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Complexity of Megaprojects

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ABSTRACT

There is nothing that illustrates complexity as completely as megaprojects. These are almost synonyms for a construct that is not precise. Project complexity is just one of several concepts, but in the world of construction of paramount importance. It can be demonstrated that a distinction among four different types of complexity helps to understand megaprojects best. One is the overall project complexity, the other three are task, social and cultural complexity. Normally, literature (Gidado, 1996) has only been concerned about task complexity. If the others are not addressed as well, a megaproject is set for failure. Contractors in megaprojects reply to overall and to task complexity by breaking it down to functional departments, to social complexity by trust and commitment, and to cultural complexity by sensemaking processes.

KEYWORDS

Mega Projects, Task Complexity, social complexity, cultural complexity

1 INTRODUCTION

Neither the notion of a megaproject nor that of complexity is used with consistency. Therefore, both will be specified in the following two subsections.

1.1. Megaprojects

Megaprojects are invariably described by using superlatives (the prefix “mega” is already one of them). They are called the “giants” among the projects (Grün, 2004) or the “new animal” (Flyvbjerg *et al.*, 2003). While such

projects are large, they are not unparalleled in history. Megaprojects are only new as subjects of research.

The label "megaproject" is not used by all authors. Some refer to them as large-scale engineering projects (LSE-Projects, Hassan *et al.*, 1999) and describe them by five attributes: (1) "high" capital cost, (2) "long" duration but program urgency, (3) technologically and logistically demanding, (4) requiring multidisciplinary inputs from many organizations, and (5) leading to a "virtual enterprise" for the execution of the project. Miller / Lesard (2000) have researched 60 LSEs and in their sample the average capital cost is 985 million US\$, the average duration six and a half years with a construction period of four years. This implies high capital cost and long duration.

Grün (2004) puts the emphasis on the aspect of multi-organizational enterprises (MOEs) and characterizes these by (1) singularity, (2) complexity, (3) goal-orientation (technical, financial, time) and (4) the nature and number of project owners. Taking these attributes together, then megaprojects are indeed daunting tasks. This only more so since cost and time overruns are typical. The list of projects with cost overruns reads like a "who is who" in megaprojects (Flyvbjerg *et al.*, 2003), among these are the Suez Canal (1,900%), the Sydney Opera House (1,600%) or more recently the Boston Artery Tunnel (196%), the Great Belt Rail Tunnel (110 %) and the Channel Tunnel (80%). Reasons given are planning optimism, mistakes, and political lies.

1.2. Complexity

There exist many definitions of complexity. A very basic and simple one starts by describing the number of different elements in a system alone as its complicity and the numbers of elements in a system and the possible relations among these elements as complexity (Simon, 1969 or McFarland, 1969). Also abstract, but with much more content is the definition given within the Luhmannian system theory. Here, complexity is the degree of manifoldness, interrelatedness, and consequential impact of a decision field. The advantage of this definition is that it takes us to one of the core concepts of organizational science: decision making (March, 1988) and thus also to the topic of megaprojects. Manifoldness refers to the differentiation of functions in a megaproject. This could be client, designer, contractor, subcontractors, suppliers, banks, authorities, and the public or it could be the internal differentiation of the contractor's organization. The interrelatedness describes the dependencies between supersystem and the different subsystems or among the latter ones. The consequential impact, finally, draws our attention to the number and importance of the causal chains or the consequential processes set in motion by any one decision. The degree of complexity is then the sum within each of the three components and over all three of them.

While the given definition of complexity can be applied to any system, we are only concerned with project complexity (and not for example with computational complexity that can be considered as part of project complexity). Gidado (1996) determines in an article on project complexity four different sources: (1) employed resources, (2) environment, (3) level of scientific and technological knowledge required, and (4) number and interaction of different parts in the work flow. A large amount of required resources, a turbulent environment, working on the edge of technology and innumerable possible interactions are certainly identifiable for megaprojects. So by this definition, megaprojects are complex and yet the definition does not consider all possible layers of complexity because it just is concerned with task complexity. There are four other layers that need to be considered: social complexity, cultural complexity, operative complexity, and cognitive complexity.

While task complexity can be defined as the density of activities in a given spatial and temporal frame, social complexity depends on the number and diversity of actors communicating and working with each other. Cultural complexity comprises the history, experience, and sense-making processes of the different groups that join their efforts in a megaproject and that have taken place before its start. Operative complexity denotes the degree to which organizations of the project are independent when defining their operations to achieve given goals. Cognitive complexity can be treated on the level of a person or the level of a group. Only the latter perspective is different in megaprojects and it identifies the degree to which self-reflection (and thus sense-making processes, the emergence of an identity, or even an organizational culture) is possible (Wilke, 2000). Due to the project character, operative and cognitive complexity have no time to develop in megaprojects and they can be discarded for the topic. What needs to be added is an overall complexity that encompasses the other three (fig. 1).

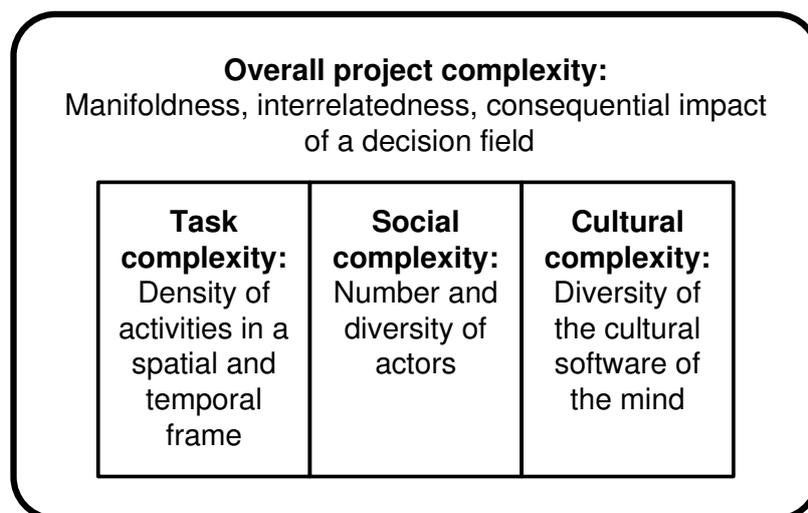


Figure 1: Overall, task, social, and cultural complexity

1.3. Research Question

To define the research question there must be a focus either on the client or the contractor's organization. Contractors employ large amounts of resources, they have less influence than the client on the environment, they use cutting-edge scientific and technological know-how, and they combine the parts in the workflow. Thus – according to Gidado (1996) – their situation is more complex. Megaprojects are normally build by international construction joint ventures (ICJVs) that comprise at least two parties, which again is more complex than the organization of a single contractor or a client. Design/build approaches are also common for megaprojects, at least in newly industrialized or least developed countries and this is more complex than the traditional design/bid/build approach since the contractor organized in form of an ICJV has to coordinate the design besides his other tasks.

With these antecedents, the research question becomes: What constitutes task, social, and cultural complexity in ICJVs that carry out a megaproject in a design/build setting, how does this complexity develop over time, and how do ICJVs deal with it?

2 METHODOLOGY

The research methodology employed is grounded theory because there is no existing theory (Strauss and Corbin, 1998). 35 interviews have been conducted using a semi-structured interview guideline. The technique was adopted from ethnographic interviews (Spradley, 1979). The interviews represent eight case studies (i.e. different ICJVs) and allow for literal and theoretical replication (Yin, 2003). The selection of the cases was guided by the ideas of theoretical sampling to allow for the use of replication logic and to create the situation of a quasi-experiment (Campbell and Stanley 1963). Six of the eight cases are taken from the Taiwan High Speed Railway (Anonymous, 2002). There were two Korean/Taiwanese ICJVs, two Japanese/Taiwanese ICJVs and two German/Taiwanese ICJVs. This allows for replication. In addition, the type of work was for all ICJVs the same, as well as the client, the contract, the economical, social, and judicial environment. This is the quasi-experimental setting.

Two other cases were from Thailand, one a subway and the other an expressway project. They serve to verify any claims with regard to a different type of work and a different micro- and macro-environment. With this arrangement it was possible to double check all statements.

Data evaluation followed the ideas of grounded theory by employing first a micro-analysis of all interviews. Then open coding helped to classify events, things and actions into categories, axial coding to develop subcategories, selective coding for connecting the categories with each other and finally process coding to detect dynamic developments (Strauss and Corbin, 1998).

3 RESULTS

The starting point for an ICJV in a megaproject is described by one of the interviewees as follows: *“Setting up this project is competitive in many ways, when you go into another country and set something up. It comes down first of all to get acquainted with all the local rules and habits and customs of the country. That is manifold. It starts with the fact that you are setting up a limited company, a company of a limited duration which is set up overnight, has to function overnight, with a bunch of people thrown together, sometimes not knowing each other. The latest status here: we have twenty-eight nationalities here, to give an example how it is grown. And then it is liquidated after the period of the contract, four years, five years, whatever.”* This quote not only names task complexity (setting up a limited company), social complexity (a bunch of people thrown together), and cultural complexity (twenty-eight nationalities) but also the tremendous time pressure (has to function overnight).

The results will be presented in four subsections. First the overall development of complexity will be discussed (3.1), then subsections will follow on task complexity (3.2), social complexity (3.3), and cultural complexity (3.4).

3.1. Development of overall complexity with time

Complexity clearly is a construct that is not used by practitioners in the way defined above. In the interviews they rather describe the outcome of complexity without referring to the construct itself. In the beginning of a megaproject there is chaos, a mess, disorder or there are just simply “head-aches”.

Complexity within the project can be reduced in many ways. Normally a functional organization is the first step, thereby transferring a part of the complexity to the departments (subsystems). In this case the project management as supersystem gives away a good part of the control over the project. In return the coordination becomes more difficult and risk compensation a priority for project management. It must also adapt the ICJV to any changes in the environment.

Project management as well as departments then reduce complexity further through decision-making, coordinating, communicating, and learning. A decision connects parts of the project with each other in a specific way by allocating resources and choosing a technology. Coordinating allows to treat a variety of problems at the same time and then bringing them to a planned result. It is an answer to the task difficulty by specialization and the time pressure by concurrence. Communication works specifically in the areas of social and cultural complexity because such barriers can be found, discussed and brought to a conclusion. Learning helps to standardize solutions and thus limit the search. The result is a reduction in the required resources (cf. learning curve). Of great importance in ICJVs is also the question whether the core management group has already learned to

know each other on previous projects. This way cultural complexity is reduced right from the beginning.

At the end of a project, task complexity for the contractor is reduced to zero, he has fulfilled his contract and he can move on to the next project. This is a great difference between project and process complexity. The latter one might never come to an end. As social relations and cultural encounters are processes, their complexity will not be reduced to zero at the end of a project.

Fig. 2 summarizes the discussion above graphically by distinguishing a theoretical and a practical level of the construct "complexity". While practitioners see chaos and start working on it until the project is completed, complexity on a theoretical level is reduced to zero over time.

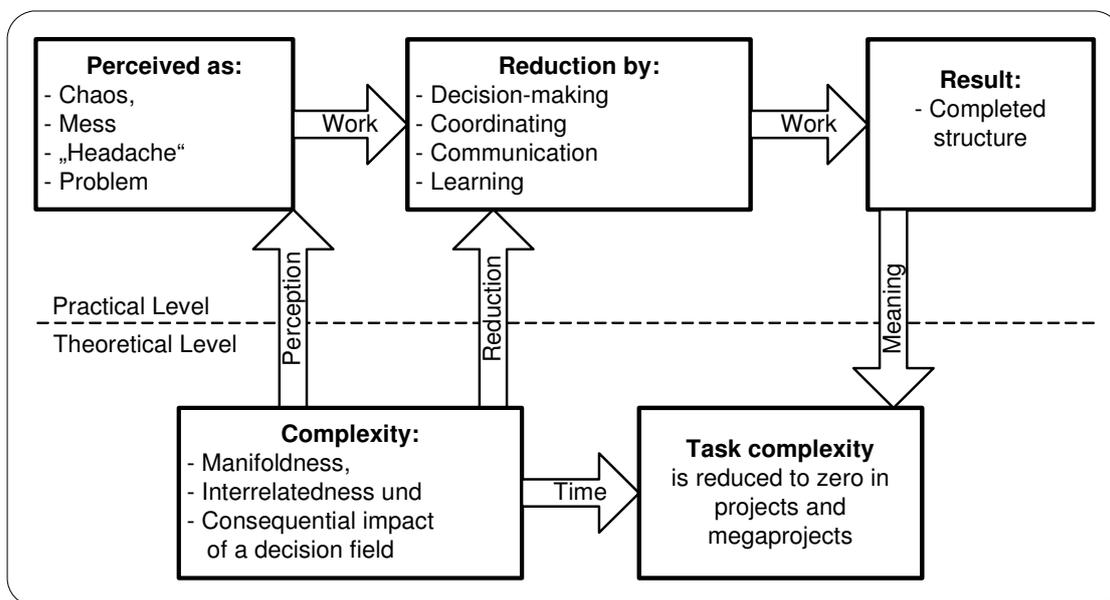


Figure 2: Complexity as practical and theoretical problem in megaprojects

Going back to the theoretical level as a basis, how does complexity develop with time? Here, it is useful to differentiate between three phases of a megaproject. In the beginning everything is in disorder: the management staff does not know each other, the partner companies want to see their views implemented, the design is only in a preliminary stage, often –at least in innovative projects – the technology has not been used before. Many decisions are required, yet project knowledge is low. All tasks seem of highest importance, all are interlinked and the consequences cannot easily be foreseen. This period lasts in smooth running megaprojects for several months, six is a good average. If the input from the clients is not coming forth timely, the period will be prolonged. From the outside there seems to be little progress.

The middle phase is characterized by a starting, then deepening routinizing of the work. A low level of complexity remains because of environmental influences or any other type of disorder (such as mistakes). Problems of social and cultural complexity always stay virulent.

During the end phase the complexity picks up again as new tasks need to be performed. The contract must be wrapped up and the site and the offices closed down.

In figure 3 there are three examples of overall project complexity shown for different environmental conditions. The first one is for a smooth running project, the second one for a project with an important change order, and the third one shows the case of a megaproject where contractual disputes are not settled at the end of the project. The client on the Taiwan Highspeed Railway introduced a variation order with an increased earth quake loading. This is a case of environment 2. A project in Bangkok was completed in 2000 and is still not settled in the courts today (environment 3).

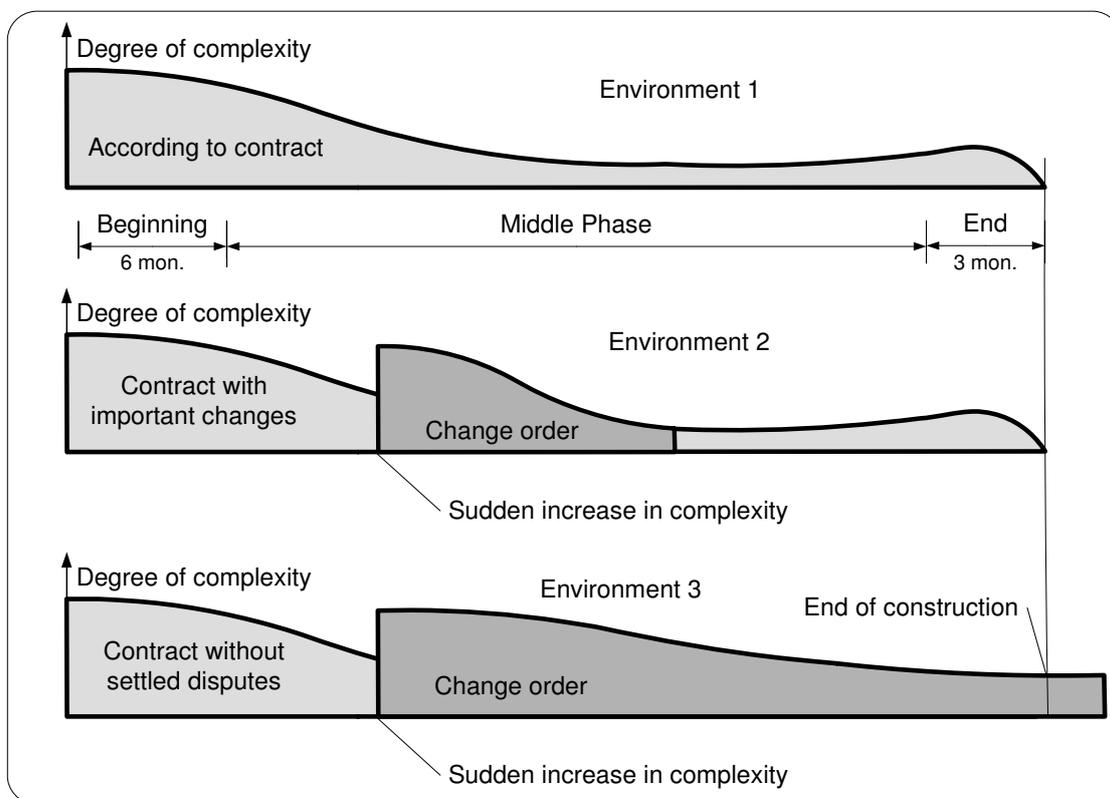


Figure 3: Overall complexity curves

The complexity curves are different for the separate departments in an ICJV. The project management is faced with the overall complexity curves as shown in figure 3. The same curve for the design department is reduced much earlier to almost zero (pending the as-built status, fig. 4).

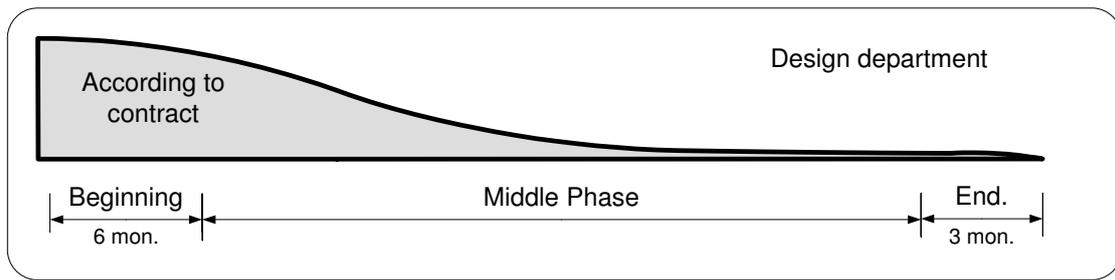


Figure 4: Complexity curve for the design department

The curve for administration has a very strong increase at the end because termination and sales of equipment are very different from the earlier tasks (fig. 5).

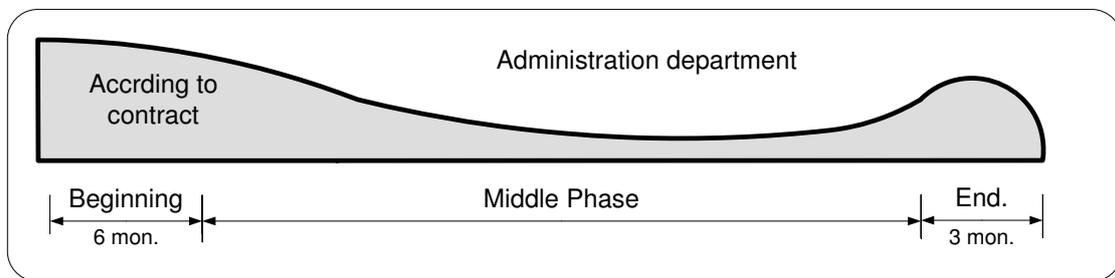


Figure 5: Complexity curve for administration department

The figures might imply that the degree of complexity is the same for the different departments. This is not true. One of the most basic ways to deal with complexity is through departmentalization. Each department (subsystem) has to deal with a part of the complexity that is considerably smaller than the overall complexity. Each department must have competencies and resources to solve their task. This independence increases on the other hand the overall complexity for the project management.

As the discussion has demonstrated, megaprojects are more complex than normal projects, therefore they must deal with the overwhelming complexity by departmentalization. According to the task of each department, the complexity curves are different (fig. 4 and 5). The way a contract is implemented through the client has also an impact on the complexity curve (fig. 3).

3.2. Task complexity

Discussions about complexity are often enough rather abstract (as above) or they do not capture the completeness of the construct. To grasp complexity, a formula will not suffice and the story of complexity is a very long one. A way out of this dilemma is a table of the task to be fulfilled on a megaproject. Yet this also has drawbacks, as neither interrelatedness nor

consequential impact can be shown. They have to be guessed by the manifoldness of the topics in table 1.

Table 1: Manifoldness of task complexity in megaprojects

Area	Tasks
Organizational planning	<ul style="list-style-type: none"> • Organization • Organization chart • Competency matrix • Job descriptions • Contract management • Quality management • Safety management • Personnel management • Purchasing • Financial accounting • Cost accounting • Communication • Correspondence and filing
Design planning	<ul style="list-style-type: none"> • Outsourcing of design • Coordination of design • Approval procedure • Design schedule • Documentation (as-built drawings)
Work preparation	<ul style="list-style-type: none"> • Work estimate • Controlling • Outsourcing • Construction methods • Scheduling • Deliveries • Planning of site installation • Logistics
Site installation	<ul style="list-style-type: none"> • Land acquisition • Purchase of plant and equipment • Utilities • Offices, labor camps, canteens, lavatories... • Waste
Construction management	<ul style="list-style-type: none"> • Production processes • Quantity and quality control of materials • Quantity and quality control of subcontracts • Deployment of plant and equipment • Deployment of work force • Deviations from contract • Hand-over • Warranty

Five main areas can be distinguished for megaprojects: organizational planning, design planning, work preparation, site installation planning, and construction management. Organizational planning has much

more importance than for normal projects, where standard solutions are used. The same holds true for site installation. The cost for site installation on a megaproject is around 15%, this is for a billion-dollar-project 150 million dollars and by itself larger in volume than most normal projects.

It should never be forgotten what size means in a megaproject. When looking at the tasks some examples might suffice: Personnel management means employment of several thousand staff and workers, coordination of designs means managing a world-wide network of engineers, construction methods means the use of an untested technology, labor camps mean setting up hole villages for one or two thousand people, and control of subcontracts means coordinating a hundred contracts with subcontractors from around the world.

All tasks are highly interrelated and a decision on one subject will have repercussions for many others.

3.3. Social complexity

Social complexity shall again be highlighted by just one example. Especially for all decisions in the area of organizational planning, all partner companies have their own experiences and preferences. Through their employees who they send to the ICJV they try to implement these preferences. The project management includes employees from all partners who are urged to follow the wishes of their bosses. Yet on the other hand, the project management must decide on a coherent set of management procedures that assure efficiency under the terms of the contract. Moreover the client has through the stipulations of the contract also an influence on the organization. In the end it is amazing when despite of all these actors an efficient organization emerges out of the maze of ICJV politics.

The case would be different if the partners and their employees in the ICJV were committed primarily to the ICJV. Then they would have to forgo opportunism and indeed the interests would merge.

On a personal level trust is another mechanism often used to reduce complexity. By delegating work to a trusted person, the problem is solved for the superior (Girmscheid and Brockmann, 2005).

3.4. Cultural complexity

Culture can be described as the software of the mind (Hofstede and Hofstede, 2005). A first programming comes about by the family (national enculturation), a second by professional training (Industry culture) and a third by the mother company (organizational culture). The diversity of the cultural software causes problems.

Even more practical than in the case of social complexity are the following two examples of cultural complexity: A Korean/Taiwanese ICJV subcontracted the design for the bridges to a world-class engineering firm in the USA. By the main contract they must also employ a contractor's

checking engineer and the ICJV gave the contract to a German engineering firm of highest reputation. The two firms fought for a full year to settle the design fundamentals in the design/build contract with a four year duration. The ICJV tried to solve the problem on the task level and despaired. With 25 % of the contract time passed there existed no design and no construction. The two firms held different values and principles, big egos were also involved. At the end it became a bitter personal fight between the engineers over these values. The objectives of the contracts were lost out of sight.

A German/Thai ICJV contracted another world-class engineering firm from the USA for the design. Since most large German contractors are design/build companies, they insisted on supervising the design by giving directions. The American engineering firm was used to not being interfered with by American contractors. Again all kinds of distractions erupted because of neglect of these fundamental cultural differences.

The two examples highlight mostly the influence of different organizational cultures. Problems between national cultures are erupting in between and on top of the two explained cases.

A typical way to deal with problems of cultural complexity is through a managed process of sense-making (Weick, 1995).

4 CONCLUSIONS

It is possible to differentiate between the overall and three further types of complexity. In megaprojects, ICJVs find very specific ways to deal with them. These are strategies of choice and they are pursued regardless of the national background of the ICJV partners with the aim to reduce the project complexity (table 2).

Table 2: Types of Complexity and Means for their Reduction

Type of Complexity	Description	Means of Reduction
Overall complexity	Degree of manifoldness, inter-relatedness, and consequential impact of a decision field	Specialization, risk compensation, levels of complexity, adaptation
Task complexity	Density of activities in a time/space segment	Decentralization
Social complexity	Number and diversity of stakeholders	Trust, commitment
Cultural complexity	Diversity of the cultural software of the mind	Sensemaking

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