A Real Case Application of Game Theoretical Concepts in a Complex Decision-Making Process: Case Study ERTMS

Femke Bekius¹ · Sebastiaan Meijer² · Hugo Thomassen³

Accepted: 25 September 2021 / Published online: 18 October 2021
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Abstract

Engineering systems are complex, amongst others due to the interdependencies between actor and technical aspects. This complexity has consequences for the way of designing such systems and, in particular, for the decision-making process. Recognizing the impossibility of having an optimal system design in such complex systems, this article explores how a game theoretical characterization of a decision-making process *assists* in the organization and design of the process itself. In contrast to a game theoretical analysis, which results in optimal outcomes, the characterization is fed back to the designers of the decision-making process during the course of the process. The study analyses how the game concept characterization was used, i.e., which strategies were defined during the game theory interventions, and what the consequences of these strategies were for the design of the decision-making process. The design of a new safety system ERTMS for the Dutch railway sector is the context in which the study was performed. The contribution is a successful approach to complex decision-making in multi-actor systems by identification of multiple game concepts over time, with periodic feedback into the designing system, and not the actual decision-making itself. In short, it supported adapting to an actor focus on the process, it affected the role and responsibilities of the program management, it contributed to (de)coupling of issues, and it influenced the capability of creating awareness amongst actors of the urgency of the decision window. The paper ends with reflections on the experience of intervening in a decision-making process with game theoretical concepts.

Keywords Decision-making · Game theoretical concepts · Engineering design · Decision support · Railway system · ERTMS

✉ Femke Bekius
femke.bekius@ru.nl

Extended author information available on the last page of the article

1 Introduction

Large scale infrastructures in our society are associated with complex stakeholder constellations and equally complex technological challenges and interdependencies. It is well-known that an integrated management of both aspects is essential for the success of infrastructures and society at large.

Different perspectives on engineering systems exist, as they can be interpreted as a large technological system (Hughes 1987), as a Socio-Technical System (STS) (Trist and Bamforth 1951), as a System-of-Systems (SoS) (DeLaurentis 2005) or as a Complex Adaptive System (CAS) (Holland 1995; Miller and Page 2007).

Considering this evolution of system theories, we observe an increase in focus on the interactions between actor and technical aspects. According to a CAS perspective, systems consist of interdependent subsystems that need to be aligned to let the entire system function. The relations between subsystems are dynamic and evolving over time and, as a result, systems show emergent and chaotic behavior (Holland 1992). The increased understanding of the complexity of systems has consequences for the designing function. In traditional engineering design, one actor could decide on an optimal solution. Nowadays, multiple actors are involved, each responsible for their own subsystem with disjoint perspectives on optimality and incentives. This is embodied in the concept of Engineering Systems (De Weck et al. 2011).

To capture and address the uncertainties in decision-making processes, several types or levels of complexity have been proposed. System complexity is rooted in the engineering sciences (Hughes 1987) and actor complexity has its origins in the social sciences (Thissen and Walker 2013). This distinction provides insight into the different elements of the process, but the real complexity is represented by the interdependencies within and between complexity levels (De Bruijn and Herder 2009). According to De Bruijn and Ten Heuvelhof (2018), decision-making processes are complex due to three main characteristics: (i) unstructured problems: there are many technological uncertainties, problems and solutions; (ii) networks: multiple stakeholders with different incentives are interdependent; (iii) dynamics: context and environment continuously change. Therefore, we distinguish three levels of complexity: technical, actor and context complexity. Moreover, the theory on complex decision-making and multi-actor systems talks about *games* (Kickert et al. 1997; Scharpf 1997; Axelrod 1984).

Game concepts describe the behavior of and interaction between actors who have to make a decision. The concepts originate from different disciplines - ranging from formal game theory to public administration (Bekius et al. 2016; Rasmussen 2007). The game concept approach provides structure in the ill-structured decision-making process by making the game elements, such as actors, actions and strategies, precise and specify the type of game. Moreover, the game concepts allow for an analysis of different scenarios and possible outcomes which creates a perspective of action. Different from formal game theory the approach does not make the assumption of rationality explicit or specifies an optimal or

right-versus-wrong outcome. Rather, the game concept approach focuses on incentive structures, responsibility and ownership of actors, i.e., actors' agency, and dilemmas existing in the decision-making process (Bekius 2019).

In this paper, we explore how a game theoretical characterization of a decision-making process assists in the organization and design of the process itself. Describing decision-making situations in game theoretical terms is not new. This paper goes one step further: theoretical models are used to assist in the continuous design of a complex negotiation process. The exploratory nature of the paper allows us to assess the value of descriptive insights for a process without being prescriptive.

The objectives of this paper are (i) to apply game theoretical concepts in a real complex decision-making process, (ii) to give back the game theoretical characterization to the designers of the decision-making process and observe the impact on the process, and (iii) to provide lessons learned from the experience (intervening in a decision-making process with game theoretical concepts) for both researchers and practitioners. Our research question is: What are the effects of giving back a game theoretical characterization of a decision-making process to the designers of the process on the process itself?

The paper contributes to the theoretical framework on complex decision-making in multi-actor systems [among others De Bruijn et al. (2010); De Bruijn and Ten Heuvelhof (2018); Kickert et al. (1997)]. We identify multiple game concepts, show how they interact and characterize the situation instead of finding an optimal outcome and defining the rules of the game. Moreover, we extend the framework by specifying particular game concepts instead of talking about the decision-making game in general terms.

Moreover, the paper contributes to the use of game theoretical models and formal models in general. It yields an example in which theoretical models are used to assist in a complex decision-making process. Opposed to the classical use of game theoretical concepts in a multi-actor setting which aims at an optimal outcome of a particular decision moment, the game theoretical characterization in this process describes a running process. Additionally, the characterization was given back to the designers of the process while the process was still going on. We explore the effects of periodic feedback to designers of the decision-making process on the process. In particular, we describe how the characterization is translated into strategies and present the consequences of these strategies for the design of the decision-making process.

The focus of this paper is to intervene in the *design* of the decision-making process without actively intervening in the behavior of actors. This is different from gaming simulation which is an active intervention in actor behavior and in which players are taken out of their usual context to play a game in a so-called safe environment. The use and effect of such interventions have been assessed in different studies (Bekebrede and Meijer 2009; Meijer 2012b; Mayer et al. 2005; De Caluwé 1997), but an evaluation of the interventions in the design of decision-making processes is missing (Grogan and Meijer 2017).

Finally, we contribute to the decision support field by outlining lessons learned from the experience. In several interventions the game theoretical characterization is presented to and discussed with senior program managers. An analysis of the

interventions provides insight into the consequences of giving back such information for the process of decision-making. Moreover, apart from a descriptive value at process level, the analysis resulted in learning points for us as researchers. The learning points are framed as points to consider when repeating this study in different organizations or domains to overcome the exploratory character of the current study.

1.1 Case Study: Railways

The European Rail Traffic Management System (ERTMS) is a European project to standardize control and improve safety of the railway system. The aim of the project is to “enhance cross-border interoperability and signaling procurement by creating a single Europe-wide standard for railways with the final aim of improving competitiveness of the rail sector” (Schuitemaker et al. 2018). For the Netherlands, it entails a major systems transition from an analogue to a digital system for the entire country. We will introduce the context of the case study using three complexity levels.

The *technical complexity* consists of the difficult content of the technical aspects and the multiple interdependencies that exist between these technical aspects. For example, implementation strategies in the Netherlands have immediate consequences for the timing of replacing trains. There is uncertainty whether program goals regarding interoperability, capacity, speed, safety and reliability can be reached. The complexity of and interdependence between these goals makes it nearly impossible to translate them to technical specifications for all subsystems.

The complex multi-actor setting with many formal and informal rules, diffuse responsibilities towards the systems results in a complicated governance and is captured by the *actor complexity*. The actors (passenger and freight train operators, contractors, leasing companies, infrastructure manager, ministries, the Parliament, and European Union) have different incentives, are not hierarchically organized, but are mutually dependent and responsible for different parts of the system. The main actors, ProRail, NS, the Ministry of Infrastructure and Water management (I&W), and freight operators, have different perspectives on time lines.

The *context complexity* comprises different dynamics: other decisions made on the railway system such as storage of trains overnight are coupled to ERTMS decision-making, historical decisions which assume the implementation of ERTMS influence the current decision-making; political pressure from European Union requirements exists as well as decisions made by other European Union countries regarding ERTMS. Moreover, the technology is new and developing. Hence, the status of the technology today is not the status at the moment of implementation.

The complexities and interdependencies create an ill-structured, and sometimes messy, decision-making process with many uncertainties. The program management of ERTMS, responsible for the design of the decision-making process and advising on the decisions to be made, can impossibly oversee the entire process. There is thus a need to gain insight into the strategic behavior of actors, actors' power and responsibilities and how both evolve in a dynamic environment. More understanding of the decision-making process and a perspective of action could help the program

management in the design of the decision-making process. To address both points we propose the use of game theoretical concepts as further explored in this paper.

The paper is structured as follows: in Sect. 2, we introduce the game concept approach and position the approach in the broader field of decision support methods. The methodology for this paper is outlined in Sect. 3 where we distinguish between a characterization of the decision-making process and returning the characterization into the designing system. In Sect. 4, we present a timeline of events capturing the main elements of the decision-making process together with the game concept elements and interventions. The analysis of the four interventions is shown in Sect. 5. Finally, we provide lessons learned from the series of interventions in Sect. 6 before we conclude the paper and discuss the results in Sect. 7.

2 Game Concept Approach

In this paper, we use game concepts to characterize a complex decision-making process. Subsequently, the characterization is given to designers of the decision-making process in interventions to support the process. The game concept approach is introduced by presenting the theoretical framework in which the approach fits and positioning the approach in the broader field of decision support methods. Finally, we introduce the seven game concepts that are central in this paper.

2.1 Theoretical Framework

Complex decision-making in multi-actor systems is a broad field that has been studied by many researchers (among others De Bruijn et al. (2010); De Bruijn and Ten Heuvelhof (2018); Kickert et al. (1997)). It goes beyond the scope of this paper to give a detailed overview of this literature. We have restricted ourselves to a couple of features that explain why decision-making processes in multi-actor systems are complex. They include: networks of multiple interdependent actors, wicked or unstructured problems, and a dynamic environment.

Actors perform strategies to deal with the complexity of a decision-making process. This can take place at (at least) two levels. First, at the level of individual actors and their strategies, for example, wait-and-see behavior or keeping-options-open. Second, at the process level actors develop strategies or interventions to deal with the unstructured process itself. For instance, share or hide information, or introduce new issues as an attempt to structure the process.

We consider the following three elements of the theoretical framework on complex decision-making in multi-actor systems to be relevant for the game concept approach: First, the decision-making process can be seen as a game. Actors perform strategic behavior and follow the rules of the game to reach an (optimal) outcome or consensus. Second, descriptive analysis of the decision-making process in terms of game elements takes into account the dynamics and context of the process. Third, the analysis of the decision-making process forms the basis for interventions in the behavior of actors.

In the remainder of this paper, we show how the game concept approach used in multiple interventions extends the theoretical framework by addressing the above mentioned elements.

2.2 Decision Support Methods

As the game concept approach is used to support decision-making processes, more precisely to support the design of the process, we present a selection of approaches and decision support methods applied in cases on large infrastructure systems. We show for each method how the game concept approach is different or complementary.

Many examples of formal applications of **game theoretical models** to support decision-making exist (Chen et al. 2012; Cantarelli et al. 2013; Hollander and Prashker 2006; Osman and Nikbakht 2014). Game theoretic modeling often simplifies the situation to one game and therefore explains only a small part of the process (Cohen 2015). In contrast, we identify *multiple* game concepts in a decision-making process and are interested in the interactions between identified game concepts to represent the dynamics of the process more accurately. Another feature of formal game theoretical modeling is that it usually aims at finding an optimal or stable outcome and thereby assumes the rationality of actors (Howard 1994). This assumption is quite strong, especially when we consider the fact that actors have different responsibilities and thus perceive an outcome differently. The game concept approach rather presents different scenarios and outcomes with potential risks. Moreover, game theoretical models are rarely presented to decision makers in their formal way (Camerer 1991). The game concept approach does not use the formal presentation of games which makes it suitable for use in interventions with decision makers.

Several **design theory frameworks** are available which aim to describe the design process of (engineering) systems (Reich 1995; Reich et al. 1996; Meijer et al. 2014). Such frameworks suggest that the components (e.g. product, actor, institution) need to be connected to or reflecting upon one another (Geels 2004; Hermans et al. 2013; Geyer and Davies 2000; Hardy et al. 2005). However, the problem with those methods, which is why they are less suitable for application to support decision-making, is that they either do not involve all components (Pluchinotta et al. 2019) or the framework is not fully operationalized. The game concept approach is applied to design processes to explain misalignments between different components in the process (Bekius and Meijer 2018).

Some well-known **decision support models** are Multi Criteria Decision Analysis (MCDA) (Ishizaka and Nemery 2013; Nikas et al. 2018), Cost-Benefit Analysis (CBA) (Flyvbjerg et al. 2008) and Analytical Hierarchy Process (AHP) (Ossadnik et al. 2016). The models compare different alternatives, or variants, based upon various evaluation criteria that can have different weights (Dodgson et al. 2009; Corsair et al. 2009). **Group Decision Support Systems (GDSS)** are specific Information and Communications Technology (ICT) applications for the support of group interaction and decision-making (Mayer and De Jong 2004; Eden 1992). De Vreede and

Dickson (2000) use a **Group Support System (GSS)** to develop and evaluate a participatory design process. Their research approach to support the design of organizational processes relates to our study. However, the game concept approach particularly focuses on interactions between actors with selected game theoretical models. Moreover, we evaluate the use of the game concept approach in a running process compared to a complete redesign of a process. The context elements of a decision-making process, such as the impact of the political environment on the decision, are difficult to quantify and these elements are usually not covered by the decision-based models (Mayer et al. 2005). The game concept approach is able to reflect the political dimensions of a decision-making process by focusing on incentive structures of actors as shown in two case studies of the Dutch railway sector (Bekius et al. 2018).

Gaming simulations have been used in various studies to support decision-making on infrastructure systems (Mayer et al. 2004; Bekebrede and Meijer 2009), including the Dutch railway sector (Meijer 2012a, 2015; Lo et al. 2013). Which elements of the process to include in the game design is crucial for the success of a gaming simulation (Salen and Zimmerman 2004). The game concept approach helps in identifying the strategic games being played in the decision-making process in terms of actor constellation, its responsibilities and power relations and how the constellation evolves over time (Roungas et al. 2019). Gaming simulation is an active intervention in the behavior of actors. Participants are taken out of their usual context to participate in a game. The game concept approach targets a different type of participants and does not intervene directly in the decision-making process, but more indirectly in the design of the process.

Operational research is a discipline which has developed a plethora of methods and tools to support decision-making processes (De Gooyert 2016). **Problem Structuring Methods (PSM)**, and as subcategory Game Structuring Methods (GSM), are a collection of techniques to model a situation one want to change (Cunningham et al. 2014; Rouwette et al. 2009). Usually the model is applied by a group of people to structure a situation, to facilitate reaching consensus or to negotiate on what needs to change instead of making a decision (Mingers and Rosenhead 2001). Hermans and Thissen (2009) present an overview of actor analysis methods and their limitations and potentials by focusing on the trade-off between analytic quality and practical usability. Although features of the various **stakeholder and actor analysis methods** overlap with the game concept approach there are three important characteristics that distinguish them: (i) game concepts focus on the behavior of actors and interactions between them, including actor's agency, i.e., responsibility and ownership of the system resulting in power relations; (ii) game concepts characterize the process of decision-making and thereby include the dynamics; and (iii) game concepts are developed in such a way that they can be used by decision makers themselves and eventually create a 'perspective of action' in the form of strategies.

So far, we introduced the theoretical framework in which we position the game concept approach and showed how the game concept approach relates to other methods investigating and supporting decision-making processes. In short, the game concept approach adds a structured way to address the constellation of actors including their responsibilities and power relations and the dynamics. Moreover, the approach is not only theoretical, but can be used with and by decision makers as we will show

later in the paper. Next, we introduce the selection of game concepts which are central in this paper.

2.3 Game Concepts

In this paper, we use seven different game concepts to characterize a complex decision-making process. The selection of game concepts is based on characteristics of complex decision-making processes such as multiple actors forming a network of interdependencies and where reaching a collective decision is the aim of the process. A taxonomy of game concepts is provided in an earlier paper, and we refer to Bekius (2019) and Bekius and Meijer (2020) for a detailed explanation of the selection criteria. The game concepts are illustrated by an example and defined in terms of the context in which they appear, the process they characterize, their possible results, and potential risks in Table 1.

The **Multi-Issue game** (M-I game) characterizes a situation with multiple actors having different incentives aim to reach consensus in a decision-making process that was in a deadlock in the first place (Winter 1997; De Bruijn and Ten Heuvelhof 2018; De Bruijn and Ten Heuvelhof 2002; Sebenius 1983).

Imagine you are part of a family (father, mother and three children) and the father sees the opportunity to have a summer holiday together. He decides on a destination and period in summer, but not everyone likes his idea. The family members have different preferences regarding the summer holiday issue and the situation gets stuck in a deadlock. How could the father resolve it? An option is to take control over the agenda and introduce new issues that matter to the family members, such as a skiing holiday during winter or having a pet. The new agenda creates a broadened solution space which enables the forming of coalitions within the family, the exchanging of issues, and the creation of a give-and-take game. As a result, the deadlock could be resolved and the family members could reach consensus on the larger set of issues. A serious risk is that too many issues are added to the agenda such that the game becomes over-complex.

The **Principal-Agent game** (P-A game) represents a hierarchical relation between a principal and an agent. The principal is dependent on the agent because of its knowledge and expertise regarding a certain decision. The game explains the power position of the subordinate, i.e., the agent (Stauvermann 2004; Gintis 2000; Braun and Guston 2003; Laffont and Martimort 2002; Cantarelli et al. 2013; Dodgson et al. 2009; Cole et al. 2014).

Suppose you are an employee in a company and your boss asks you to deliver a report before the deadline on the feasibility of a certain technique for measuring the well-being of elderly people (Roungas et al. 2019). Apart from the content of the report, you know it is important for the company to be able to report good results in order to be chosen by the regional government for implementing the technique. As employee, you are the agent in a principal-agent relation with your boss, i.e., the principal. The relation is asymmetrical since your boss puts pressure on the deadline and the content of the report, i.e., the principal has more power. On the other hand,

Table 1 Seven selected game concepts

	M-I game	P-A game
Process	The introduction of new issues when one issue leads to deadlock in the decision-making. Formation of coalitions of actors such that linkage, negotiation, and exchange of issues takes place. Focus on (new) actors in the process.	A contract exists between principal and agent resulting in a hierarchical relation. Pressure from the principal and information of the agent influence the relation.
Results	A broadened agenda which contains pain and gain for each actor results in room for consensus. A too broad agenda does not contribute to a decision. Negotiated knowledge; incentives for cooperation; give-and-take game; participation in the process; increased trust; shift in process focus.	The agent accepts or rejects the contract proposed by the principal. The principal accepts or rejects the outcome of actions or decisions by the agent. A rejection reflects misalignment between agent and principal.
Risks	The game develops in a free-fight or becomes over-complex due to too many actors and issues. Focus remains on content of issues, underestimating the actor aspects.	The principal is the affected party, not accepting actions or decisions of the agent damages the relationship, and vice versa. Increasing information asymmetry between principal and agent leads to pressure or delay.
	CG	H-S game
Process	A decision taken at one decision level is input for a decision at the next decision level. Actors observe previous decisions and decisions need to be adopted by various predefined decision levels.	The role of the hub is assigned (or taken) to steer the process. Spokes are responsible for a part of process and need to reach overall goals. The hub negotiates with spokes separately, negotiations follow a plan, and the hub has the power to decide on issues.
Results	A decision spreads through the various levels. A decision is blocked at one (or more) levels. Convergence of decisions can lead to sub-optimal outcomes.	Spokes are aligned and different responsibilities are clear. Spokes are not aligned and/or responsibilities are not accepted leading to strategic issues for the hub.
Risks	Sub-optimal outcomes emerge because of incorrect information or a lack of awareness of convergence of decisions. The solution space converges which means missing out of new solutions.	Separation between actors (spokes) can result in an ask-as-much-as-you-can game, a blockade of decisions, no stimulation of cooperation among spokes, and can be time consuming.
	VD	DD
Process	There is individual consideration to volunteer, i.e. take responsibility for the group. Incentives for free-riding and wait-and-see behavior exist.	Agreements are made about decisions or goals. Incentives for 'free-riding' and individual balancing concerning violation of agreements exist.
Results	No volunteer means everyone loses. Volunteers can be supported by other actors or they do not gain support and get blamed for their action.	The costs for the diner depend on the number of violations. It is beneficial to be the first to violate. Meeting repeatedly under same agreement may lead to cooperation.
Risks	Costs to volunteer are too high. Volunteers block and delay the process, they are not recognized in time.	If everyone violates the agreement, then no one benefits from free-riding, and there is no urgency to cooperate.
	BS	
Process	Two actors share a common goal, have different incentives, decide simultaneously, and anticipate to the other's strategy.	
Results	A conflict between actors exists since no one can overrule the other by using power or information. The involvement of a referee can resolve the conflict and decide, eventually a compromise is found.	
Risks	Wrong anticipation on other's strategy, a compromise leads to sub-optimal solutions, conflicts cannot be resolved due to power issues, or a referee is not accepted by the actors.	

you have more information and know the details of the technique. The information is the agent's power to argue with or convince the principal.

The **Cascade Game** (CG) shows the tendency of intelligent actors, in case of uncertainties, to follow the decisions of others independently of the quality of the content of the decisions (Bikhchandani et al. 1992; Easley and Kleinberg 2010; Anderson and Holt 1996; Conradie et al. 2015).

Imagine you are in a new place and you want to make a roundtrip. Based on your own research you intent to go for operator A. However, when you arrive at the departure point you notice that it is completely empty, and operator B has a line of people waiting for tickets. At this point, it would make sense to have your private information, decide for operator A, to be outweighed by the public information you infer from others' decision for operator B. The decision has an either-or character, it is either A or B, players make the decision sequentially, and each player can observe the choices made by those who acted earlier. The Cascade game makes clear that players tend to follow others and this creates a cascade-effect. It has an important implication: the actors who made their choice first have an impact on the following actors.

The **Hub-Spoke game** (H-S game) describes a situation with multiple actors (spokes) having different incentives who are steered by one actor (hub) via command-and-control. The game creates an incentive for inflated claims, the spokes can reach agreements among each other and create strategic issues for the hub (Elrod and Fortenberry 2017; Adler 2005; Adler and Smilowitz 2007; Adler et al. 2010; Takebayashi 2015; Markusen 1996; De Bruijn et al. 2010).

Suppose there is a company, called the hub, which wants to found a business unit in a certain area. To succeed it needs to deal with several parties, called the spokes, for example local companies and municipalities. The hub initiates the plan and starts negotiating with the spokes. The negotiations follow a plan and it can enact several strategies. The hub can make agreements with each spoke separately and propose a unique deal to each. Alternatively, it can propose the same deal to each of the spokes. A local company can try to block the plan of the hub by performing a wait-and-see strategy or exchanging information with other spokes. The communication between spokes can create strategic issues for the hub.

The **Volunteers Dilemma** (VD) explains why one or more actors take the responsibility for the group to prevent a worst-case scenario from happening. Performing wait-and-see behavior is beneficial, but increases the risk of a bad outcome of the decision-making process (Archetti 2009; Goeree and Holt 2000; Diekmann 1985).

Imagine a situation in which you live in a flat and suddenly the electricity fails. There are many people in your flat, but no one calls an electrician. Performing wait-and-see behavior, not calling the electrician, is beneficial, since it requires no effort and thus no cost. Moreover, there are so many others, why would you be the volunteer? No volunteer acting increases the time of being without electricity. A very bad outcome no one wants. The longer this dilemma, calling or not calling, is present, the higher the risk, and thus the more pressure exists for a volunteer to take action.

The **Diners Dilemma** (DD) represents a situation in which multiple actors come to an agreement about the process of decision-making, e.g. collaboration and mutual interaction. Due to the agreements made it becomes attractive to be the first one to violate the agreements (Teng et al. 2013; Gneezy et al. 2004; O'Donovan et al. 2013; De Bruijn and Ten Heuvelhof 2018).

Suppose you decide to have dinner with a group of people in a restaurant. You agree in advance that the costs of the dinner will be divided equally among the participants. Upon arrival, there appear to be two options: there is a cheap menu and an expensive menu. The participants come to an additional agreement to order the cheap menu. However, there is an incentive to be the first one to violate the collective agreement and order the expensive menu. The profit for this person is high, and there are limited additional costs for the other group members. However, the other group members seeing the bill will understand that the agreement has been violated. It becomes attractive for others to join the first mover and, in the end, the agreement will erode.

The **Battle of the Sexes** (BS) describes a case in which two actors are completely dependent upon each other. Moreover, they share the same goal, but have different incentives. In order to reach a decision one of the two actors needs to adopt the others' idea (Shoham and Leyton-Brown 2008; Van Benthem 2014; Easley and Kleinberg 2010; Vollmer 2013; Goeree and Holt 1999; Camerer 1997; Binmore 2007; Rasmusen 2007).

A man and a woman share the same goal of going out together, but prefer a different destination. The woman prefers a baseball match and the man prefers the opera. The different preferences result in different strategies and create a 'battle'. To reach a decision and achieve the shared goal they need to anticipate each other's strategy. One of the two actors needs to adopt the other's viewpoint and go to the baseball game instead of the opera or the other way around. However, given the complete dependency of actors and the fact that no one can overrule the other by using power or information this is unlikely to happen. The battle will thus continue, probably delay the process, and eventually one of the actors will be the winner and the other the loser, which results in sub-optimal decision-making.

3 Methodology

Action research was the research approach employed in this study. It aligned with the general definition that says "research leading to action" (Lewin 1946) and was intended to have a dual outcome of action (in the design of the decision-making process) and research (exploring how the game concept approach was used) (Argyris and Schön 1989). The game theoretical characterization of the decision-making process came about as an interplay between researchers and participants in interventions. In the interventions, the participants used the game concept characterization to reflect on the situation and formulated strategies. Moreover, we assessed the uptake from the formulated strategies for the design of the decision-making process.

In this study, we performed an iterative process from data collection to data structuring, data analysis and data validation through various methods such as participatory interventions, interviews and reconciliation meetings.

Important to mention is the dichotomy in this research between (i) characterizing the decision-making process using game concepts, and (ii) giving back the characterization to designers of the decision-making process. The latter always happened during the interventions and, apart from intervention 1, by the researcher. The first

point, however, was sometimes performed by researchers beforehand, other times by participants during interventions, and at times by both researchers and participants. In Table 3, we specified the role of researchers and participants during the interventions.

3.1 Data Collection

In this study, we collected different types of data. The reason why the data was collected varied.

- Creation of an **overview** of decision-making process to understand the context, the actors involved and the issues present.
- **Identification** of game concepts to characterize the decision-making process.
- Presentation and discussion of game concepts with and by participants to come to **strategies**.
- Estimate the **uptake** of defined strategies and its consequences for the design of the decision-making process.
- **Validation** of results, in particular, validation of the overview and identification.

Table 2 lists the types of data collected and the above mentioned purposes. The order of the table does not correspond to the order in which data was collected. Since the interventions were an important part of this research we specify the details of the interventions in Table 3.

3.2 Data Structuring, Analysis and Validation

To explain how we structured and analyzed the data we use the different purposes of data collection.

An *overview* of the decision-making process was created by a timeline of events. The timeline contained the important decision moments, the actors and their incentives, and the issues present. Both researchers and program managers contributed to the timeline. Program managers did this during intervention 2 and intervention 3. Researchers provided a timeline, based on documentation, interviews, memos of meetings and recordings of interventions, before interventions 3 and 4 and adapted these afterwards. The interventions together with the validation sessions served to check the details of the process overview.

Identification of game concepts was performed by both program managers and researchers. In intervention 1 program members identified the game concepts using a game concept identification tool (Bekius 2019). The tool consists of characteristics of the game concepts. These characteristics were translated to questions regarding the process of decision-making. By answering a sequence of questions the tool presented one or more game concepts. In intervention 3, the game concepts were identified using the descriptions of the game concepts (see Sect. 2). In interventions 2, 3 and 4, researchers identified the game concepts before the intervention based on data

collected in interviews, meetings, and from documentation. Hence, those interventions were also a validation session for the game concept identification performed by the researchers. Moreover, during these interventions the identified game concepts were connected to the events on the timeline.

Formulation of *strategies* took place during the interventions. After the game concept characterization was presented to the participants, they discussed its meaning for the process of decision-making. The participants thought of ways to steer the game(s) identified and prevent the potential worst case scenarios from happening. More precisely, they defined strategies to (re)design the decision-making process. Researchers made notes during the interventions or coded the transcripts of the discussion afterwards.

Assessing the *uptake* from strategies formulated during the interventions happened both directly and indirectly. During validation sessions and meetings with program members we asked them which strategies were implemented and how they worked out. The program members formulated the strategies during the interventions and were able to assess to which extent these actions steered, changed, or contributed to the design of the decision-making process. Additionally, we questioned the consequences of strategies in an indirect way by interviewing different actors involved in the decision-making process. Questions during interviews concerned the quality of the decision-making process, the preparation of the decision weeks, the essential moments in the process, information and time available, and collaboration with other actors. Moreover, we followed the development of the process of decision-making using documentation and reconsolidation meetings with program members. In intervention 4, we described potential future game concept dynamics and interactions based on the previous collected information. Afterwards, we evaluated whether the dynamics and interactions of game concepts happened as expected by interviewing different program members. The interview questions concerned elements of the game concepts, and for each of these elements we questioned which strategies were performed to deal with that situation or what context prevented this situation from happening.

The methodology explained so far described how we accomplished the iterative process of collecting, analyzing, structuring and validating data. It showed how we applied game theoretical concepts in a real complex decision-making process, and returned the game theoretical characterization to the designers of the decision-making process and observed the impact on the process. The third objective, to provide lessons learned from the experience (interventions), is based on a reflection of the researchers and practitioners on the process afterwards.

4 Case Study ERTMS and Game Concepts

The case description considers a specific part of the decision-making process regarding the roll-out of ERTMS starting from the beginning of 2018, when preparations for a first decision week started, until mid-2019, when the Parliament decided on the implementation of ERTMS. This section gives an overview of the important moments in the decision-making process and highlights the elements and strategies of the game concepts present. Figure 1 provides an overview of the game concepts

Table 2 Data collected and its purpose

Data	Purpose	Details
Six interviews, actors: I&W, ProRail, NS, Regional operators, Freight operators	Overview, Uptake	Interviews used a semi-structured interview protocol and were recorded and transcribed afterwards. Questions concerned the process of decision-making, the first decision week, and the final decision. Moreover, game concept elements such as behavior of actors, trust, political influence, dilemmas and worst-case scenarios were included in the interview protocol
Documentation of decision week and decision moments	Overview	Documents (agendas, minutes of meetings, preparation documents, formal correspondence between main actors) were collected to trace the important decision moments in the process
Eight reconciliation meetings program management	Overview, Uptake, Validation	Memos of meetings were made, meetings were used to follow the process of decision-making, prepare for interventions, and keep track of the dynamics of the process
Four intervention sessions	Overview, Identification, Strategies Uptake, Validation	Use of game concepts to design decision-making process. Video and audio recordings were made from interventions. Discussions were transcribed
Four validation sessions chair program ERTMS	Overview, Strategies, Uptake, Validation	Memos of meetings were made. Feedback was included in content analysis and game concept interpretation

Table 3 Interventions

Session	Purpose	Details	Role(s)
1	Overview, Identification, Strategies	Identification of game concepts by program management using game concept identification tool. The workshop followed a structured format. Observations by facilitator were documented. (5 program management members, 2 hour session)	(i) Participants characterized the process and game concepts (during). (ii) Participants and researcher fed back characterization to other participants (during)
2	Overview, Strategies, Validation	Creation of a timeline of events with important moments, actors, issues, and incentives. Follow-up of intervention 1, discussion of how game concepts developed over time. (1 program management member, 1,5 hour session)	(i) Participants characterized the process (during), researchers characterized the game concepts (before & during). (ii) Researchers feedback characterization (during)
3	Overview, Identification, Strategies, Validation	Independent identification of game concepts using game concept descriptions. During session game concepts were placed on timeline of events. Discussion on how game concepts appeared, interacted, and what this meant for the process of decision-making. (chair program ERTMS, 1,5 hour session)	(i) Researchers characterized the process (before & during), participants and researchers characterized game concepts (before & during), and (ii) both feedback characterization (during)
4	Strategies, Uptake, Validation	Presentation of timeline of events using game concepts with a forecast of potential future game concepts and its elements. Discussion on what this could mean for the process of decision-making. (2 program management members, 1 hour session)	(i) Researchers characterized process and game concepts (before). (ii) Researchers feedback characterization (during)

Fig. 1 Game concepts present throughout the decision-making process

present throughout the decision-making process. Details about the role of the actors and strategies played in the game can be found in the text description.

Beginning 2018: Letter from freight operators to the Parliament The roll-out of ERTMS needed a timely and technically coordinated refurbishment of trains and infrastructure. Freight operators sent (separate) letters to the Parliament (a principal in the Principal-Agent game) about their worries regarding the process of introducing ERTMS. For the freight operators it was unclear which costs they needed to cover and no agreements were made regarding this issue. The need for investment in new trains by freight operators created a deadlock in the decision-making process (Multi-Issue game). Moreover, contractors wanted to confirm their position. As a result, freight and regional passenger operators started participating in the steering group of ERTMS which brought new perspectives to the decision table. New actors were introduced in the Multi-Issue game.

April 2018: Decision to start preparation phase of program ERTMS The first decision week concerned the approval of the ERTMS dossier for starting a BIT (Bureau ICT-Toetsing) test.¹ In preparation of this week, the actors of the steering group made process agreements which included finalizing the ERTMS dossier and investigating, and solving, a list of issues. The process agreements were an element of a Diners Dilemma. Final decisions regarding the list of issues needed to be made before summer 2018. The focus of the process so far had been mainly on content issues and new issues arose constantly because of the complexity of the system transition and the many uncertainties present. Content and context issues were on the agenda of the Multi-Issue game. The focus on content issues explained the over-complexity of the decision-making process. Moreover, technical uncertainties influenced the hierarchical relation between the Ministry (principal) and the railway

¹ The BIT test is a necessary gateway test conducted by the Ministry of Internal Affairs for all major ICT programs of governmental organizations in the Netherlands.

sector: ProRail as infrastructure provider, NS as main operator, regional and freight operators (agents) in a Principal-Agent game.

Mid-May 2018: Intervention 1 “Workshop session Patterns in decision-making processes” Members of the central program management organization ERTMS (in Dutch: programmadirectie ERTMS) identified game concepts for the current stage of the decision-making process and discussed their different views. Moreover, they discussed a possible design of the decision-making process.

Beginning June 2018: Intervention 2 “Follow-up workshop session” Building on Intervention 1, a timeline of events, including actors involved, their incentives, and the main issues was constructed. The participants recognized a Multi-Issue game and discussed its potential effects on the process of decision-making.

End June 2018: Final preparations of the first decision week At this point in time, two main issues were present. The first issue concerned a discussion between the Ministry and freight operators about the Masterplan freight transport. Exchange of issues, such as track access charges and noise pollution, took place in return for freight operators being committed to ERTMS. It influenced their position in the decision-making process. The exchange of issues to broaden the solution space was a Multi-Issue game strategy performed by the Ministry. Moreover, agreements between freight operators and the Ministry in the Masterplan were an element of a Diners Dilemma. The second issue reflected the following situation: there was asymmetry of information between the Ministry (principal) and the ProRail (agent). The Ministry did not have sufficient railway knowledge to fully steer the technical part of the program. Given its knowledge and position, ProRail was the best candidate to take a larger responsibility in the governance of the ERTMS program by being responsible for the program management. Moreover, the principal assigned to the agent the role of referee in conflict situations and distributed its power to close information gaps. This was a Principal-Agent strategy and concerned the positioning of ProRail, and especially the program management, as hub in a Hub-Spoke game. Therefore, one of the main questions to be answered in the decision week was: do the other main actors agree with the steering of the program ERTMS by ProRail?

The decision week was prepared in a very short time, resulting in limited time for reflections on the decisions to be made and late communication of information. This affected the pressure on and quality of the decisions to be made. The program management and the Ministry put pressure on deadlines, heading for a freeze of the dossier for the BIT test. Its aim was to decide on the list of issues prepared and finally decide on starting the BIT test after summer 2018. Pressure to start the BIT test was forced by European Union agreements. The pressure from the European Union (principal) was part of another Principal-Agent game in which the Parliament, and indirectly the Ministry, was one of the agents.

9-13 July 2018: The first decision week The main goal of the first decision week was to decide on the readiness of the ERTMS dossier to start the BIT test. The decision week was set-up as a ‘cascade’ of decisions which needed to be made by the different layers of the organizations. First, the different organizations discussed the decisions internally within their own organization. Then, the actors met at the Director meeting (in Dutch: Directeuren Overleg (DO)) and discussed the list of decisions again. Subsequently, the DO-meetings provided input for the Board of

Directors (in Dutch: Raad van Bestuur (RvB)) before the final decisions were made by the ERTMS steering committee at the end of the week. The decision week was organized as a Cascade game and as an effect the entire process before and after the decision week converged to and built on a Cascade game structure. The decisions needed to be adopted by the various predefined decision levels involving representatives of different organizations.

Decisions present in the decision week were connected to one another which is an element of a Multi-Issue game. For example, the issue concerning one or two system suppliers for implementing ERTMS was connected to the number of corridors which could be equipped with ERTMS given the available budget. Moreover, investing in a test corridor affected the number of corridors that could be included in the roll-out strategy. Starting the roll-out with corridor Kijfhoek-Roosendaal would give freight operators the burden of dealing with first-time issues. However, connecting this decision to the decision of assuring a test corridor resolved the issue. For the ATB-NG issue (an old safety system that needs to be replaced before ERTMS is implemented) no solution was found yet. ProRail as infrastructure provider wanted to introduce ERTMS immediately. However, this raised several new issues, contributing to the over-complexity of the process (Multi-Issue game), concerning the roll-out strategy that was decided upon and the need for investments in new trains earlier than expected.

Everyone was committed to provide clarity to the steering committee at the end of the week and postponing decisions until after summer was not challenged. The commitment showed that an agreement on the list of decisions and the shared goal to start the BIT test after summer was made (Diners Dilemma). Moreover, the Cascade game was not blocked by any actor at this point. After the decision week, the starting point for the introduction of ERTMS was clear, but certainly not everything was set. For instance, there were still no (formal) agreements with freight operators about the exact costs and the train specifications. Moreover, many issues remained and new issues were expected, therefore no consensus was reached in the Multi-Issue game.

End July 2018: Intervention 3 “Construct timeline of game concepts” The earlier constructed timeline was adapted and a game concept characterization was added to the timeline based on the dynamics of the first decision week.

Summer 2018: Completion of tasks after the first decision week Although freight operators agreed during the decision week on the list of decisions, afterwards they claimed that they needed more time and they actually disagreed with some decisions made. The freight operators, leasing companies, and contractors had different perspectives and were thus split-up. Additionally, ProRail, NS, and the Ministry sent letters to the program management with additional wishes and issues. The objections of actors after the decision week, due to the fact that time was limited and information was late, could be seen as a sub-optimal results of the Cascade game.

Some actors organized themselves and consulted political parties to influence the political level. This is an example of actors who were ‘freeriding’ (Diners Dilemma). It was in the freight operators’ interest to delay the process since investments in the future were necessary anyway. NS did not have an incentive to delay the process, but they wanted to have sufficient time to prepare the operation before introducing

ERTMS and they wished to maintain their autonomy. This situation could eventually result in actors violating the agreements made (Diners Dilemma) and blocking the Cascade game or at least delaying the process. The program management was positioned as independent actor (the hub), i.e., separate from the organization ProRail itself (one of the spokes). Its role was to challenge project plans from different actors and departments (other spokes). The spokes in the Hub-Spoke game were not aligned, moreover, the exact responsibilities of the hub were not fully clear and if they were clear they were not fully accepted by the spokes. The result was that spokes created strategic issues easily which delayed the process and created chaos (Hub-Spoke strategy).

The period after the decision week and before the start of the BIT test appeared to be too short to address all remaining aspects of the decision week. NS was worried about aspects concerning the planning of infrastructure and the readiness of the test corridor. Both situations could lead to a blockade of the Cascade game.

October 2018: The BIT test officially started.

January 2019: Results BIT test The advice from the BIT test arrived and its main point concerned the position of the program management in the process of decision-making. The program should conduct a system engineering approach and provide guidance on technical content towards the main actors. The advice suggested to use additional methods for managing this program. It said to change the role of the hub (program management) to a more strict and controlling role that did not leave room for conflicts and issues between spokes to occur (following a client-contractor model), this was a Hub-Spoke game strategy.

An example of such a conflict was the technological issue of where to build an antenna: on the train (preferred by ProRail) or into the infrastructure (preferred by NS). Both actors shared a common goal of introducing ERMETS in a feasible and good way, however, on this issue their preferences were in conflict. Since no one could overrule the other actor with power or information and no compromise was possible the conflict appeared (Battle of the Sexes). The fact that institutional uncertainty existed, i.e., no one could decide on the issue alone, this resulted in a delay of the process and affected the (trust) relations between actors. A solution (Battle of the Sexes strategy) was to involve a referee, in this case the hub (program management), who decided upon the issue and resolved the conflict.

February 2019: Intervention 4 “Potential future game concepts” A timeline including the period until mid-2019 was presented to participants based on the previous constructed timelines (including events, actors and issues) and a game concept characterization of the process. The timeline also described potential future activation of and interaction between game concepts. Participants validated the timeline and discussed how to deal with the game concept dynamics in the process of decision-making.

March/April 2019: Towards the second decision week In preparation of the second decision week, the program management organized several meetings with directors to make sure that urgent issues were covered. The main issues were the delayed tendering process concerning the infrastructure, the connection of the budget of the high speed line (HSL) and ERTMS, and the fact that freight train operators searched for support from the political level.

Moreover, technical briefings with the Ministry were held to discuss the details of the dossier ERTMS and the role of freight train operators in the process. This was a Principal-Agent strategy to minimize information asymmetry between the Ministry (principal) and the program management (agent).

April 2019: The second decision week The goal of the second decision week was to decide whether the ERTMS program could move from the planning phase to the realization phase. Hence, the decision to be made was: Is the ERTMS dossier ready for the decision by the Council of Ministers in May 2019? Depending on their decision, the decision would be reconsidered by the Parliament. If the Parliament's decision was positive, the tender process for new rolling stock and infrastructure could start, but only after an independent review approved that the recommendations of the BIT test were adequately implemented, as the Ministry promised to the Parliament. A third Principal-Agent game, the Parliament being the principal and the Ministry being the agent, was present.

During the second decision week the remainder of the decisions from the previous decision week and final points for finalizing the dossier were discussed. The decision week was organized similar to the first decision week starting with decision-making at the DO-level, then decision-making at the RvB level, and finally the steering committee ERTMS decided. Again a Cascade game was present since decisions needed to be adopted by the various predefined decision levels.

May 2019: Council of Ministers decision The Ministry of Infrastructure and Water management decided positively on the start of the implementation of ERTMS on 17th of May 2019.

June 2019: Parliament decision Despite the large budget allocated by the Parliament for implementation of ERTMS, the number of motions was relatively low and the decision of the Council of Ministers was adopted. Hereby, the principal in the second Principal-Agent game, i.e., the Parliament, finalized the cascade of decisions. During the process information asymmetry was minimized by the Ministry (agent) providing access to documentation, technical briefings, and progress reports (a Principal-Agent strategy). As a result, the principal and the agent shared the same incentives which meant that pressure for a certain outcome from the principal was not necessary.

5 Analysis of Interventions With Game Concepts

The previous section presented an overview of the ERTMS decision-making process and highlighted the elements of and strategies performed by actors in terms of game concepts. This section analyses the four intervention moments in which the game concept characterization was given back to designers of the decision-making process, i.e., program management ERTMS. For each intervention, we describe the main observation points by the participants of the intervention and explicate the strategies they formulated during the intervention. Subsequently, we present the consequences of those strategies for the design of the decision-making process. Notice that this section discusses game concept strategies at another level compared to the previous section. Where Sect. 4 characterized game concept strategies performed

by actors in the decision-making process, in Sect. 5, we discuss the game concept strategies (to be) performed by participants of the interventions as a result of the intervention.

5.1 Intervention 1: Workshop “Patterns in Decision-Making Processes”

Short summary: Participants identified the game concepts individually using a game concept identification tool (Bekius 2019). They discussed their view on which game concepts were present and reached consensus on two game concepts: the Multi-Issue game and the Cascade game. Additionally, they discussed potential next steps in the process of decision-making given the game concept context.

5.1.1 Observations and Strategies

- Actors involved in the decision-making process brought up new content issues continuously, but most new issues were not that much relevant with respect to the overall program goals. There was a risk of creating an over-complex process (Multi-Issue game). The over-complexity could have resulted in no decision being made in the first decision week. Extension of the decision was an undesirable outcome and seen as a worst case scenario due to the planned external BIT-audit. It was unlikely that after all the engineering work new insights would occur. Strategy (1): Change the focus of the process, from content to actors, their incentives, and the process of decision-making.
- The incentives of the different actors were not always clear, or at least not made transparent. Some actors could have retained the decision. This was something to pay attention to and affirmed that trust between actors played an important role. Strategy (2): Create an overview of actors’ preferences towards the issues of the Multi-Issue game. Focus on strengthening the trust relation with actors who can block the decision.
- The aim of the decision-making process, consensus among actors (Multi-Issue game outcome) or sufficient actors on board regarding the weight of the program goals and design of solutions, changed over time due to politics. Strategy (3): Aim for sufficient support of actors, i.e., their agreement with the main or sufficient decisions, and particularly focus on the interests of potential blocking actors. More specifically, give actors the opportunity to put their final points on paper and discuss them in the steering group.
- The process was not about one decision, but a sequence of decisions to be made in the coming years (Cascade game). The program management was part of a much larger game playing at different decision levels. Strategy (4): Create an overview for actors of those decision levels (Cascade game) and how the sequence of decisions evolves over time.

5.1.2 Consequences for the Design of the Decision-Making Process

Strategy (1) led to a focus on actors and the larger context in the process of decision-making. Together with strategies (2), (3) and (4) this resulted in the following: incentives of actors involved in the process were planned to be made explicit in the program plan, the next decision week as extension to make decisions was framed as no option, the number of issues was limited with support of actors, and the program specified a decision-making process as a sequence of decisions rather than as one decision.

In general, awareness of the Multi-Issue game and Cascade game, and how to use them explicitly in the decision-making process, increased. Based on these insights there was a need to further develop and investigate the game concepts identified. This was the motivation for a follow-up session on how to approach and organize the first decision week based on the Cascade game and the Multi-Issue game.

5.2 Intervention 2: Follow up “Patterns in Decision-Making Processes”

Short summary: Participants created a timeline of important events in the decision-making process. Attached to the events we specified the actors involved, their incentives and the main issues present. The discussion then focused on the Multi-Issue game and the Cascade game: How could the program management steer these games and thereby manage the process of decision-making, in particular, towards the first decision week?

5.2.1 Observations and Strategies

- The program management had to manage the Multi-Issue game and the Cascade game to reach the desired outcome. Two risks were observed: i) an over-complex Multi-Issue game (more and more issues on the table) and ii) a Cascade game blocked by one or more actors.
- There were two main issues: Masterplan freight train operators and the governance of the program ERTMS. Moreover, these two issues influenced decisions on other issues in the Multi-Issues game. In the decision week, decision makers needed to decide over the totality of issues. Strategy (1): Create an overview of the totality of issues and collect actors’ opinions on these issues.
- The desired outcome of the process was a decision supported by the actors involved, i.e., consensus reached in the Multi-Issue game. An undesired outcome was no decision since this would delay the process. Strategy (2): Focus on actors who can potentially block the Multi-Issue game. Which issues can be added to the agenda to stimulate exchange of issues?

5.2.2 Consequences for the Design of the Decision-Making Process

Strategy (1) led to a collection of opinions (in favor, neutral, or against) of the actors regarding the issues (decisions) planned for the decision week. It resulted in

a categorization of the decisions: decisions that were not ready and would be postponed to a later stage, decisions not objected to by any actor, content decisions with objections from at least one actor, financial decisions, and decisions regarding the roll out of ERTMS in the Netherlands. The categorization provided the basis for the agenda, i.e., the sequence of topics and issues, of the decision week. Apart from collecting opinions on single decisions, the program management questioned the dependencies between the two main issues and preferences for the other decisions. This provided an idea on how potential blocking actors could be kept in the game to support the total set of issues (strategy 2).

The program management used the information to decide on the order of decisions on the agenda and balance decisions that would take short time (since everyone agreed) with decisions that would need more time for discussion (since actors had opposing opinions). This process steered the way in which the cascade of decisions in the decision week was structured (Cascade game) while taking into account the multiple issues that played a role in the context (Multi-Issue game).

Actors involved in the decision-making process were informed about the agenda and the structure of the decision week by the program management before the decision week started. This helped in giving the program management a neutral position (as hub in the Hub-Spoke game) during the decision week in which the actors involved should come to an agreement. The position of the program management as such contributed to the level of trust between actors. It had been reported that the decision week was structured and well prepared, the right issues were discussed and there was room for all actors to present their opinions. Moreover, actors involved in the decision week reported a high level of trust.

5.3 Intervention 3: Analysis of Game Concepts Over Time

Short summary: Participants adapted and extended the timeline of events from Intervention 2 with future events, actors and issues. They were able to identify and describe the game concepts themselves in the process of decision-making. The intervention included the total set of game concepts instead of only focusing on the Multi-Issue and Cascade game. Moreover, the scope was broader since it considered future decisions until the year 2025 and its potential dynamics.

5.3.1 Observations and Strategies

- The position and coordination role of the program management was crucial for the continuation of the process. There was an increased focus by the Ministry to strengthen the position of the program direction ERTMS in legal terms. Strategy (1): The Ministry positioned the program management as hub in the Hub-Spoke game and agent in the Principal-Agent game.
- One could not change decisions at a later stage without risking a lot of budget to be spend. This is called the convergence of decisions in the Cascade game. Strategy (2): Create awareness of this aspect to prevent sub-optimal outcomes of the Cascade game.

- Actors violating agreements (Diners Dilemma) or creating deadlocks (Multi-Issue game) would delay the process. Strategy (3): The Ministry connected ERTMS issues to context issues, i.e., they created a support package for freight train companies (Maatregelenpakket) and thereby broadened the agenda of the Multi-Issue game. Strategy (4): Moreover, the Ministry wanted to stimulate cooperation between operators to prevent violation of agreements in the Diners Dilemma.

5.3.2 Consequences for the Design of the Decision-Making Process

Positioning the program management as a hub (strategy 1) aimed at minimizing information asymmetry and confusion about incentives. The program management functioned as an intermediate actor between the other actors and the Ministry. As a result, the Ministry did not need to be involved in all technical discussions. Moreover, in case of conflicts between actors (the spokes) about system integration aspects, the program management (hub) had the power to decide in favor of one actor and provided the other actor with compensation. The Ministry had limited knowledge of these system aspects and could not make an objective decision. The formulation of the hub-position in legal terms in the governance led to situations in which conflict situations could be dealt with easier and faster.

To prevent sub-optimal outcomes of the decision week (strategy 2), the cascade of decisions was taking place in one week. During the decision week, both internal decision-making within organizations and decision-making between organizations was performed iteratively. The fact that decisions were made consecutively in a short time decreased the risk of forgetting or ignoring what had been decided upon previously and alerted decision makers to inconsistencies among decisions.

The connection between ERTMS issues and context issues (strategy 3) led to a broader agenda. The discussion between freight operators, program management and the Ministry created room for a give-and-take of issues eventually preventing a deadlock in the decision-making process. Together with stimulation of cooperation between operators (strategy 4) this reduced opposition during the decision week.

5.4 Intervention 4: Forecasting Future Game Concepts

Short summary: Participants discussed a characterization of the decision-making process based on Intervention 3. Researchers included a preview of the decision-making process and described potential future game concepts and their dynamics. The total set of game concepts was included. Participants explored options and solutions to prevent situations which could be destructive for or delay the process of decision-making.

5.4.1 Observations and Strategies

Given the game concept characterization over time of Intervention 3 we expected the multiple Principal-Agent games, Multi-Issue game, Cascade game and Hub-Spoke

game to continue towards the second decision week. Moreover, a Battle of the Sexes, Volunteers Dilemma and Diners Dilemma could appear and be destructive for the process and its outcome. The program management recognized the game concepts presented and their potential risks. A worst-case scenario for them was the final decision being postponed by the Parliament which could happen for several reasons.

- Actors who disagreed with the set of decisions started lobbying by the Parliament. Strategy (1): Show actors that cooperation is key for this process with financial incentives (prevent a Diners Dilemma), and invest in the trust relation between actors by recognizing their worries and providing solutions.
- New issues emerged at the table and opened up a new area of issues to be resolved (over-complex Multi-Issue game). Strategy (2): Create a context in which actors are aware that this is the only moment for a decision by the Parliament to go from ERTMS plan to implementation. Focus on actors' incentives instead of technical issues they bring up.
- Actors could leave the process or block the cascade of decisions (Cascade game). Strategy (3): Provide information regarding the second decision week on time and give sufficient time for internal decision-making within organizations. Moreover, focus on the importance of the decision moment at the level of directors of organizations.
- Pressure from European Union due to time, budget, and cooperation with other countries increased. Strategy (4): Manage the multiple Principal-Agent games by reducing information asymmetry and differences in incentives. This is crucial to prevent misalignment of actors, in particular between the Ministry and the Parliament.
- Conflicts and dilemmas between actors on content issues delayed the process (Battle of the Sexes). Strategy (5): Position the program management as mediator and objective actor in conflict situations between actors (to resolve a Battle of the Sexes). Moreover, introduce an extra condition in the subsidy arrangements such that the program management has the mandate to decide on technical issues.

5.4.2 Consequences for the Design of the Decision-Making Process

In meetings with directors of organizations prior to the second decision week the decision makers accommodated to the message of the program management: "there is a single chance to get the ERTMS dossier from plan to implementation and the chance is now" (strategy 2 and 3). Decision makers came to a common understanding of this situation which helped the discussions and decreased the number of issues coming up. This prevented an over-complex Multi-Issue game. Moreover, it set the basis for actors not performing unexpected behavior in the final stage close to the decision week. For example, blocking a Cascade game or acting as a volunteer in a Volunteers Dilemma.

The Ministry took its role in decreasing the information asymmetry and minimizing power play with the Parliament (strategy 4). This helped in dealing with the limited number of motions and during technical briefing with the Ministry. Moreover,

they addressed the urgent issues in the final stage and permitted the actors involved to negotiate about it. These issues therefore did not complicate the decision week or decision-making at the Parliament level.

In case of conflicts or issues such as with the HSL, the program management formulated one consistent answer. Its role as mediator and objective decision maker was to a certain extent accepted by the actors involved (strategy 5). The acceptance was caused by the shared understanding that a decision was needed (strategy 2) and thus actors kept their opinion to themselves and did not bring it up with others.

Freight train operators did not try to block the decision of the Parliament, since they realized that a broad support across the Parliament had emerged and wanted in an upcoming stage to fight again for more budget. The program management acknowledged the position of the freight operators and promised extra support for their issues (strategy 1).

To conclude this section, we summarize the main consequences for the design of the decision-making process as a result of the formulation of strategies based on the game concept characterization.

The program management shifted towards a focus on actors and their incentives instead of on new issues, and they adapted the decision-making process accordingly. A result was the implementation of two separate decision weeks. To prepare for the decision weeks the program management identified the incentive structures of actors. Moreover, the program management adapted its role and responsibility to resemble a client-contractor model in which they became the neutral organizer of the decision-making process. It had been reported that decision weeks were well structured with decisions clustered around themes and the ordering dependent on the incentive structures of actors. This contributed to the level of trust between actors.

We observed a strengthening of the program management to better deal with conflicts in and prevent delays of the decision-making process. As a neutral actor, close to the technical system integration issues, they were better able to make objective decisions than the Ministry. In the final stages, the initiated coupling of issues was prevented by the program management being more secure in its role.

Coupling of issues by the Ministry for the freight train operators resulted in a broader decision-making process. Due to this strategy, smaller freight train operators got involved, which had historically proven difficult. Moreover, the program management invested in the relation with freight train operators, all to prevent them from blocking the decisions.

The game concepts assisted in supporting a consistent communication of the main message: there is a single chance for a decision by Parliament and that is now. This consistency decreased the number of new issues and set the basis for actors not enacting unexpected behavior in the final stage close to the decision week.

Finally, we observed an effect in minimizing the information asymmetry between principal and agent when multiple Principal-Agent games were present. It has been reported that the decision by the Parliament after the decision of the Ministry went quite fast. Due to minimizing the information asymmetry and sharing the incentives a level of trust was created which helped adopting the final decision.

In the next section, we take a step back and provide lessons learned from the experience of intervening in a decision-making process with game concepts.

6 Reflection on Methodology

Pursuing a project like this brings with it a number of challenges, as is common for action research. This section provides some reflections from the experience of intervening in a decision-making process with game concepts. Initially, the lessons are framed as points to consider when repeating this study in different organizations or domains to overcome the exploratory character of the current study. However, these lessons could even be valuable for practitioners who are interested in approaches that assist in the design of a decision-making process.

The research design can be seen as a cycle: process analysis → intervention with designers → evaluation of strategies, and back to process analysis. Zuber-Skerritt (1991) distinguishes four phases: plan (analysis), act and observe (intervention), and reflect (evaluation). In this study, we performed the cycle four times. However, the phases (analysis, intervention, evaluation) are not always distinct. During interventions, so when one acts and observes, analysis as well as evaluation can take place.

Lesson 1: A rigid design of steps and cycles provides clarity, but requires flexible adjustment during the process.

As with the nature of action research, the role of researchers and participants in the research cycle is dynamic (Robertson 2000). The role of researchers and participants can vary between the phases of the cycle and can differ across cycles. In our study, the role of researchers and participants in the interventions was made explicit in Table 3. We observed that participants had a larger role in the characterization of the process and game concepts in the earlier interventions and researchers were more dominant in giving the information in the later interventions. An explanation for the shift in roles could be that researchers gained more insight in the decision-making during the process and were therefore better able to characterize, and even forecast future dynamics of, the decision-making process. Given the information asymmetry between researchers and process designers, we experienced several moments of tension between roles.

Lesson 2: Be explicit about the role of researchers and participants in the different phases of the research cycles. In particular, regarding the use of game concepts. Questions to clarify are: Who identifies the game concepts? Who validates the identification? (process analysis); Who presents the game concept characterization? Who interprets the game concept characterization? (intervention); Who assesses the effect of the formulated strategies of the intervention? (evaluation).

Although the interventions took place at the level of the design of the decision-making process, i.e., with designers of the process, the perspectives of the other actors at different levels involved in the process needed to be included. This was necessary to obtain an overview of the process itself, but most importantly to evaluate the consequences of strategies formulated for the design of the decision-making process.

Lesson 3: Include information from actors involved at different levels of the decision-making process. This can be done in two ways: Indirectly, by asking the designers of the process to introduce the perspectives of different actors; and directly, by interviews with, observations of, or documentation from actors themselves.

It was crucial to be aware of the changing dynamics of the decision-making process to prevent the game theoretical characterization being inaccurate (or just wrong). Assuming a constant actor constellation is not reasonable for such processes.

Lesson 4: Find a way to keep track of changing dynamics between intervention cycles. There are a couple of solutions here: (i) let participants characterize the process themselves during the intervention; (ii) start the intervention with validating the characterization, or do this beforehand; (iii) have at least one linking actor, part of the design team, who can provide updates about the process and changing dynamics.

Similar strategies were formulated in different interventions. For example, strategy 2 of intervention 1 and strategy 1 of intervention 2 overlap. An explanation could be that different participants were involved in the interventions, but also that the observation of the situation preceding the formulated strategy was still present. During interventions, participants did not always come up with new strategies, but also re-articulated strategies that were formulated before. Sometimes the moment to put the strategy into action was not directly after the current intervention, but only after the next intervention.

Lesson 5: A suggestion for further research is to not only consider the interventions separately, but to view them as a whole and examine how strategies developed over time as well as the consequences of these strategies for the design of the decision-making process.

In all interventions, the participants used the game concepts, but the way in which they used them was different. In this study, the way in which game concepts were used was dependent on (i) the size and constellation of the group, (ii) previous experience with and thus existing knowledge of the game concepts, (iii) the time available for the intervention, and (iv) the information researchers had about the decision-making process beforehand.

Lesson 6: When repeating this study on a larger scale, align a number of those points such that the value of the way in which the game concept approach is used by participants can be better assessed.

7 Conclusion and Discussion

The objective of this paper was to explore the value of descriptive insights from game-theoretic analysis for dynamic interventions in the design of a process. The study applied game theoretical models to characterize a complex decision-making process and gave back the information to the designers of the process. The experience showed that the effects of such an approach could potentially make game theoretical models relevant to practical decision-making in a new way. Moreover, we provided lessons learned based on the experience for both researchers and practitioners. The context in which this research took place is the case of ERTMS in the Dutch railway sector.

First, we described the process of decision-making and highlighted the game concept elements. Second, we analyzed the four interventions with designers of the decision-making process. They used the game concept characterization to formulate

strategies. Subsequently, we investigated the consequences of the strategies for the design of the decision-making process. The consequences for the process can be summarized as follows: an actively supported adaptation of an actor focus in the process, it affected the role and responsibilities of the program management, it contributed to the (de)coupling of issues, and it influenced the capability of creating awareness amongst actors of the urgency of the decision window. It also avoided the expected actor behavior of complicating the final stage of the decision-making process. Finally, we reflected upon the study as action research and drew six lessons learned for both researchers and practitioners.

The paper contributed to the theoretical framework on complex decision-making in multi-actor systems. We characterized the process by multiple game concepts instead of talking about a (single) game and an optimal outcome. Parallel interacting game concepts existed in the decision-making process which played at different levels of the organizations involved.

We showed how game theoretical models can *assist* in a complex decision-making process by giving back the game theoretical characterization to designers of the process. We provided a successful example of a case where a descriptive analysis led to the formulation of strategies instead of using the normative value of game theoretic models. This point is of interest for the broader use of game theory, or formal models in general, in the area of participatory decision-making and design of organizational processes.

Moreover, instead of actively intervening in behavior of actors outside their real context, these interventions targeted the design of the decision-making process. By investigation of the consequences of the formulated strategies in interventions, we contributed to the area of evaluation of participatory interventions. The game concept approach proved to be flexible in aligning with an ongoing process, and did not overtake the process as, for instance, decision-support systems do and to a certain extent also gaming does.

Finally, the paper contributed to the field of decision support and action research by providing methodological reflections on the use of the game concept approach as presented in the paper. The exploratory nature of the study makes it impossible to draw firm conclusions and shows its limitations, however, the reflections provide a starting point for further research in this area.

Acknowledgements This research was funded by ProRail (Dutch Railway Infrastructure Manager) and Delft University of Technology. The authors especially thank Peter Scheffel for his input and time during this study. Moreover, we thank the editor and reviewers for the valuable comments which definitely improved the paper.

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Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Femke Bekius¹ · Sebastiaan Meijer² · Hugo Thomassen³

Sebastiaan Meijer
smeijer@kth.se

Hugo Thomassen
thomassen@slotcoordinator.nl

- ¹ Nijmegen School of Management, Department of Methodology, Radboud University, Heyendaalseweg 141, Nijmegen, The Netherlands
- ² Department of Health Informatics and Logistics, KTH Royal Institute of Technology, Halsovagen 11C, Stockholm, Sweden
- ³ Director Airport Coordination Netherlands, Former Director Program ERTMS, Ministry of Infrastructure and Watermanagement, Schiphol, The Netherlands