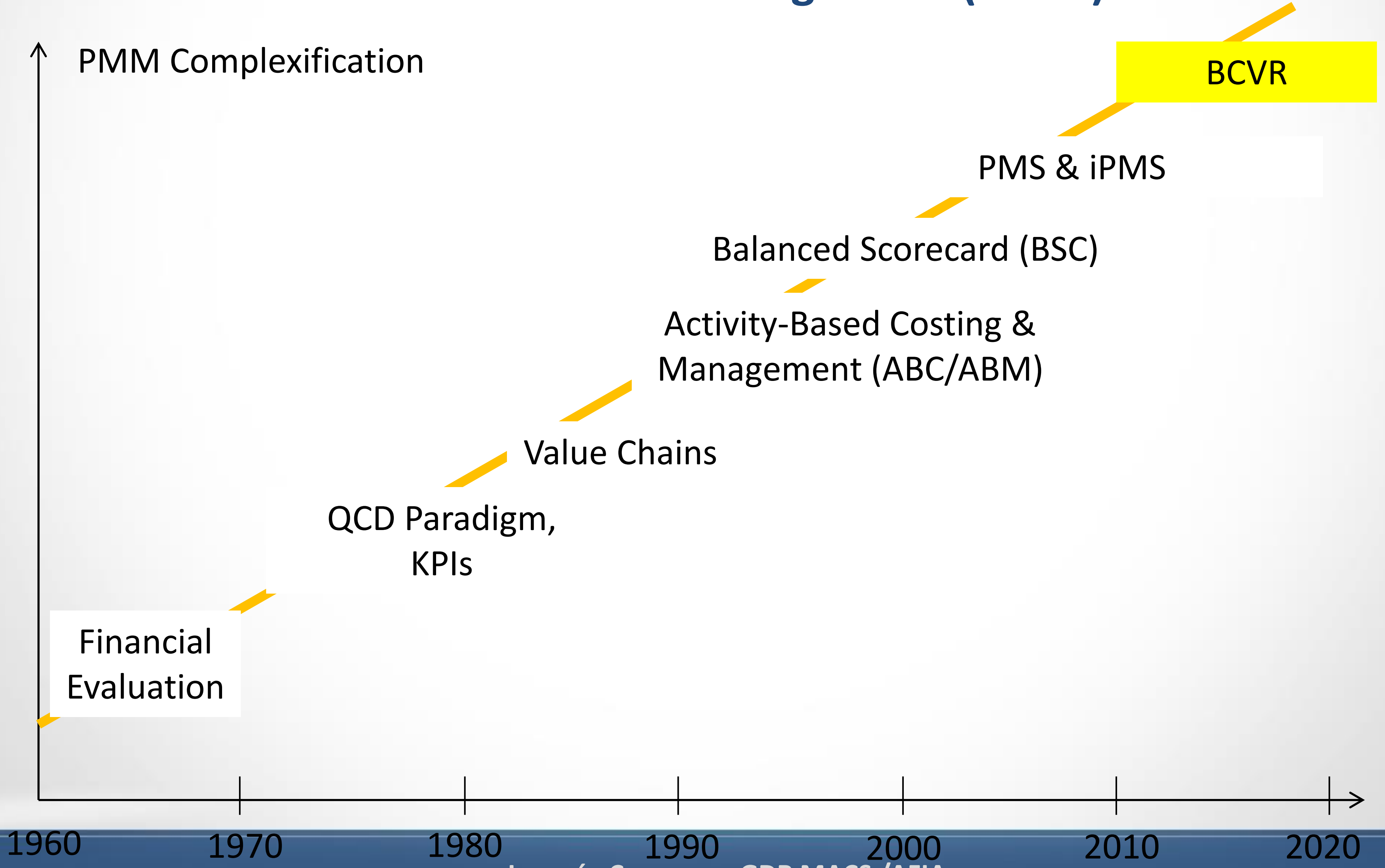




Performance Aggregation Example

	C1	C2	C3	C4	P_{ag}	R1	R2	R3	R_{ag}
PP1	0.6	0.9	0.89	0.33	**0.56**	1.0	0.22	0.1	**0.36**
PP2	0.5	0.6	0.78	0.17	**0.39**	0.29	0.11	0.2	**0.18**
PP3	0.2	−0.2	0.44	1.0	**0.12**	1.0	0.14	0.44	**0.42**
v_i	0.34	0.24	0.28	0.14		0.47	0.18	0.35	
I_{ij}	I_{12}	I_{13}	I_{14}	I_{23}		I_{12}	0.052		
	0.049	0.131	0.049	0.098		I_{13}	0.052		
	I_{24}			I_{34}		I_{23}	0.10		
	0.016			0.081					

Performance Measurement & Management (PMM) Evolution

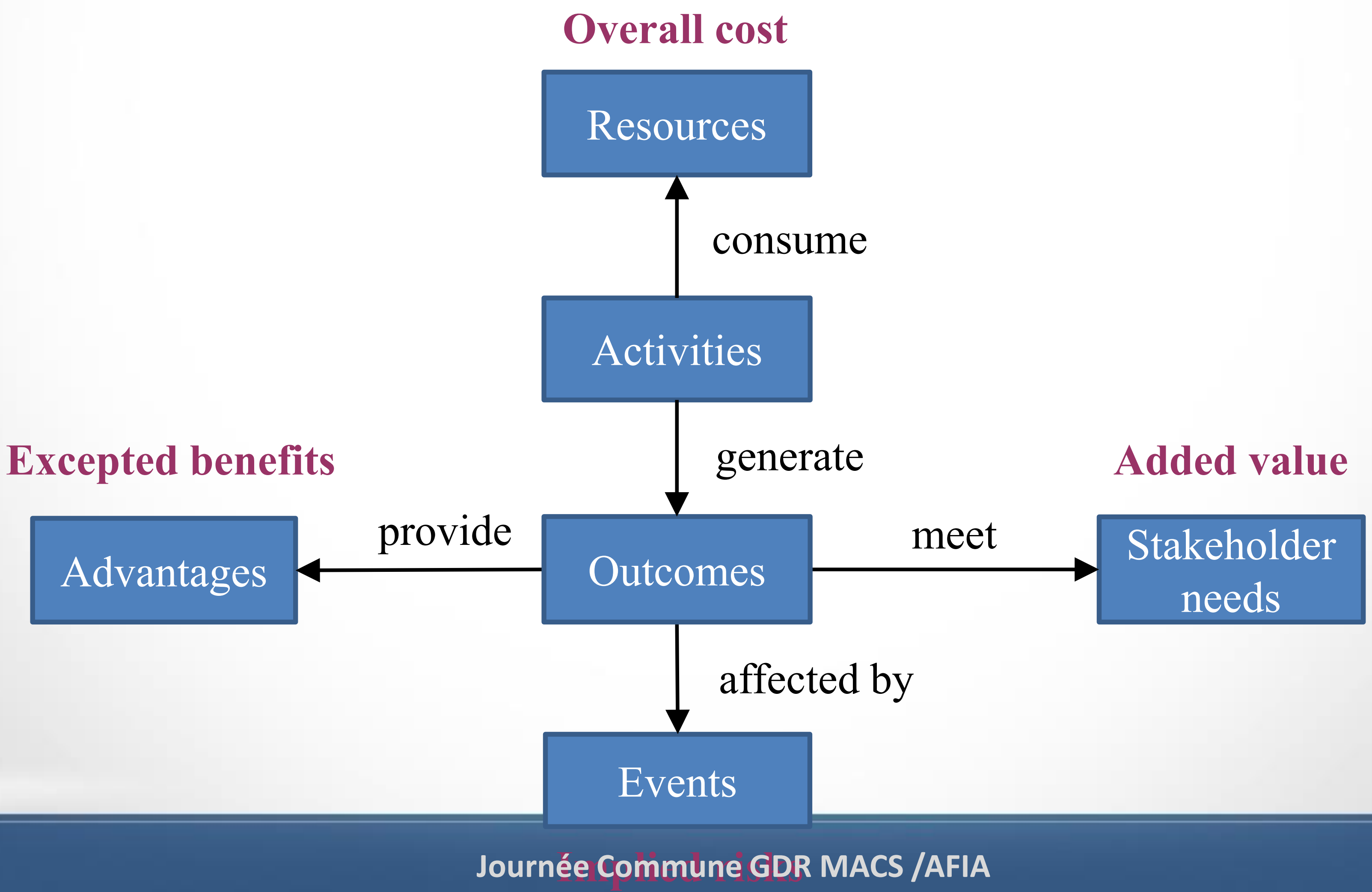


Major PMM & iPM Methods

- ABC/ABM (Cooper & Kaplan, 1990)
- Balanced Scorecard (BSC) (Kaplan & Norton, 1992)
- ECOGRAI (Bitton, 1990)
- QMPMS: Quantitative model for PMS (Bititci, 1995)
- IDPMS: Integrated Dynamic PMS (Ghalayini et al., 1997)
- IPMF: Integ. Perf. Meas. Framework (Medori, 2000)
- Performance Prism (Neely et al., 2002)
- ENAPS (Browne, 1999)

BCVR Methodology: Motivation

Our claim: The performance of an industrial system can be comprehensively measured and managed using four dimensions: **benefit, cost, value and risk**



Adapted definitions for BCVR

- Benefit

  A qualitative list of potential advantages or gains for a given stakeholder compared to an objective that is set beforehand with the realisation of an industrial project or system.

- Cost

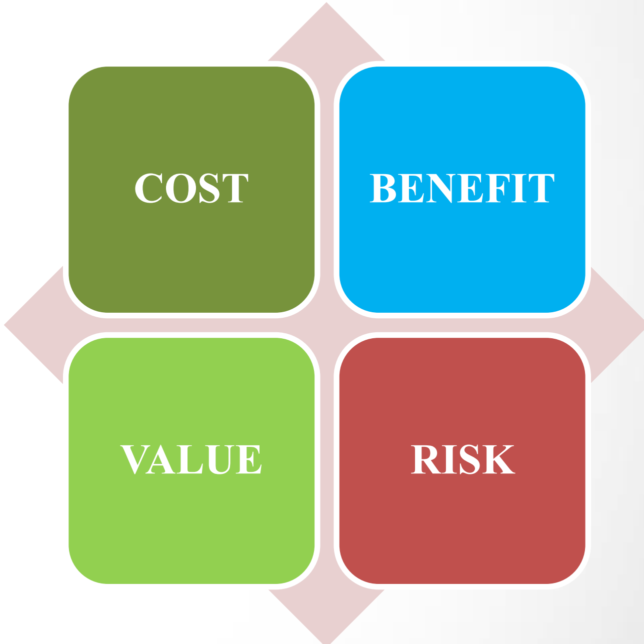
  Total expenses (or TCO) for the design, production, distribution and acquisition to deliver the final result of a product or system.

- Value

  Degree of satisfaction of a set of stakeholder expectations or needs, expressed by the appreciation level of a number of performance indicators.

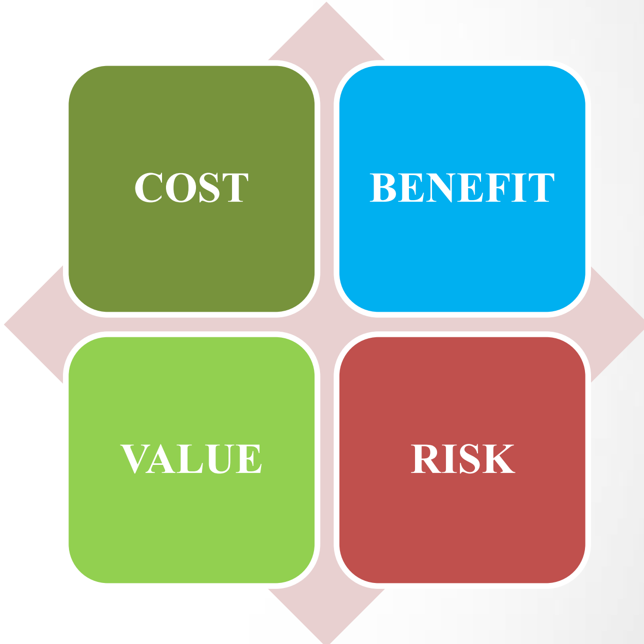
- Risk

  Consequences of an event occurrence impacting the achievement of different stakeholders' objectives.



Performance aggregation methods

- Arithmetic weighted sum
- Average weighted sum
- 2-additive Choquet integral



$$p_{ag} = Ag(p_1, \ldots, p_i, \ldots, p_n) = \sum_{i=1}^{n} \phi_i p_i - \frac{1}{2} \sum_{i,j=1, j>i}^{n} I_{ij} \left| p_i - p_j \right|$$

$$\left(\phi_i - \frac{1}{2} \sum_{j=1, j>i}^{n} \left| I_{ij} \right| \right) \geq 0 \quad \forall i \in [1, n] \qquad I_{ij} \in [-1, 1]$$

BCVR objective & applications

❖ Research objective

To develop a **methodology (methodological framework and associated tools)** for decision-makers in performance evaluation and decision making processes on the basis of four assessment dimensions: benefit, cost, value and risk.

❖ Applications

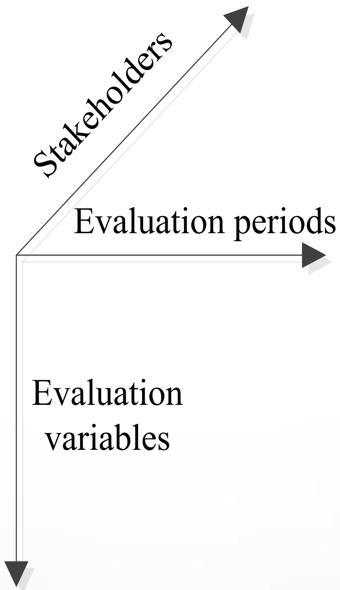
- Perform **opportunity evaluation** for a new project/process/system
- **Predict future performance** of a project/process/system
- **Control and monitor execution** of an on-going project/process/system

Performance expression - Proposition

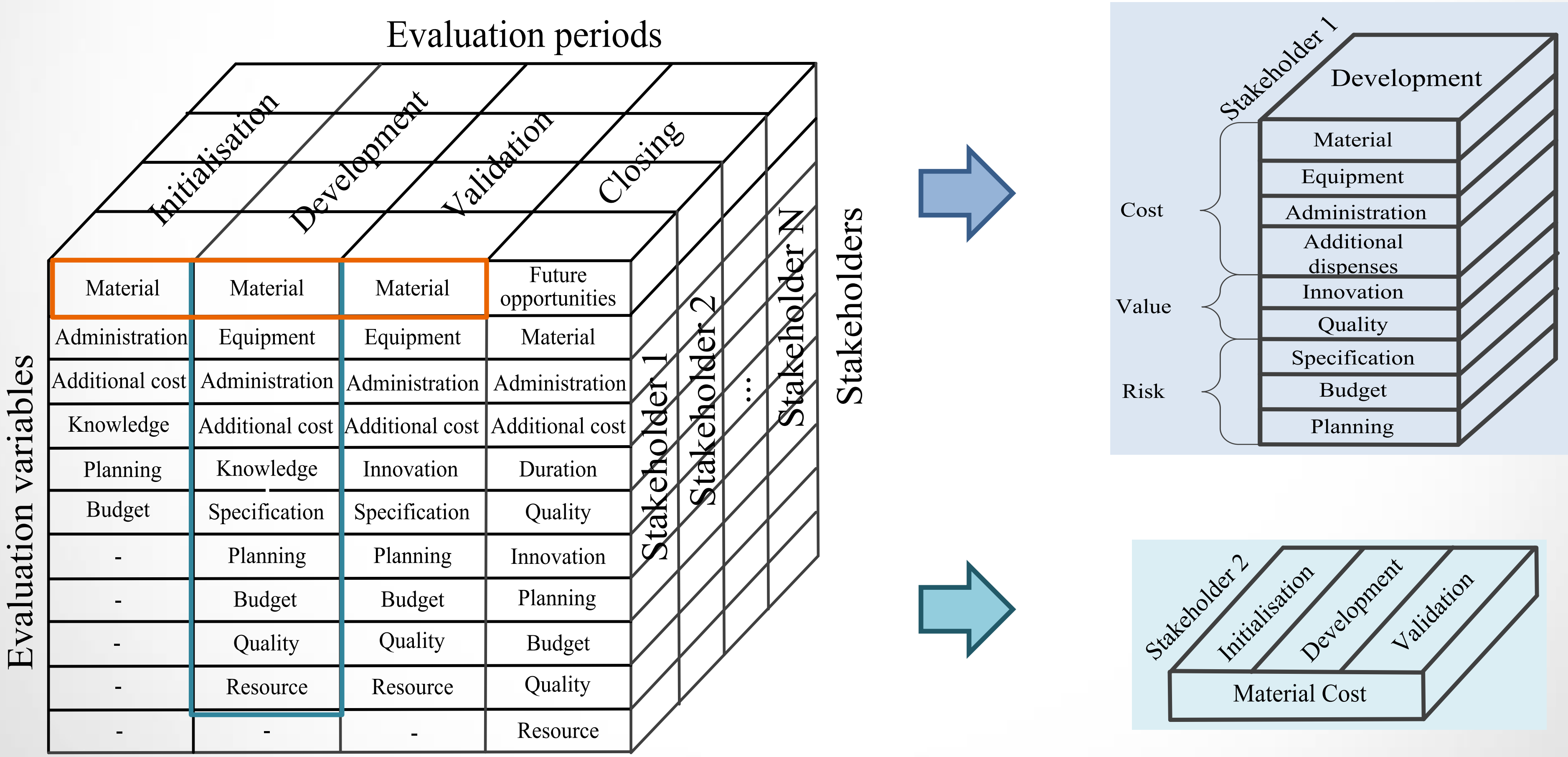
Industrial performance (P) must be comprehensively identified from three perspectives:

- **Stakeholders (S)**: a set of viewpoints from selected stakeholders
- **Evaluation periods (T)**: an instant, a life cycle phase or the whole project period
- **Evaluation variables (v)**: a set of components that are used as elementary performance measures

$$\mathbf{P} = (\mathbf{S}, \mathbf{T}, \boldsymbol{v}) \qquad \text{with } v \in B, C, V, R \ldots$$

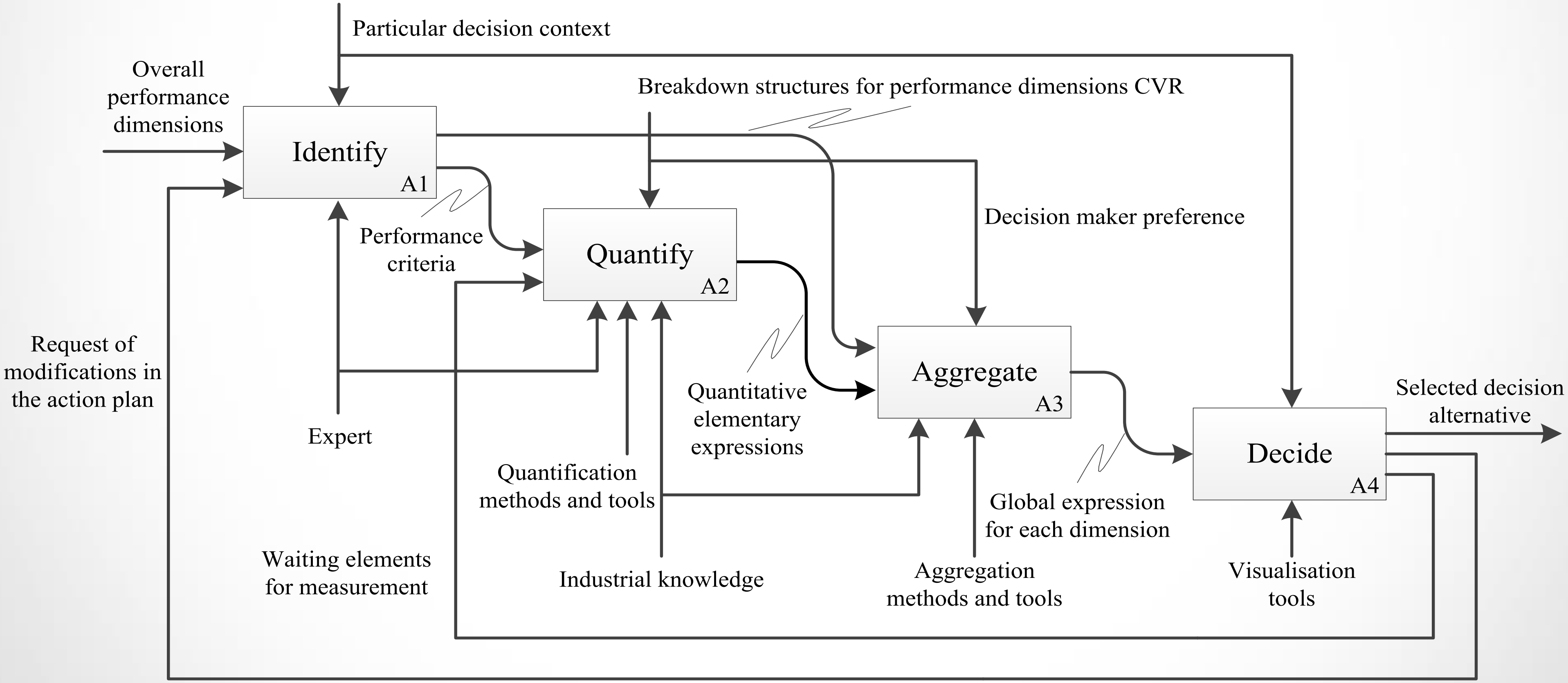


Performance expression - Illustration



- Copes with the **multidimensional** and **relative** characteristics of industrial performance
- Proposes a **flexible** structure that can be adapted to the particular decision context

Performance evaluation process

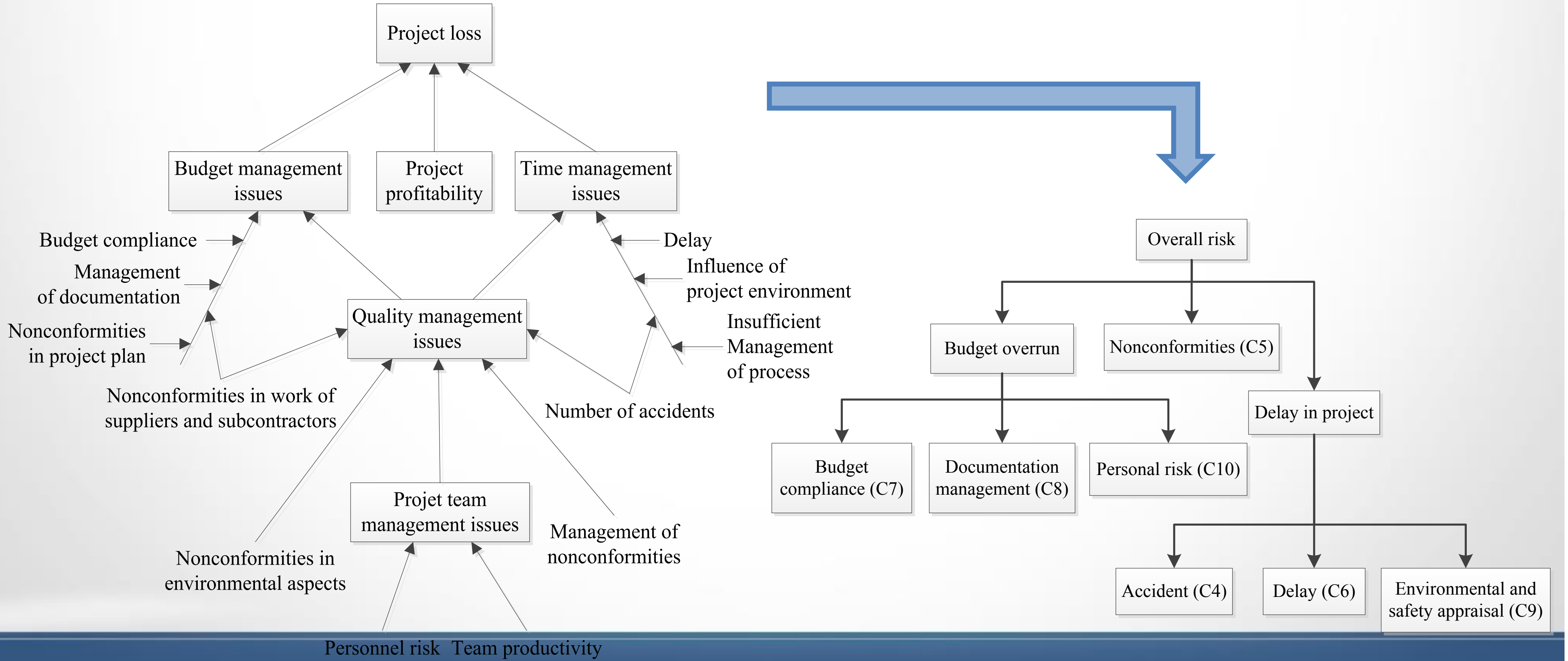


The methodology is a set of tools and methods which provides guidelines to decision makers in performance evaluation for the purpose of objective achievement

Experimental application - 1

Performance evaluation of three construction projects during the implementation stage to make decision on the allocation of enterprise resources

❖ **Breakdown analysis**



Experimental application - 2

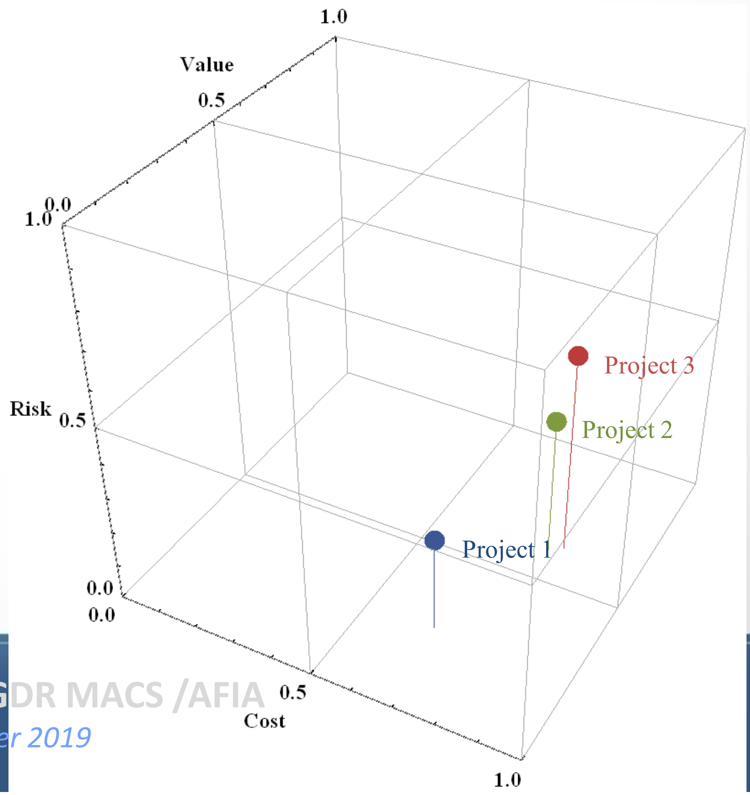
❖ Aggregation operation

	Cost variables		Value variables			Risk variables		
	Estimated expenditures	Additional costs	Budget management	Profitability	Quality management	Budget overrun	Nonconformities	Delay in project
Project 1	0.74	0.41	0.42	0.33	0.26	0.28	0.70	0.47
Project 2	0.82	0.67	0.60	0.60	0.63	0.41	0.50	0.41
Project 3	0.85	0.66	0.97	0.73	0.69	0.66	0.60	0.56
v_i	0.86	0.14	0.11	0.63	0.26	0.52	0.14	0.34
I_{ij}	I_{12}	-	I_{12}	I_{13}	I_{23}	I_{12}	I_{13}	I_{23}
	0.17		0.25	0.51	0.56	0.15	0.75	0.31

❖ Overall performance expressions

	Project 1	Project 2	Project 3
Overall cost	0.67	0.79	0.81
Overall value	0.25	0.60	0.63
Overall risk	0.27	0.40	0.57

❖ Graphical decision support



Conclusions

❖ Overall performance of a project/process/system can be managed by evaluating four dimensions: benefit, cost, value and risk (BCVR)

❖ BCVR based methodology to model, measure and evaluate the overall industrial performance for decision support

- Considers the **multi-dimensionality** and **relativeness** aspects of industrial performance
- Integrates the four selected assessment axes into a **common framework**
- Proposes an **efficient** and **pragmatic** methodology with global structure and detailed operations
- Proposes a **visualisation means** to support decision makers in evaluating the different scenarios

Perspectives

- To develop an IT tool to allow automated computation regarding the various operations of the whole evaluation process
- To extend the aggregated overall performance expressions with tolerable levels of cost, value and risk
- To validate and improve the proposed methodology with different cases in other decision making contexts
  - Product/service design
  - Process planning
  - Project management
  - Control of production systems

Thank you for your attention!

Questions ?