SoSECIE Webinar

Welcome to the
2021 System of Systems Engineering Collaborators Information Exchange (SoSECIE)

We will start at 11AM Eastern Time

You can download today's presentation from the SoSECIE Website:

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NDIA System of Systems SE Committee

- **Mission**
  - To provide a forum where government, industry, and academia can share lessons learned, promote best practices, address issues, and advocate systems engineering for Systems of Systems (SoS)
  - To identify successful strategies for applying systems engineering principles to systems engineering of SoS
- **Operating Practices**
  - Face to face and virtual SoS Committee meetings are held in conjunction with NDIA SE Division meetings that occur in February, April, June, and August

NDIA SE Division SoS Committee Industry Chairs:
Mr. Rick Poel, Boeing
Ms. Jennie Horne, Raytheon
OSD Liaison:
Dr. Judith Dahmann, MITRE

Simple Rules of Engagement

- I have muted all participant lines for this introduction and the briefing.
- If you need to contact me during the briefing, send me an e-mail at sosecie@mitre.org.
- Download the presentation so you can follow along on your own
- We will hold all questions until the end:
  - I will start with questions submitted online via the CHAT window in Teams.
  - I will then take questions via telephone; State your name, organization, and question clearly.
- If a question requires more discussion, the speaker(s) contact info is in the brief.

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2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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October 19, 2021
Resilience in Systems of Systems: Electrified Transport Systems
Pontus Svenson, Kerstin Eriksson, and Sara Janhäll

November 2, 2021
Conceptual Models to Support Reasoning in Early Phase Concept Evaluation – a Subsea Case Study
Siv Engen

November 16, 2021
A Design Method for Collaborative Systems of Systems Applied to Metropolitan Multi-Mode Transport System
Pontus Svenson, Frida Reichenberg, and Jakob Axelsson

November 30, 2021
Should I Stay or Should I Go? How Constituent Systems Decide to Join or Leave Constellations in Collaborative SoS
Pontus Svenson and Jakob Axelsson

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2021-2022 System of Systems Engineering Collaborators Information Exchange Webinars

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December 14, 2021
A Heterogeneous Autonomous Collaborative System for Powerline Inspection Using Human-Robotic Teaming
Srikanth Vemula, Jovany Avila, and Michael Frye

January 11, 2022
Approach for Complex Deterministic and Nondeterministic Systems (ACDANS)
Dr. Paul C. Hershey

January 25, 2022
Applying SoSE in Healthcare: the case for a soft systems methodology approach to Digital-first Primary Care
Iqra Shahzad, Melanie King, and Michael Henshaw

February 22, 2022
System of Systems Engineering Conference and Industry Perspectives and the Role of System of Systems Engineering Conference: INCOSE and IEEE Collaborations
Paul Hershey, Garry Roedler, and Mo Jamshidi

May 3, 2022
Cross-Domain Stakeholder-Alignment in Collaborative SoS – Lego Serious Play as a Boundary Object
Johann Shuetz, Julia Koehlke, and Sebastian Hanna

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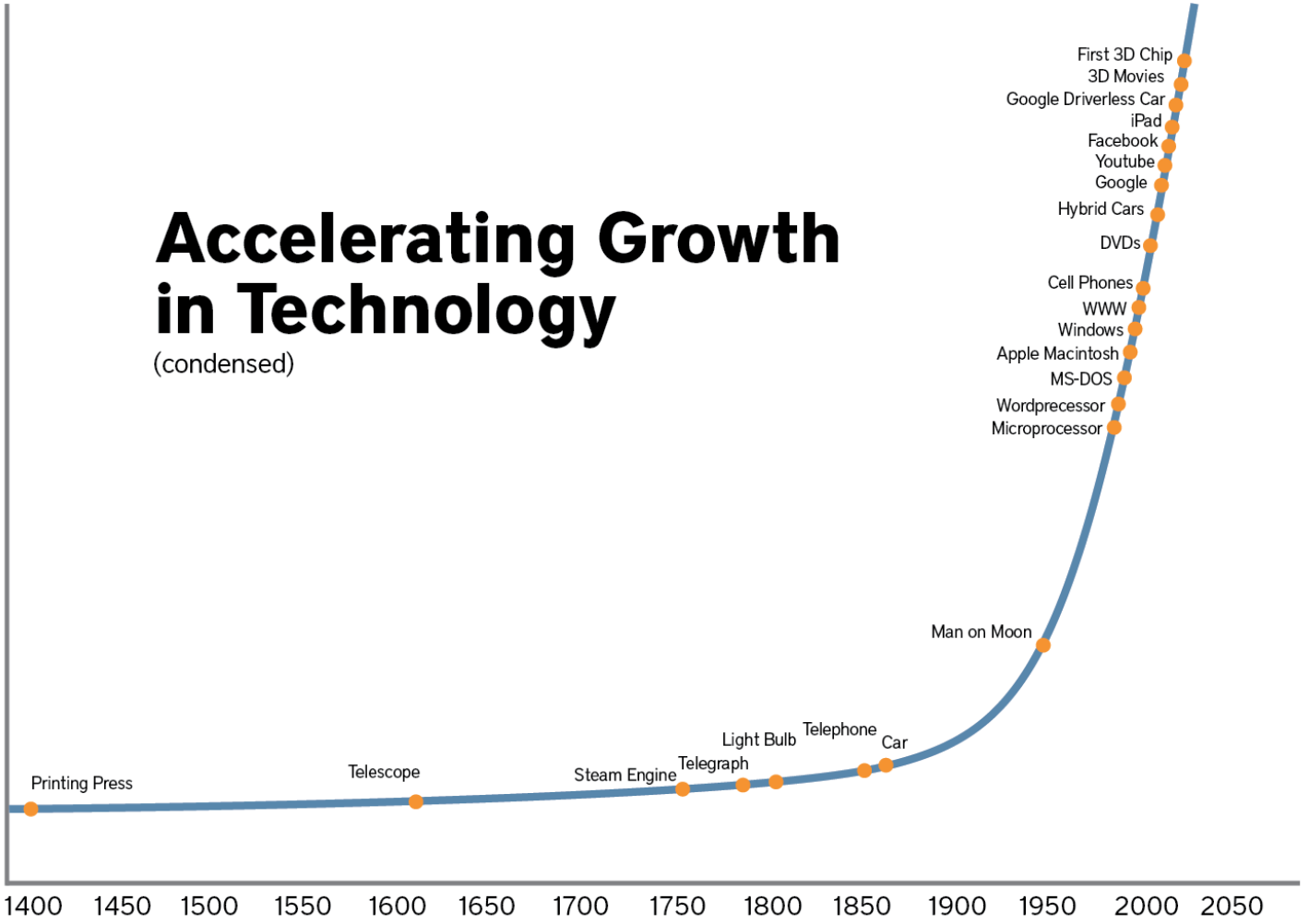
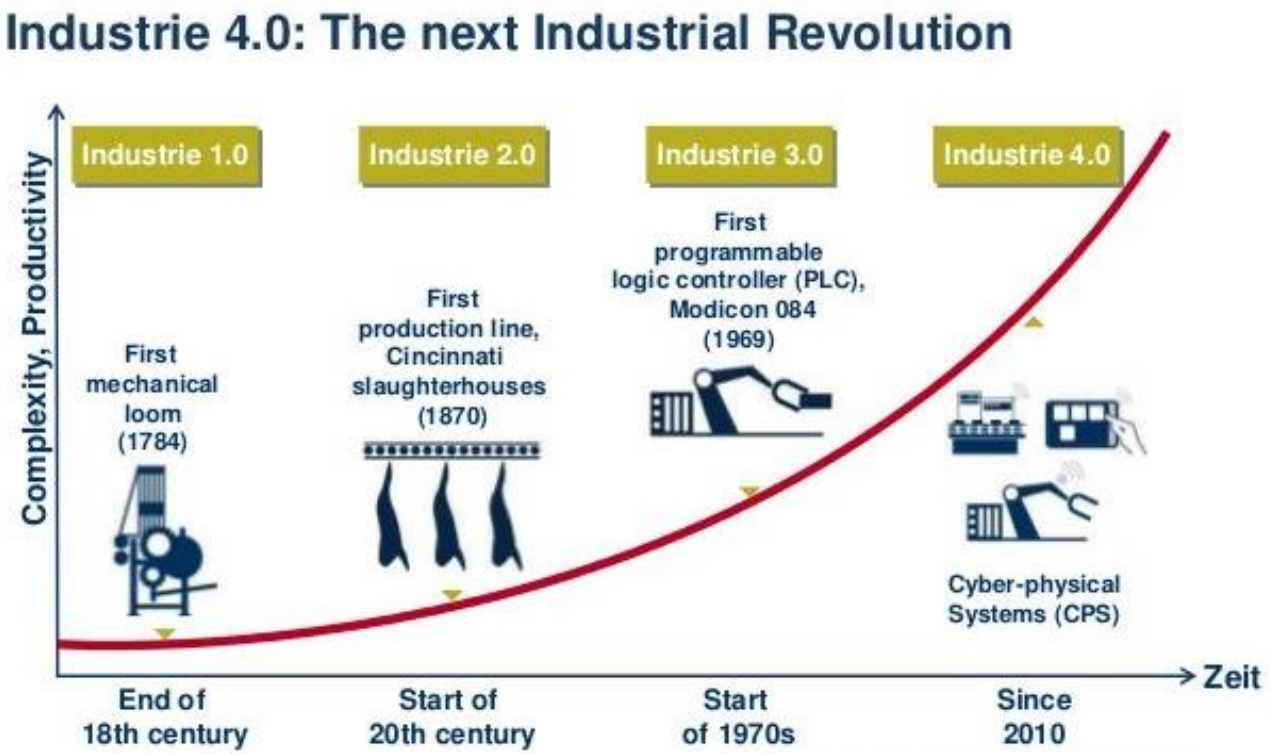
Towards the Definition of a Strategic Complexity Management Framework for Complex Industrial Systems

Lucas Freund, Salah Al-Majeed & Alan Millard

Technology progresses exponentially…



...and Industry becomes exponentially complex!



Being able to manage complexity allows to...

...reduce overall cost of production

...achieve higher product variability

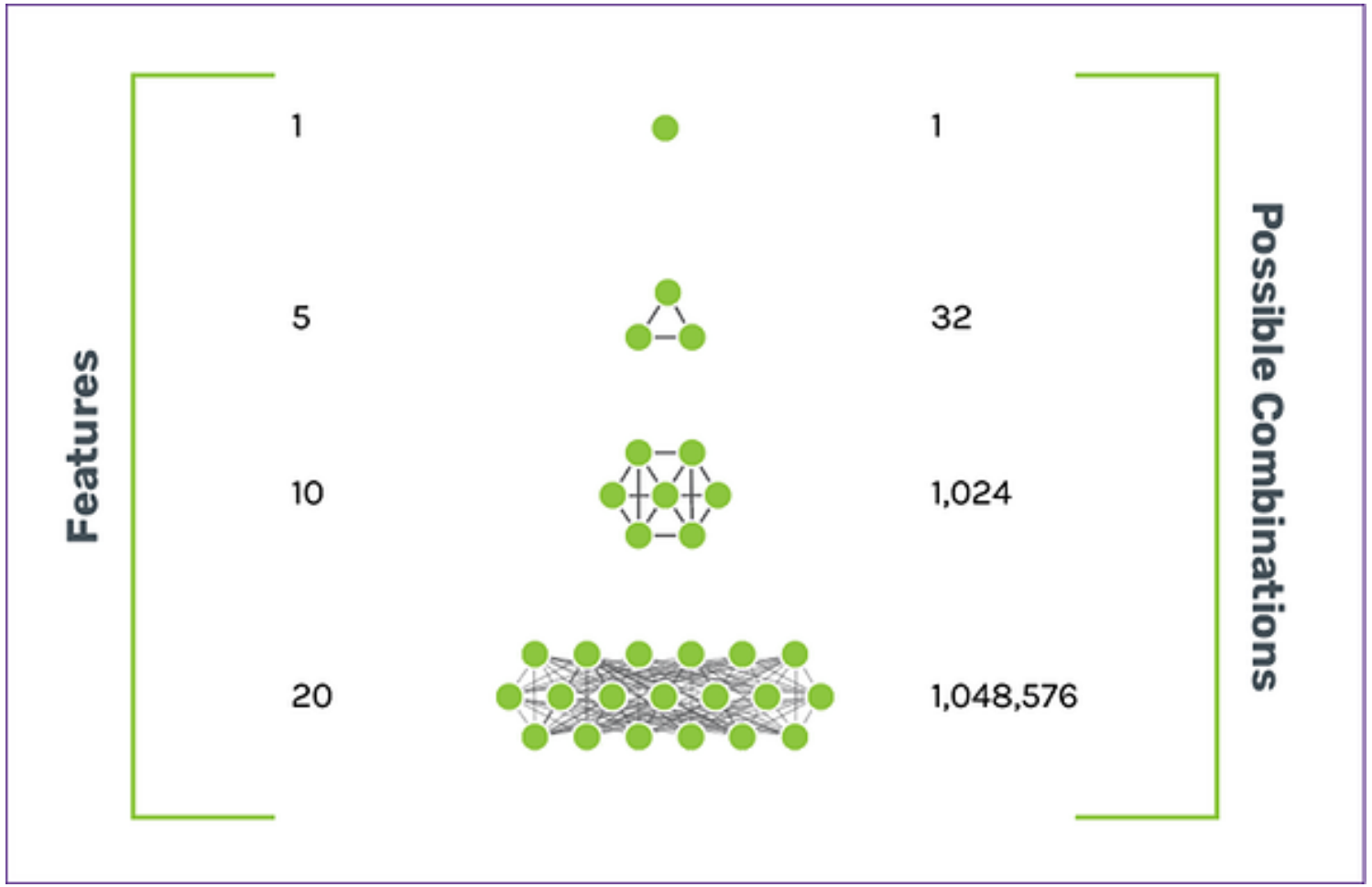
...integrate more advanced production systems

...create a safer production environment

...ensure less production downtime

and many more benefits!

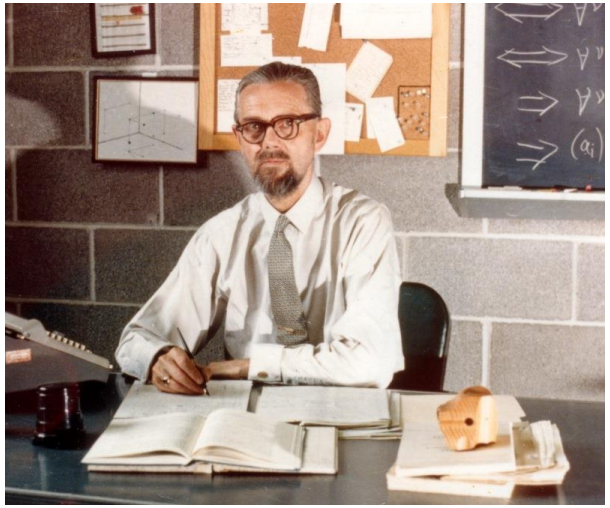
One example: Product features & combinations



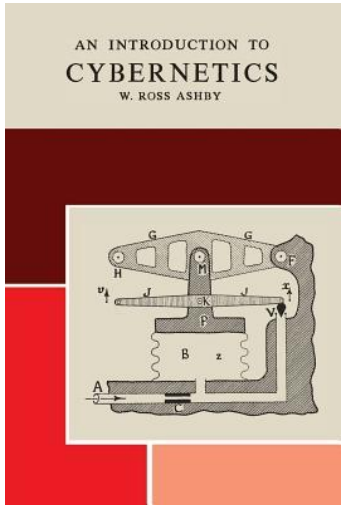
Ashby´s Law of Requisite Variety: The first law cybernetics

W. Ross Ashby was a British cyberneticist and psychologist who, during the 1960s, proposed a law with regards to levels of variety and regulation within biological systems. In his words:

When the variety or complexity of the environment exceeds the capacity of a system (natural or artificial) the environment will dominate and ultimately destroy that system.



Or in more simpler words:



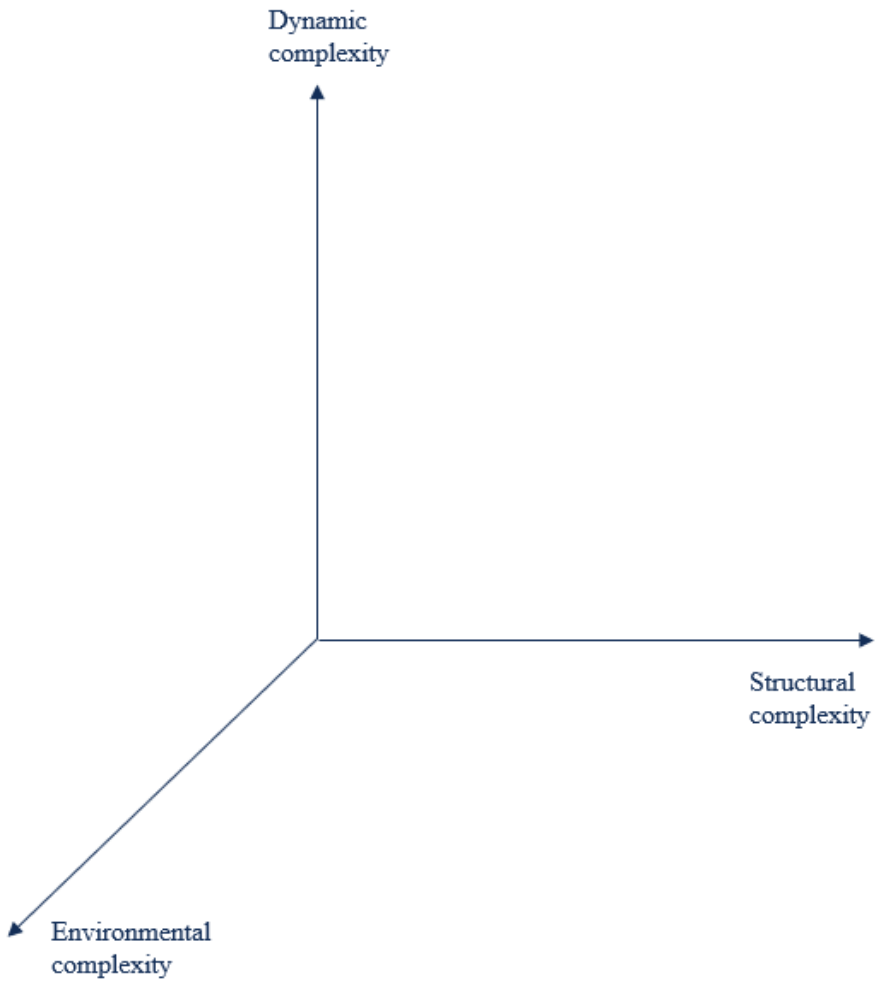
In order to deal properly with the diversity of problems the world throws at you, you need to have a repertoire of responses which are (at least) as nuanced as the problems you face.

Defining Complexity

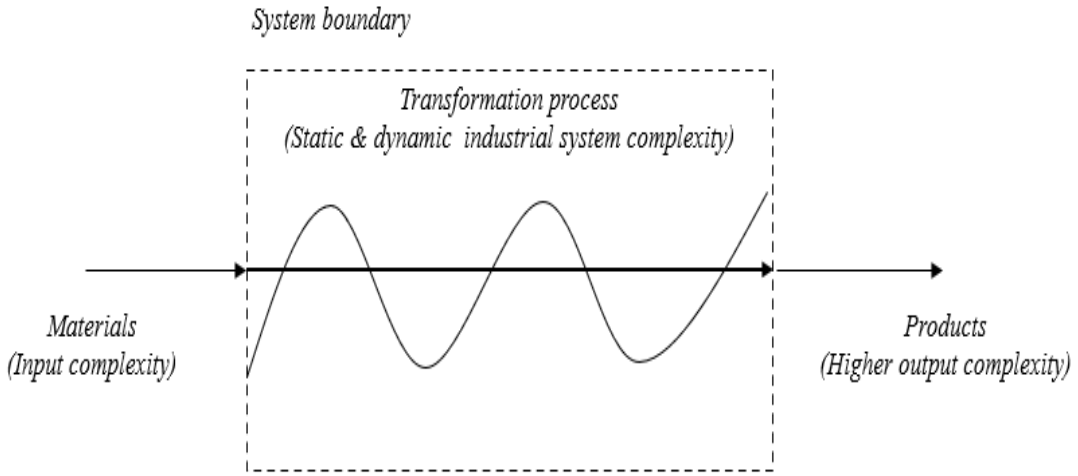
What does Complexity mean?

Complexity often has complex definitions lacking applicability.

To avoid this we define three complexity dimensions:



Static & Dynamic Complexity in the Manufacturing Process



- From a complexity engineering perspective, the systematic application / management of structural and dynamic system complexity enables the transformation process of a lower input complexity (materials) to a higher output complexity (product)

Consequently: More complex manufacturing systems / products require a higher output complexity and thus the application of more complexity in the transformation process.

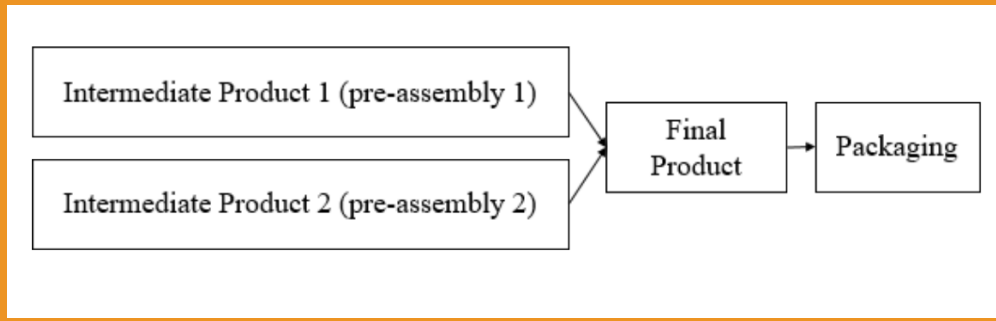


Fig: Example: Simple 2-Step Production Line

Complexity Dimensions

Structural (S)

The static, time-independentarchitectural layout of a manufacturing process represented by *machines*, operations, their connections via links, and their level of interconnectedness.

Dynamic (D)

Information in a system is regarded in the context of the SCM as a measure of entropy and disorder in the form of uncertainty in the system. A low entropy value implies low uncertainty and vice versa. The higher the disorder, the higher the entropy. If the system is well ordered, it is easy to understand, predict its behavior, and to describe and communicate it.

Environmental (E)

Three main environments can be identified: Task environment (all aspects relevant to setting goals and achieving them), technical environment (location where companies produce their products and services), institutional environment (formal rules and beliefs of the company).

Main „Symptoms“ of Information Complexity

Information complexity or “entropy” can be regarded as the main barrier to achieve a systems target function.

It causes:

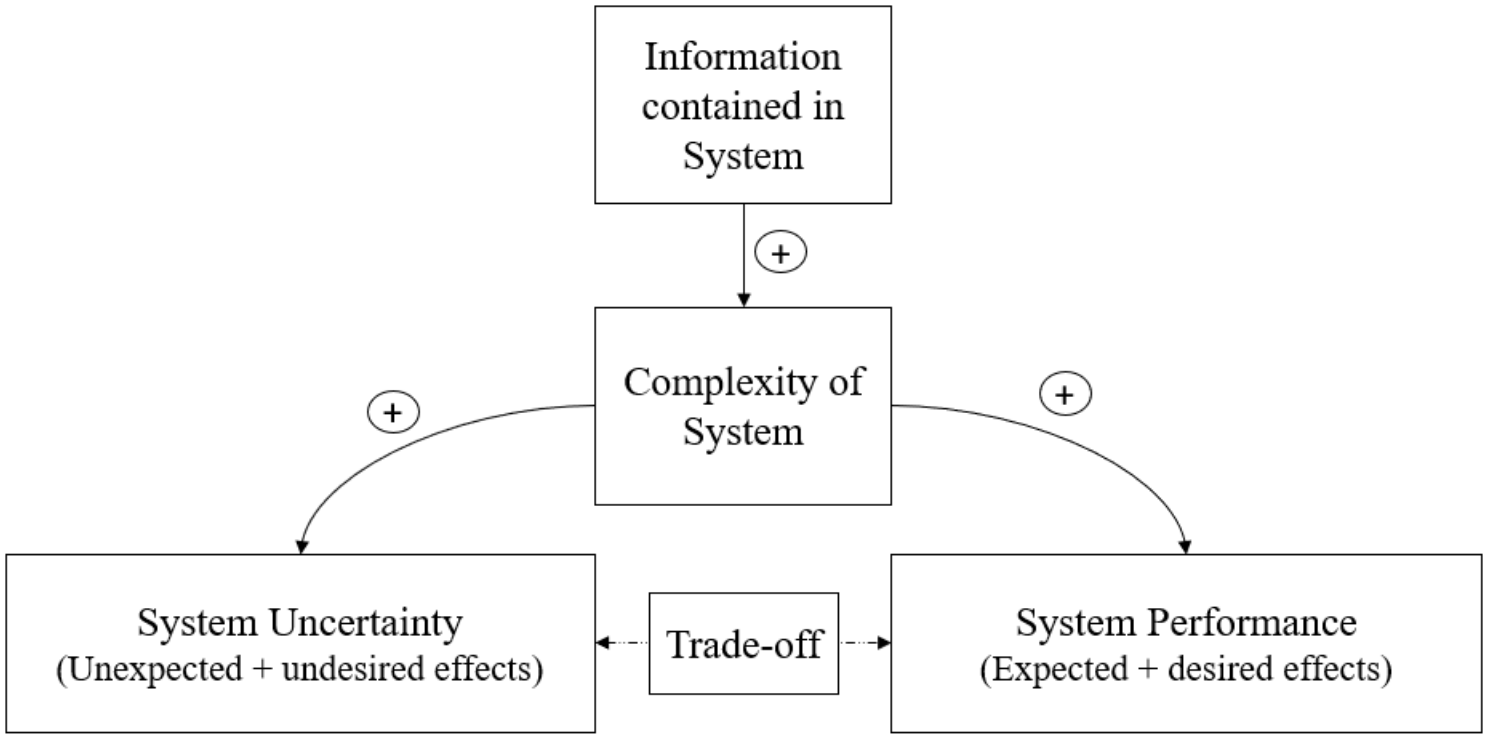
- System volatility
- Random system breakdowns
- ”Unexplainable” system errors
- Decision-making problems

→ Can be regarded as a central barrier to a functioning system

Main paradoxon:

More enabling features (e.g more information circulating in a system) lead to a less stable system

Hypotheses concerning Impact of Complexity on Systems



*Freund, Lucas, and Salah Al-Majeed. "Hypotheses concerning complexity surges in modern and future industrial information systems ." Logforum 17.3 (2021): 1. DOI: 10.17270/J.LOG.2021.3.1
And
L. Freund and S. Al-Majeed, "Cyber-Physical Systems as Sources of Dynamic Complexity in Cyber-Physical-Systems of Systems," 2020 International Conference on Innovation and Intelligence for Informatics, Computing and Technologies (3ICT), 2020, pp. 1-5, doi: 10.1109/3ICT51146.2020.9312015
And
L.Freund, S.Al-Majeed and A. Millard, "Complexity Space Modelling for Industrial Manufacturing Systems", International Journal for Computing and Digital Systems, 2021 – to be published

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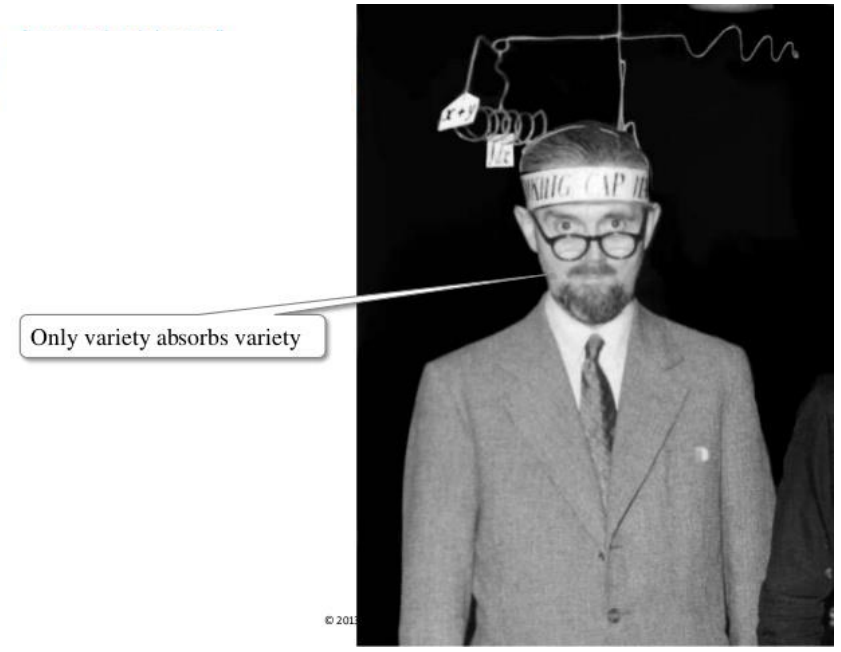
Back to Ashby´s Law of Requsite Variety

What does this mean for businesses?

For organisations and teams, Ashby's law effectively means that they must always remain more flexible with their approaches to management, strategy and operation than the levels of structure and complexity within their systems and operating environment.

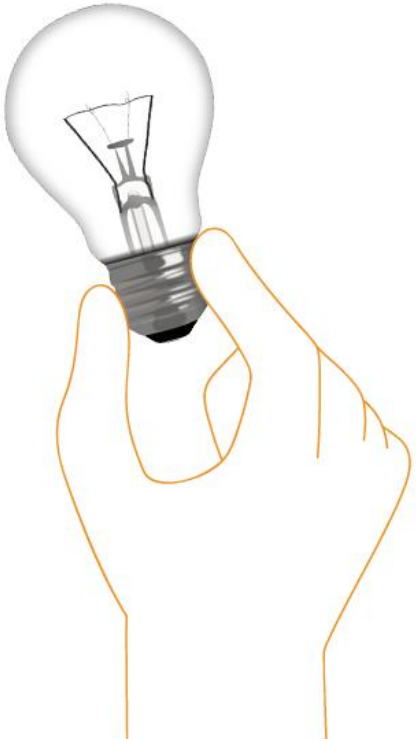
-The more variable the operational environment, the more flexible the organisation and its internal systems need to be.

→ Management must adapt with new strategies!



Research Vision

Develop **strategic management tools** to better **manage complexity** of current and future **industrial systems**.



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Research Vision: Managing & improving complexity

Increasing complexity leads to the VUCA environment!

VUCA

Complexity
Multiple key decision factors

Volatility
Rate of change

Ambiguity
Lack of clarity about meaning of an event

Uncertainty
Unclear about the present

A highly difficult environment for decision-makers!

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Strategic Complexity Management

Definition: Strategy

Strategy is a central concept for the field of strategic management, as it directly concerns the planning process of the deployment of resources to achieve a given set of objectives.

Strategies shall be defined as a means for companies to generate a competitive advantage. In a business context, strategies are assumed to not be absolutely formulated or formed, also are they not purely realized or intended.

Companies do not only create new strategies but also modifying existing ones, based on facts as well as on the intuition and experience of senior managers.

Strategic Management & Strategic Management Dimensions

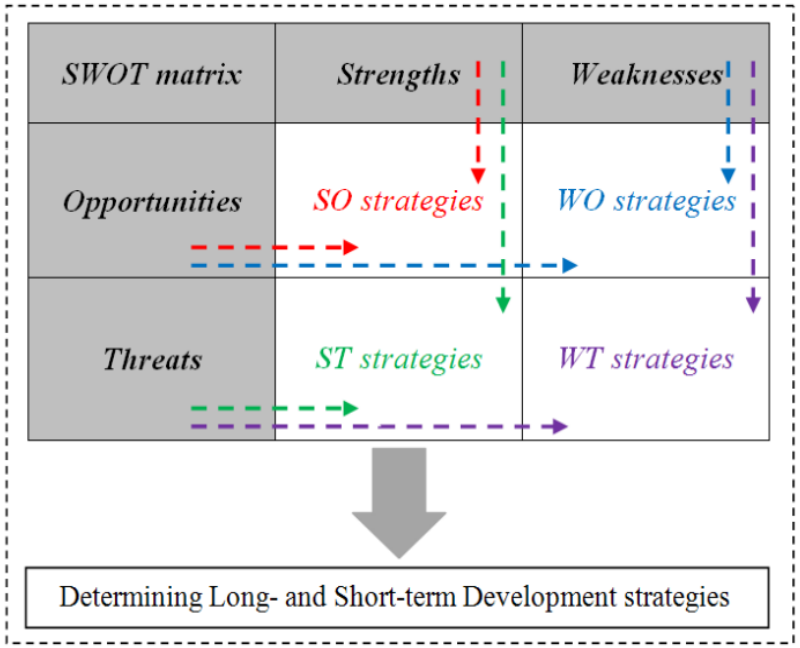
Strategic management as a discipline focuses on the development and implementation of strategies.

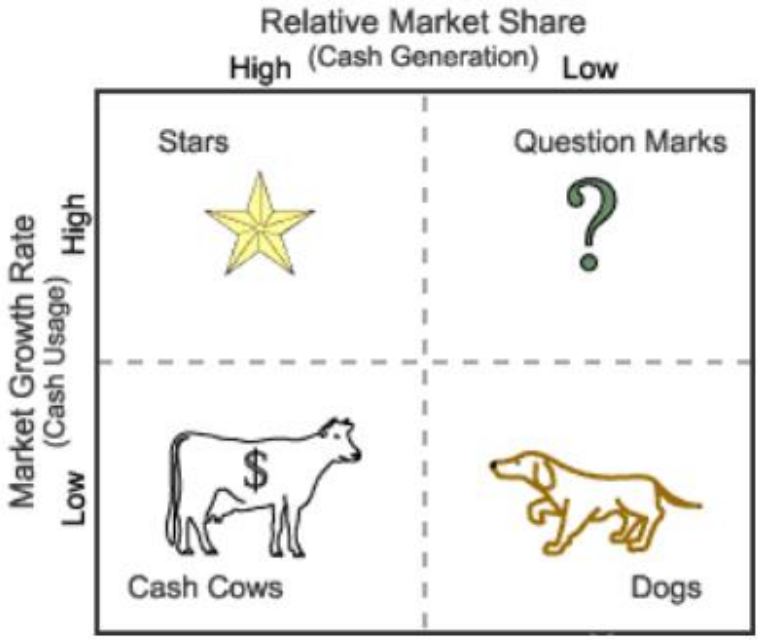
It focuses on the direction of organizations, companies and businesses and the application of theories, frameworks, tools, and techniques to assist the decision-makers in the planning, thinking and design process of strategy for organizational purposes.

It has two dimensions:

Strategic Management	
Internal perspective	*External perspective*
Resource & capability-based view	**Environmentally-based view**

Strategic Management Tools, like SWOT & BCG Matrix





Widely & sucessfully used by most decision-makers

But: Often very old (SWOT was invented 1960, BCG 1970)

Tools for complexity management are needed!

Managing & improving complexity

Tools for strategic complexity management can help to achieve complexity reduction!

Strategic complexity management tools are:

- *„easy“ & fast to apply*
- *focusing on strategy*
- *Big Picture*
- *making decision-making easier*
- *“Manager in Mind“*
- ***Small but powerful!***

What they achieve:

- *simplify strategy & processes*
- *allows managers to understand sources of complexity*
- *identify opportunities to simplify processes, systems and structures*
- *reveal hidden costs*
- *identify bottlenecks for value*
- ***Complexity management & reduction!***

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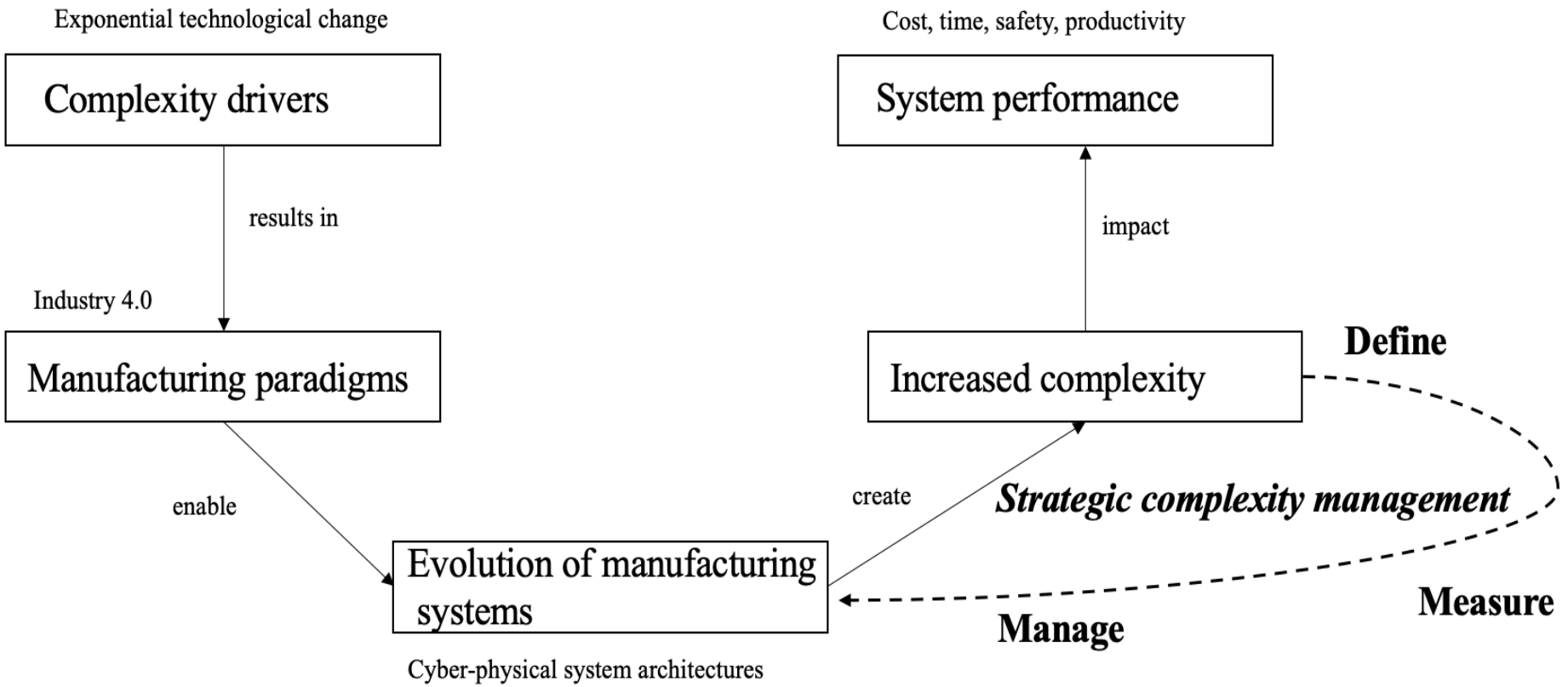
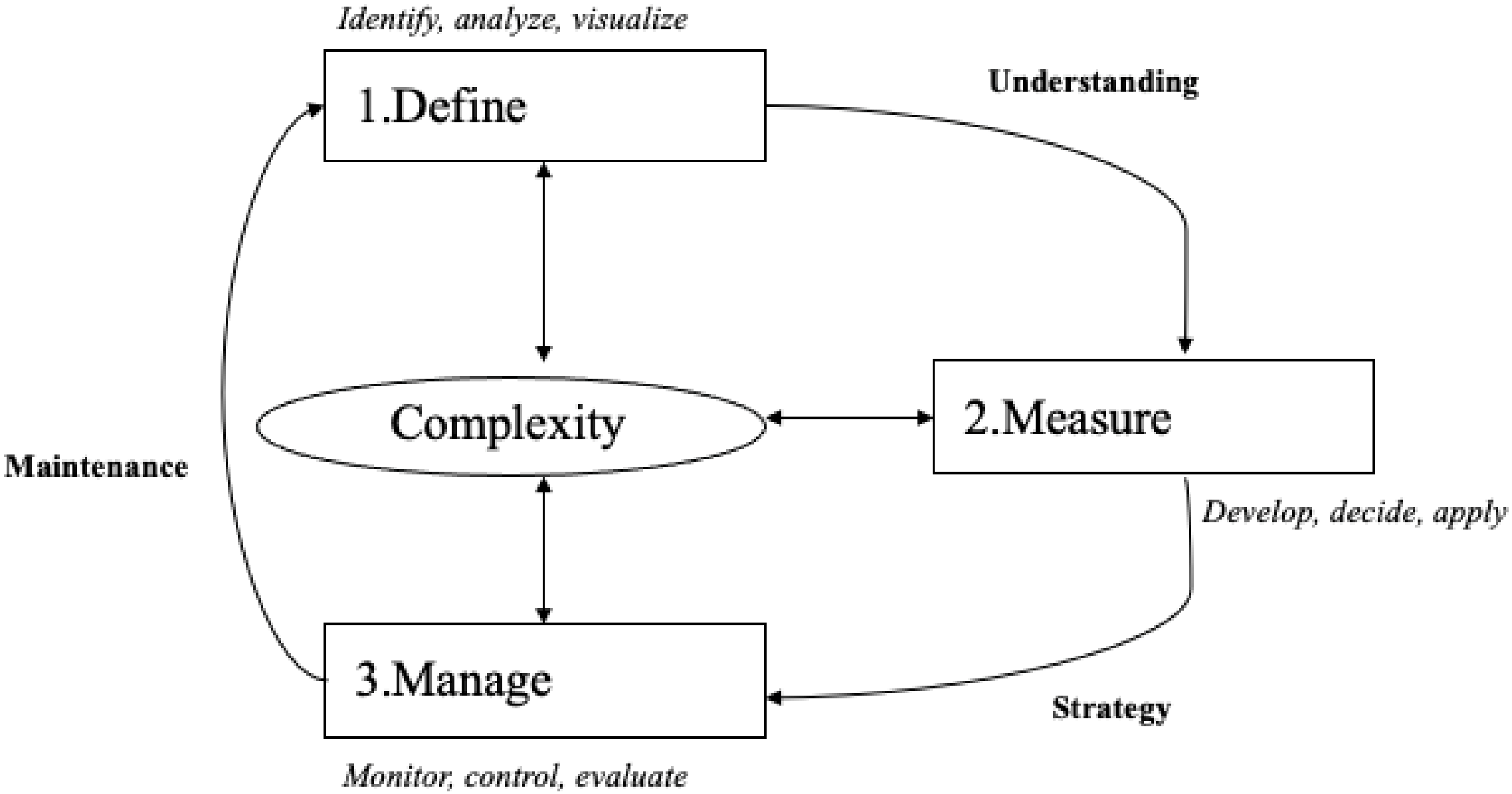
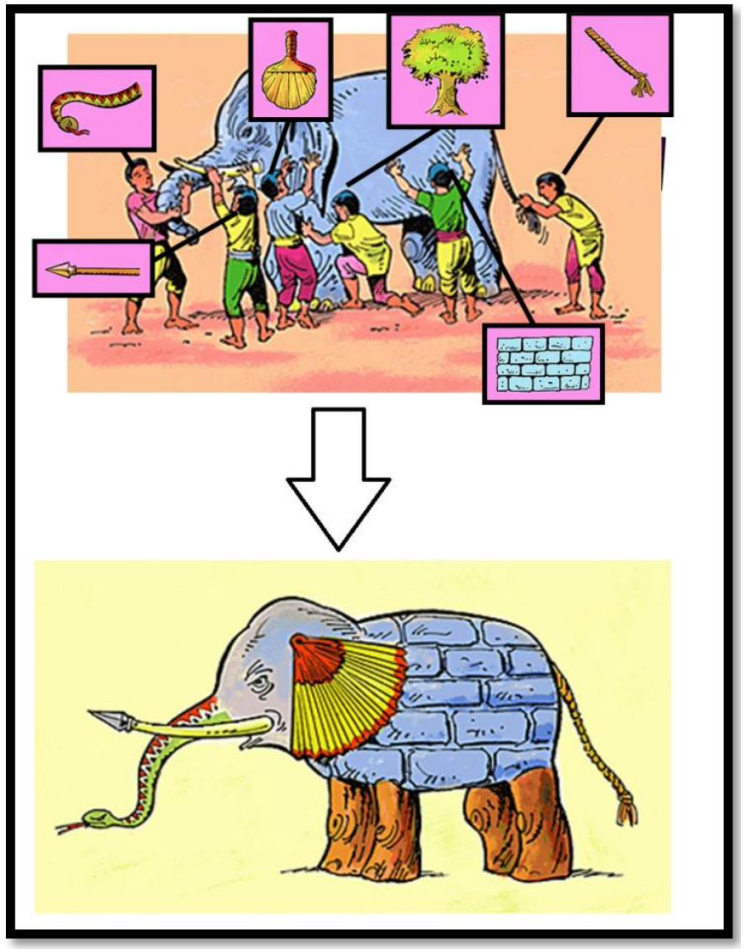
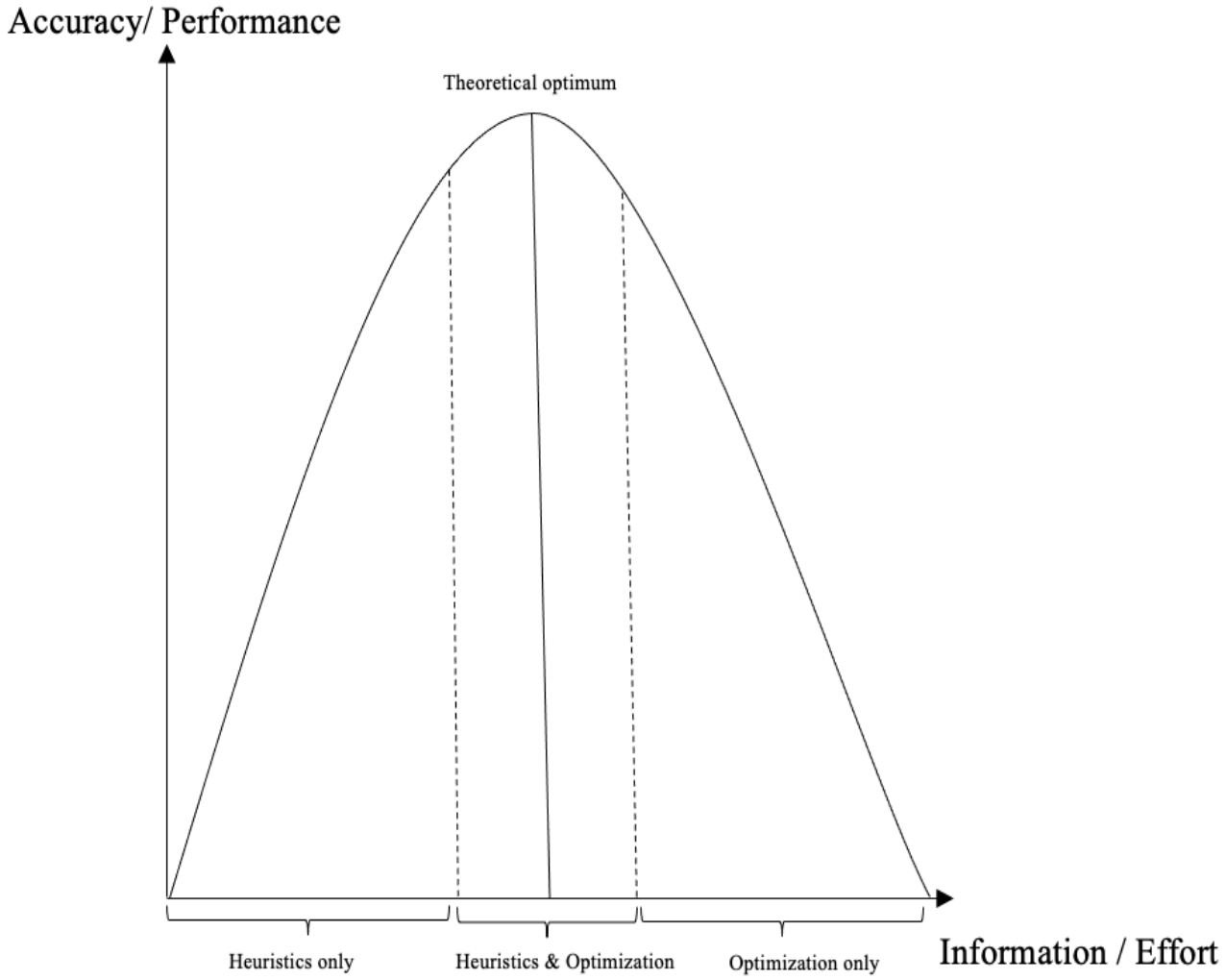
Strategic Complexity Management Cycle





Why heuristics matter

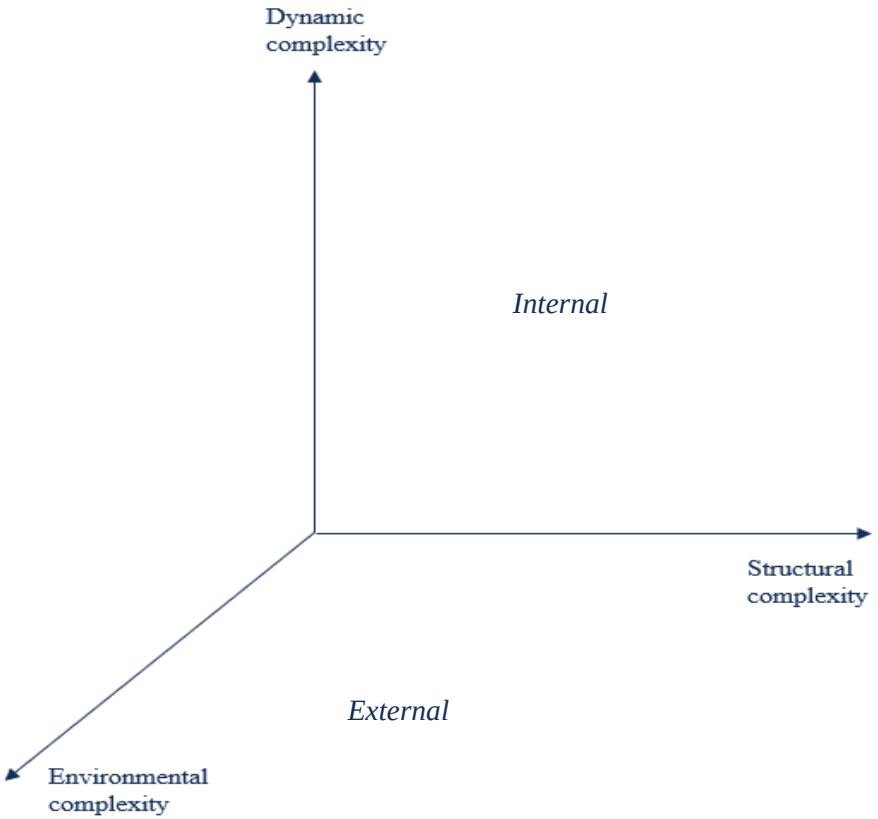


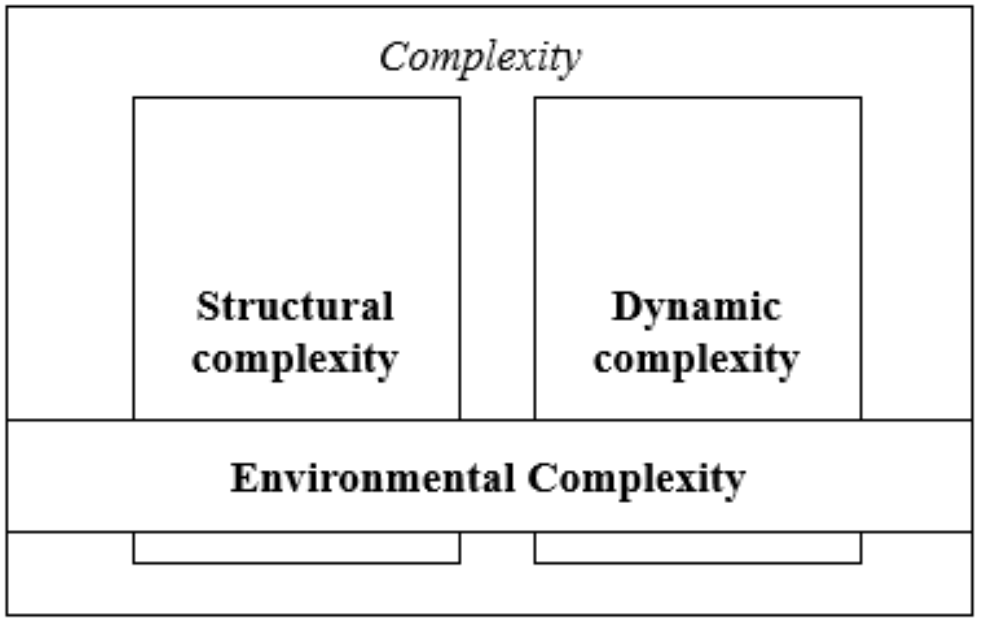


Defining Industrial System Complexity

What does Industrial System Complexity now mean?

Three complexity dimensions:





The third dimension: (External)Environmental Complexity

In contrast to the other two dimensions, environmental complexity is more difficult to define.

In general, it can be stated, that environmental complexity shall encompass the relationship of the analysed system to its system external environment and **shall refer to how different parts of the system are connected to system exterior elements.**

In the context of business and economic-driven systems three main environments can be identified:

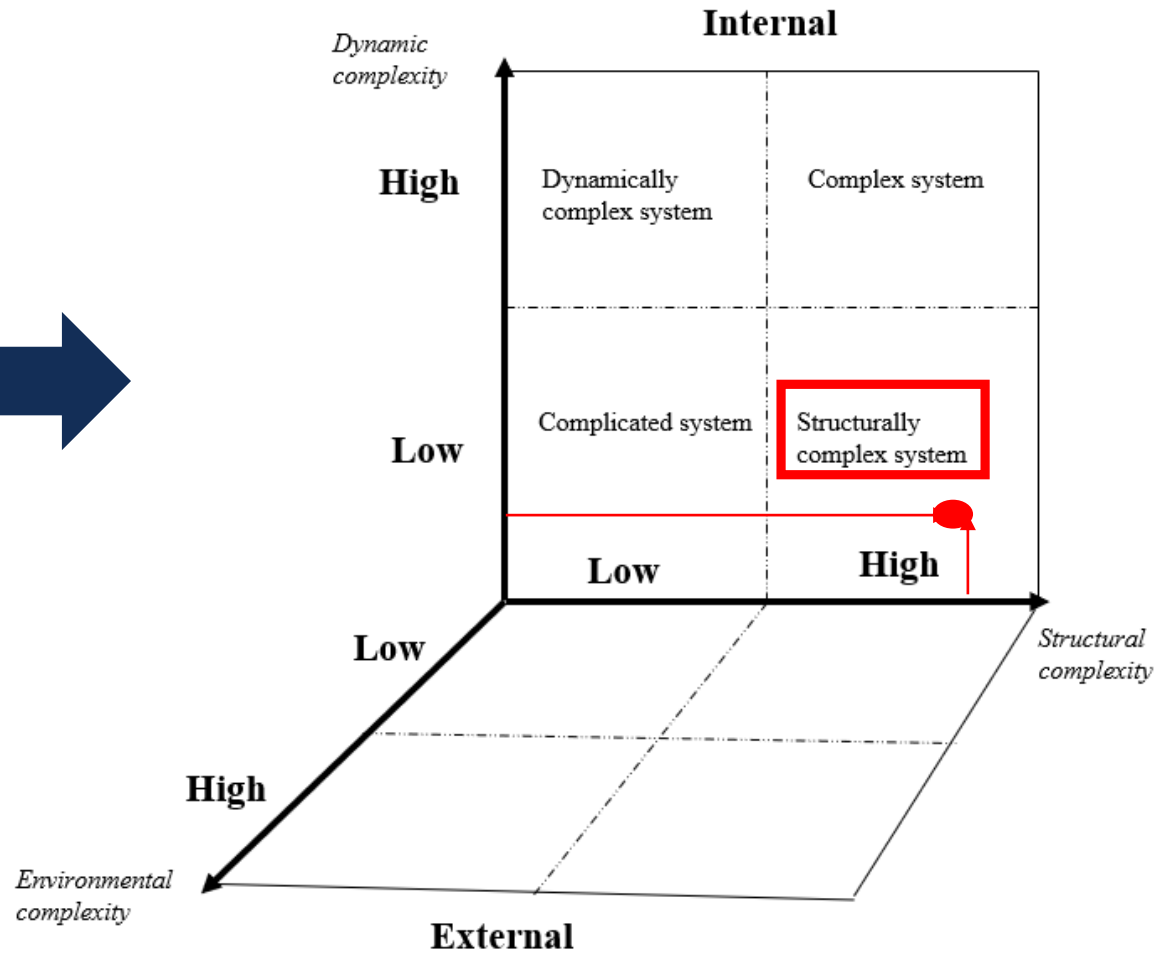
- Task environment (all aspects relevant to setting goals and achieving them)
- Technical environment (location where companies produce their products and services)
- Institutional environment (formal rules and beliefs of the company).

It shall be assumed for this dimension, that when the environment of a system is difficult to define and unstable it results a higher degree of uncertainty and complexity, since the overall information that decision-makers must process is complex, fragmented, scarce, difficult to collect or interpret

The Strategic Complexity Management (SCM) Framework: Internal Perspective

Strategic Management	
Internal perspective	*External perspective*
Resource & capability-based view	**Environmentally-based view**

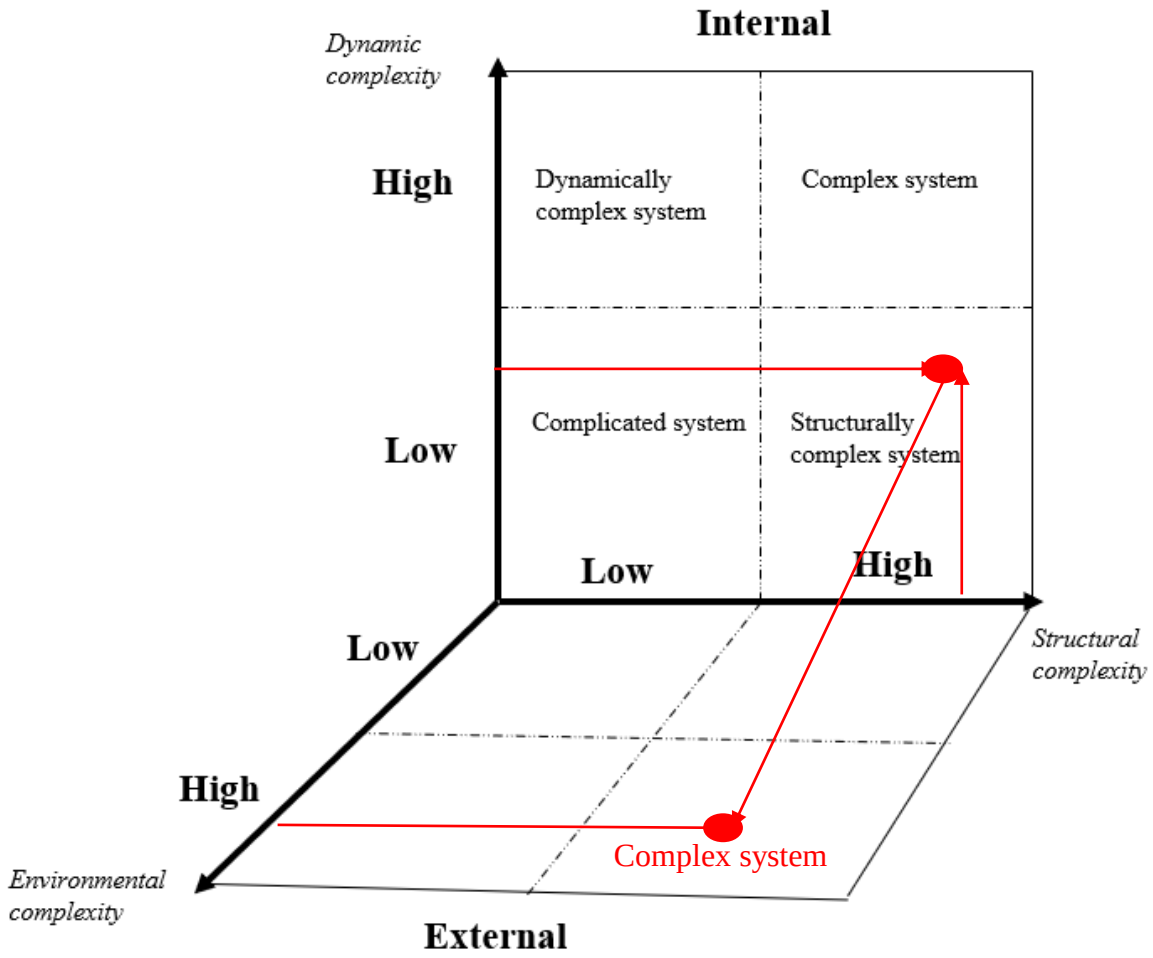
SCM Framework	
Internal perspective	*External perspective*
Resource & capability-based view	**Environmentally-based view**
Structural complexity & Dynamic complexity	**Environmental complexity**



SCM Internal Classifications

Classification	Qualification combination (S / D)	Description
Complicated system	Low/Low	Non-complex, well-understood system
Complex system	High/High	Non-linear, partially random system
Structurally complex	High / Low	Structure as main source of complexity
Dynamically complex	Low/High	Information as main source of complexity

The Strategic Complexity Management (SCM) Framework: External Perspective & Resulting System Classification

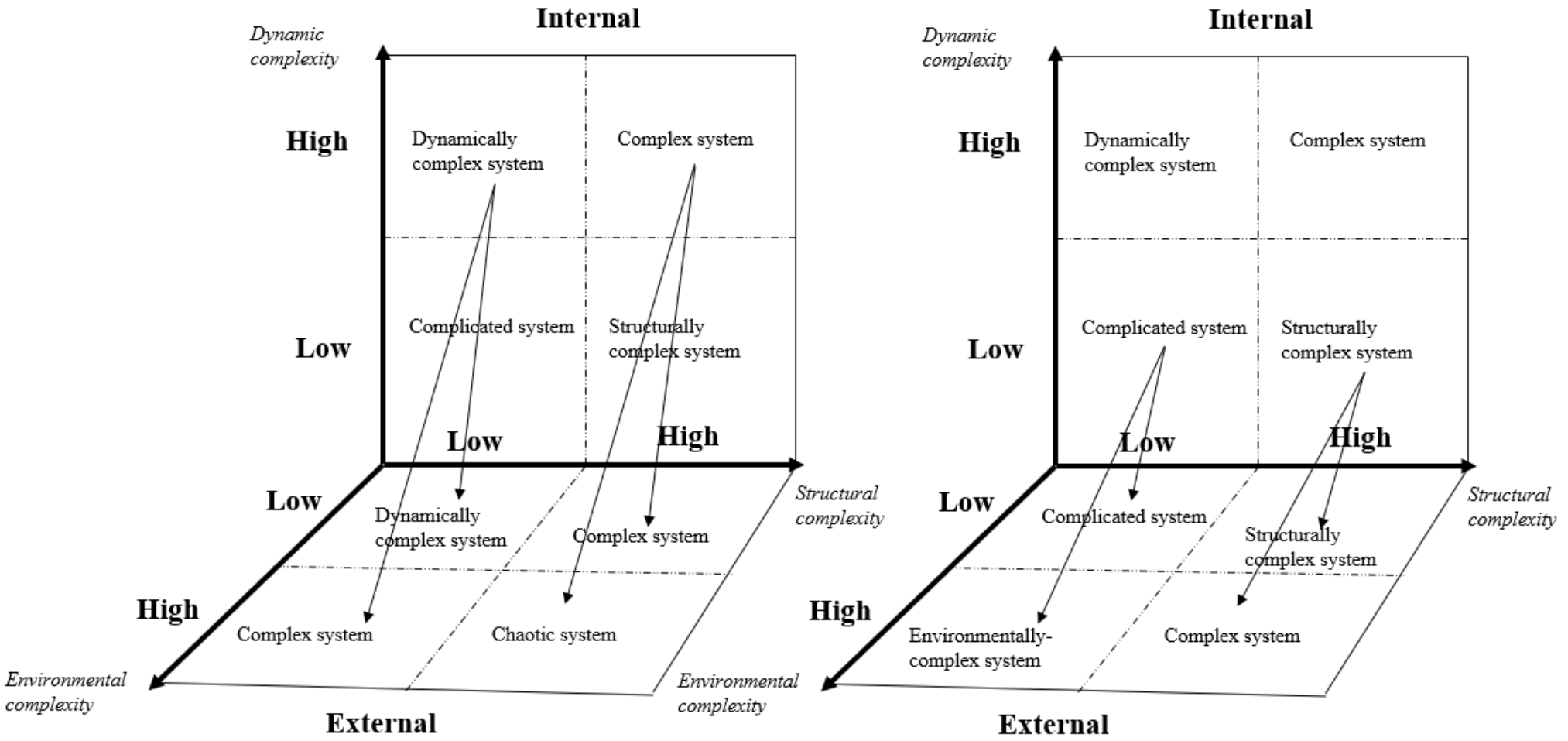


Low → classification stays the same

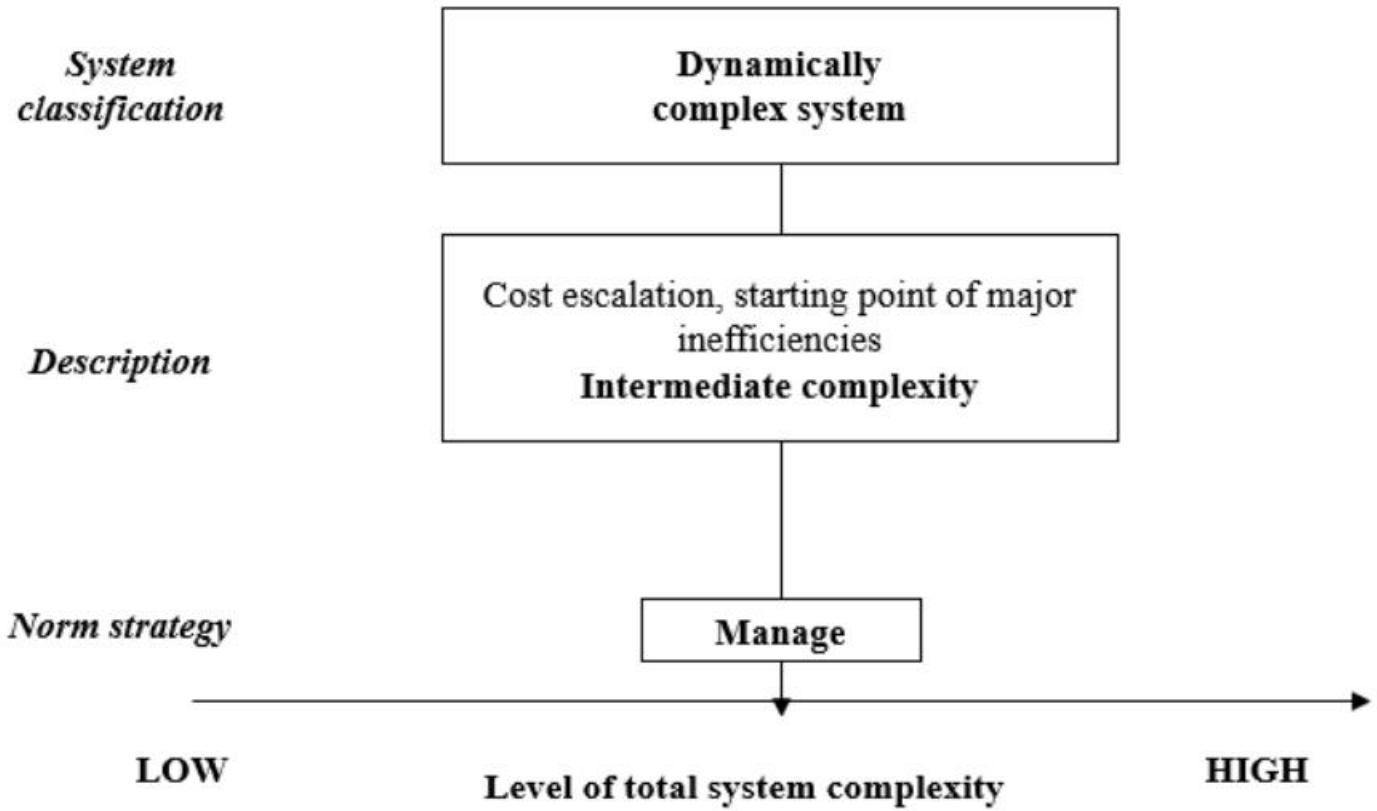
High→ classification increases

→ High/Low/High qualification leads to the system classification upgrade from „structurally complex system“ to „complex system“

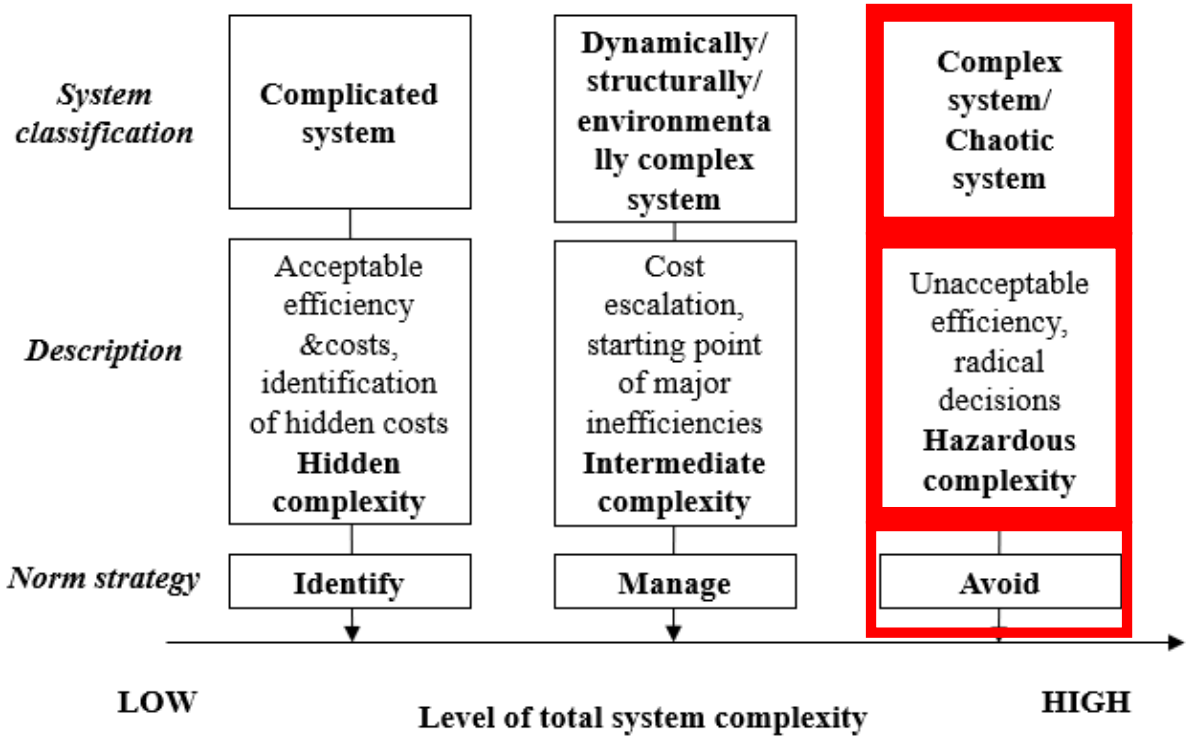
Many more SCM Combinations…



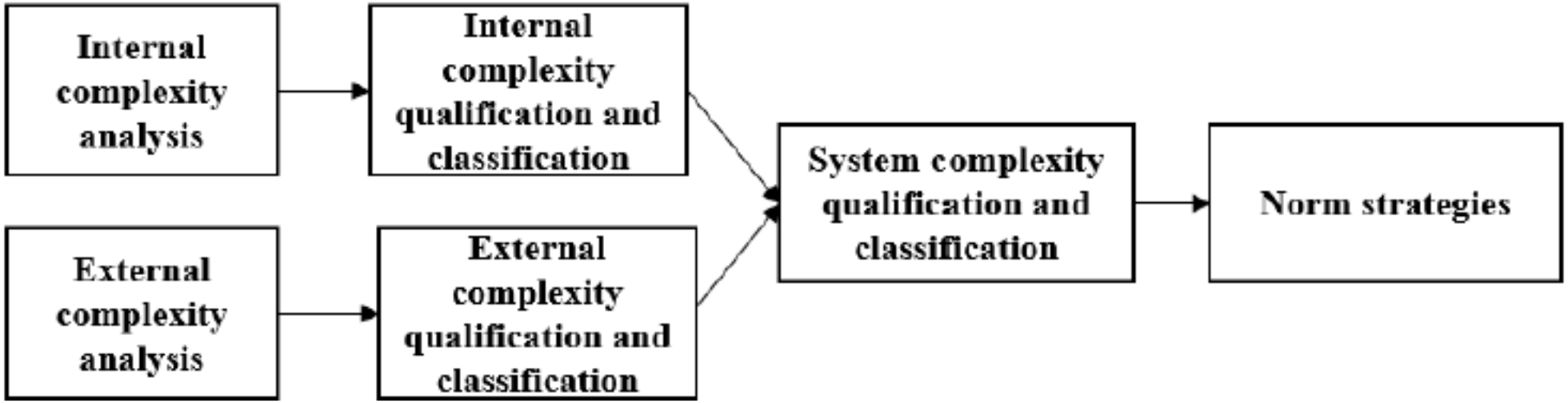
Logic of Interpretation



SCM Norm Strategies: The Meaning of the SCM Analysis



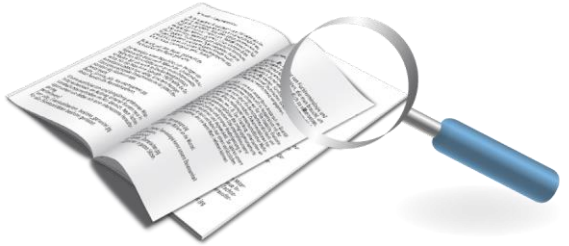
SCM Process


Internal complexity analysis
Internal complexity qualification and classification
External complexity analysis
External complexity qualification and classification
System complexity qualification and classification
Norm strategies

SCM Case Study

Case Study Methodology

Document Analysis!



Why? Some Arguments:

An **excellent starting point** to enter a research field.

Organizational documents are **reliable, objective sources of information** for case studies and are not impacted by the analysis process.

Is especially **useful for intensive studies** for producing rich descriptions of a single phenomenon e.g. a case.

Can be used as a **stand-alone method** or **can be extended** by other qualitative research methods through triangulation, like interviews.

Is actually **used by companies.**

Documents analysis is:
efficient, available, cost-effective, **unaffected by the research process**, stable and **suited for repeated reviews**, exact, **delivers fast results** and **paves the road for more participative research, like interviews or workshops.**

Information sources include:

I. Project documents (Factory layouts)
II. Project reports, including quarterly reports, midterm review
III. Calculations
IV. Facility assessment reports
V. Maintenance reports

and others (videos etc.)

Over **44 different documents received and stored** in databank!

Reviewed documents are then analyzed and interpreted for the SCM

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Our Current Database for 4 SCM projects

Document Type	SCM Dimension(s)	Amount
Production schedule	Dynamic, Environmental, Structural	17
Cost calculations	Dynamic, Environmental, Structural	3
Shop floor layouts	Structural	2
Maintenance procedures	Dynamic	10
Quality management	Structural, Dynamic	5
Material treatment	Structural, Environmental	2
Operating procedures	Structural, Dynamic	1
Supply chain	Environmental, dynamic	2
Other (videos etc.)	Dynamic, Environmental, Structural	2

Context of Case Study Example

Case Context

The SCM framework is applied to three real-world different industrial production systems (denoted as alpha, beta, gamma) of a world-market leading SME beauty & health product manufacturer.

The aim of the conducted study is to support the responsible managers of the SME in the strategic management and development process of the three production lines.

New types of products are to be manufactured in more advanced production systems that are both unknown to the managers.

In general, it can be stated, that all three production lines produce products that are of high complexity for the company. Additionally, the production lines themselves are of unprecedented size for the company.

Case Study Results

System	Qualification	Classification	Norm strategy
α	HIGH/LOW/LOW	Structurally complex	Manage
β	HIGH/LOW/LOW	Structurally complex	Manage
γ	HIGH/LOW/LOW	Structurally complex	Manage

Conclusion

All three analyzed systems are qualified as HIGH/LOW/LOW and are classified as structurally complex systems. The resulting norm strategy is defined as “manage” for all systems.

The application of the SCM framework on the production lines alpha, beta, gamma showcases that it can be meaningfully applied on the context of a real-world case.

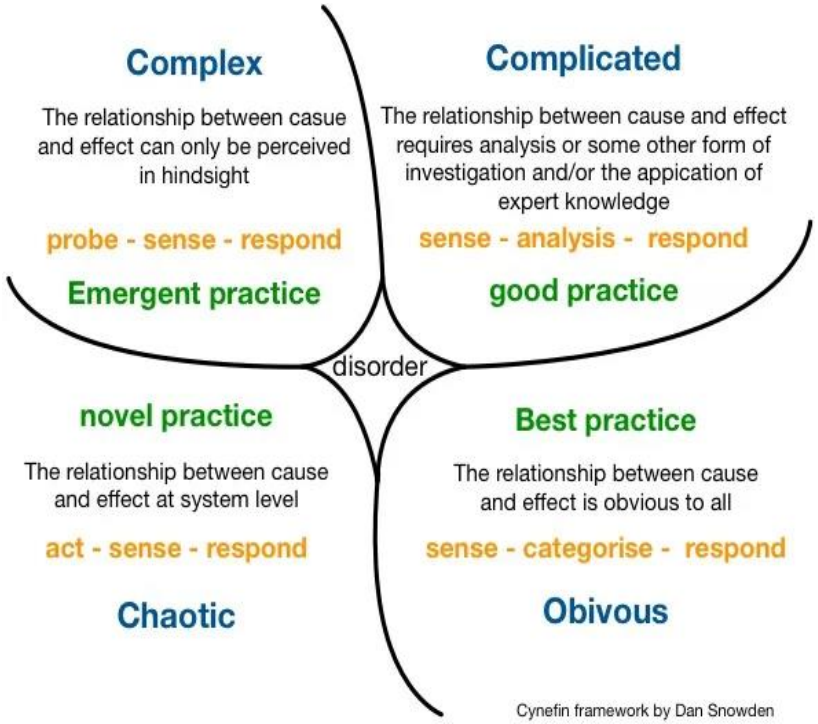
Nevertheless, even though results in the form of qualification, classification and norm strategies are generated by the SCM framework, until this point it is unclear how applicable the deducted results of the framework are for the company in long-term practice.

Learnings

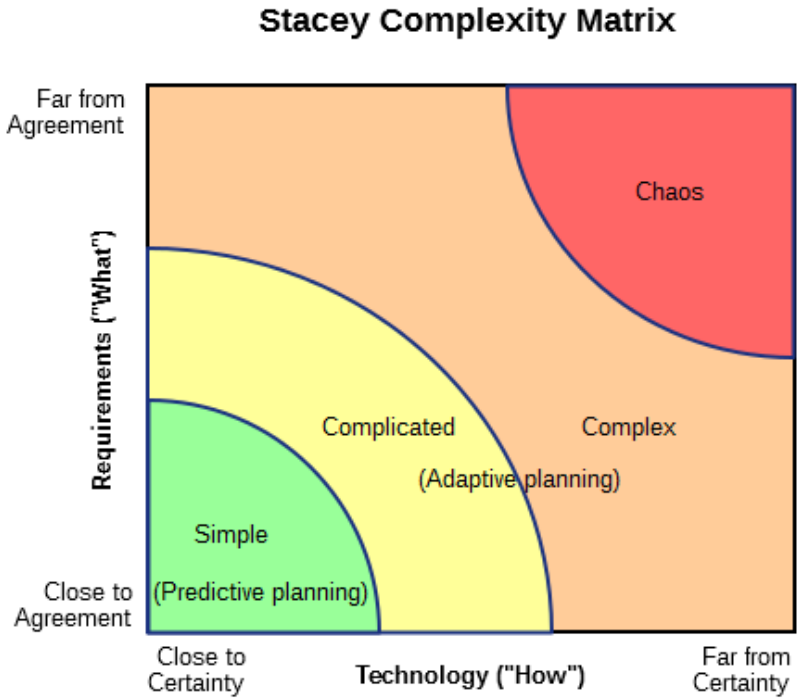
- The application and results generated by the SCM show that the framework can successfully be applied on a range of real-world cases.
- Strategic management tools, like the SCM, can provide meaningful and helpful strategic assistance to decision-makers in the manufacturing industry when dealing with problems concerning system complexity.
- Very positive feedback from companies ☺

Comparison to other Frameworks

SCM Comparison to other Frameworks

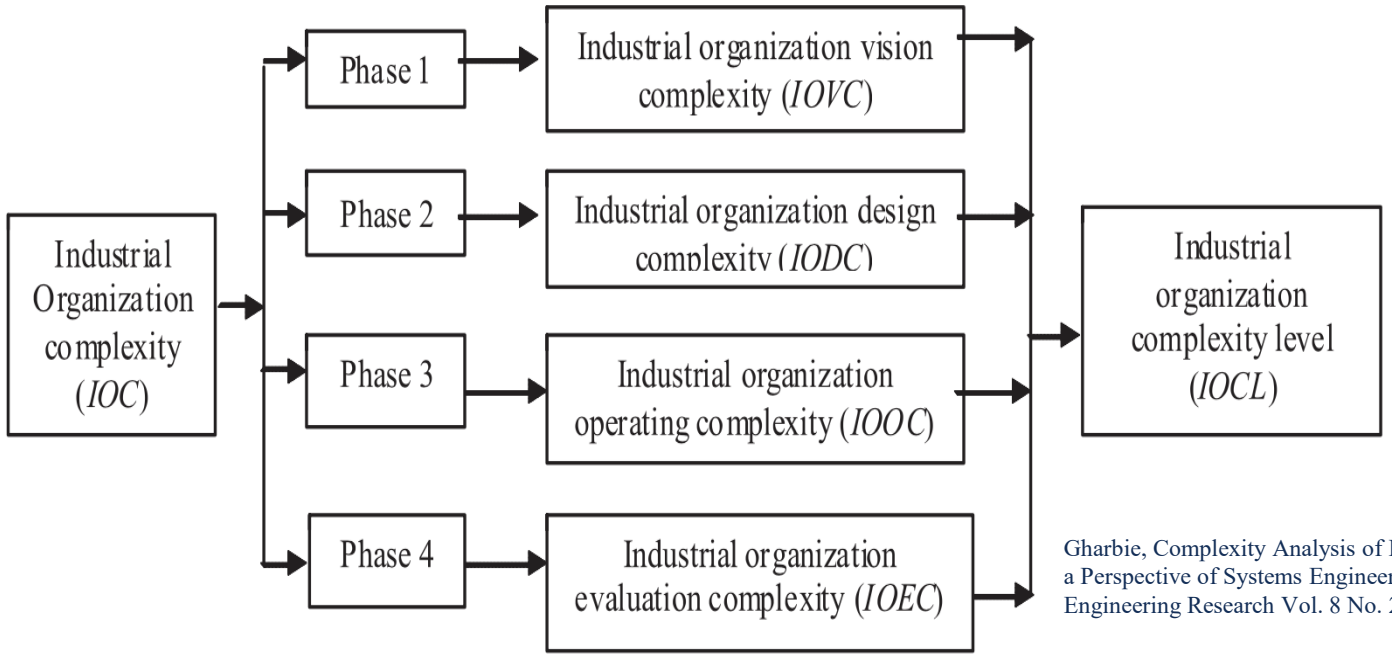


Cynefin Framework – focus on human relationships, context and experience.
Widely used (IBM, Microsoft)



Stacey Complexity Framework – often used in agile work culture

Frameworks for Industrial Complexity Management



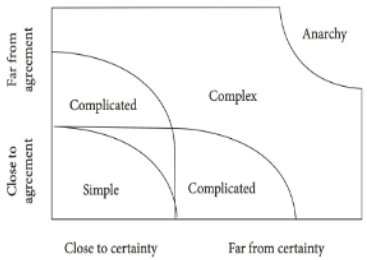
Gharbie, Complexity Analysis of Industrial Organizations Based on a Perspective of Systems Engineering Analysts, The Journal of Engineering Research Vol. 8 No. 2 (2011) 1-9

No dedicated strategic complexity management framework for industrial system complexity management exists.

Existing approaches are highly conceptual and difficult to apply –

A gap the SCM aims to solve for industrial system complexity analysis and management!

Complexity management frameworks



Identify, analyze, visualize

Understanding

1.Define

Optimization models

Maintenance

Complexity

2.Measure

Develop, decide, apply

3.Manage

Strategy

Monitor, control, evaluate

SCM vs. Other frameworks

Comparative benefits of the SCM / Potential Drawbacks

Has clearly defined internal and external dimensions of complexity that allow to identify complexity sources, comparability and repeatability.

Allows to define coherent norm strategies based on framework outcome which can be translated in management action with **Identify, Manage and Avoid.**

Complexity dimensions and respective definitions allow more precise complexity estimations and thus better judgement.

Specifically designed for complex engineered systems and is based on novel complexity space conception, allows for analytical depth if necessary (but not required!)

Only intended for application on industrial manufacturing systems.

Complexity estimates can be subjective.

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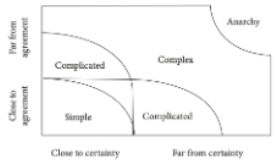
Complexity management frameworks



Identify, analyze, visualize

1.Define

Understanding

Optimization models

Maintenance

Complexity

2.Measure

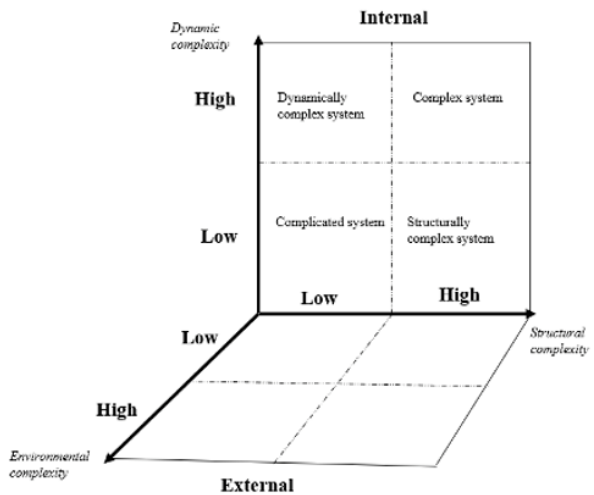
Strategic Complexity Management Frameworks

Develop, decide, apply

3.Manage

Strategy

Monitor, control, evaluate



Outlook

There are now many open directions for future work.

Firstly, the rudimentary assumptions made to construct the framework need to be tested by additional case study applications and potentially modified.

Second, the norm strategies need to be more clearly defined through results of case applications and practical experience.

Finally, longitudinal case applications of the SCM framework would help in understanding the long-term value of results.

Thank you for your Attention!

Questions?