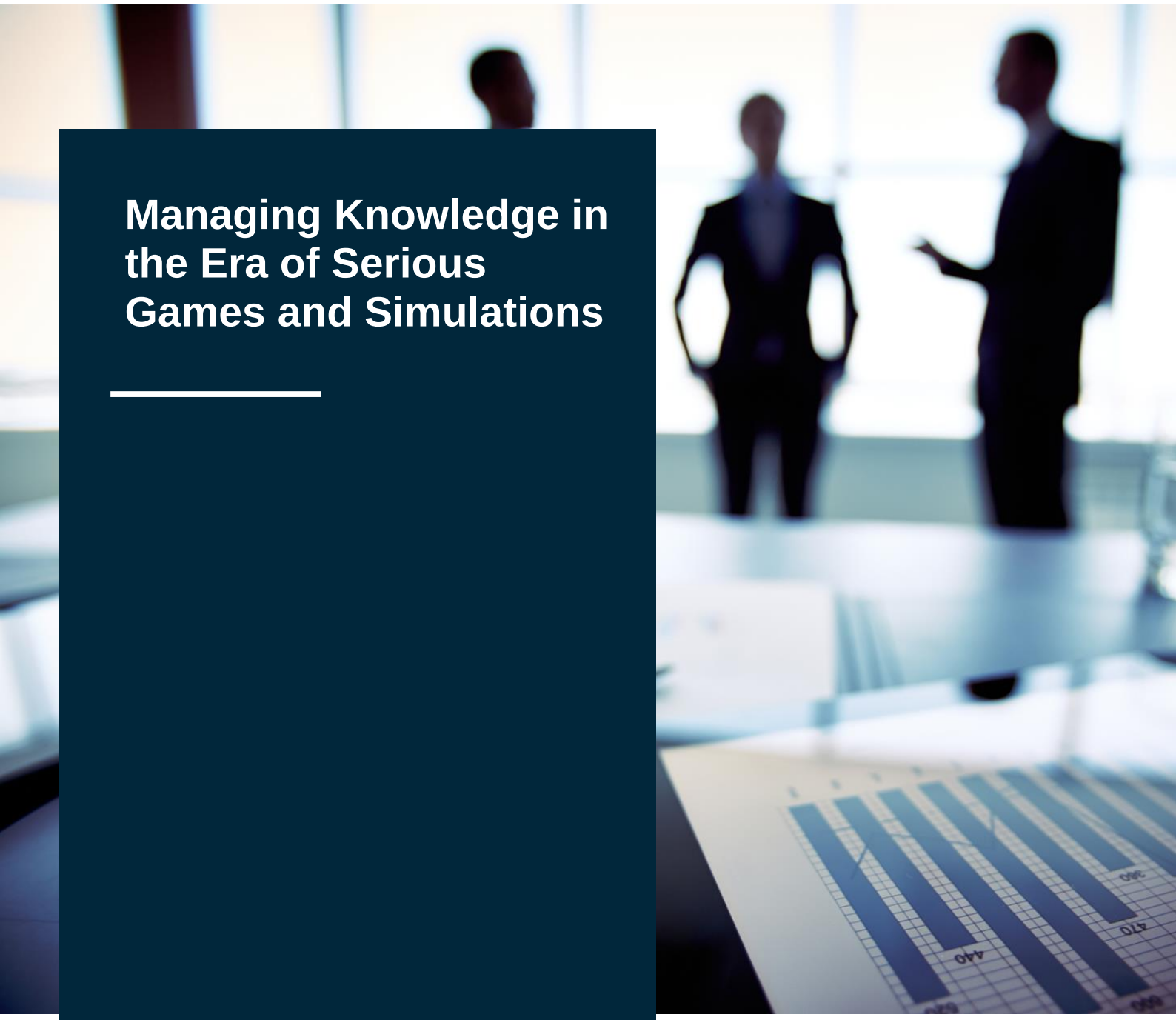

Managing Knowledge in the Era of Serious Games and Simulations

Master Thesis

M.Sc. Management of Technology
Faculty of Technology, Policy and Management
Rachele Angeletti 4581652

ProRail

TU Delft

MANAGING KNOWLEDGE IN THE ERA OF SERIOUS GAMES AND SIMULATIONS

An exploratory study on the elicitation of serious games' requirements for the generation and reuse of knowledge

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Rachele Angeletti
Student number: 4581652

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Graduation committee

Chairman:	Prof.dr. Alexander Verbraeck, TU Delft, Policy Analysis
First Supervisor:	Prof. Scott Cunningham, TU Delft, Policy Analysis
Second Supervisor:	Dr.ir. Udo Pesch, TU Delft, Ethics and Philosophy of Technology
External Supervisor:	Jelle van Luipen, ProRail

EXECUTIVE SUMMARY

The extensive amount of knowledge possessed by an organization represents one of its most valuable resources. Nonetheless, it is not always easy to pinpoint, arrange and reuse such knowledge in an effective and productive manner. Nowadays, in fact, organizations are overwhelmed by the quantity data and information, making it more and more difficult to retrieve the needed knowledge at the right time for the right person, to create value from available knowledge, or to make use of non-directly available knowledge (e.g. individuals' know-how, skills, processes and procedures). Moreover, in the last two decades companies have been increasingly using serious games and simulations for the most diverse scopes. While a consequent interest has been growing in the field of knowledge management regarding how to codify and reuse the information generated by these new innovative tools, there is still no clear understanding of what are the games' requirements which are responsible for the generation of knowledge. In addition to this, many theories can be identified in the available literature which developed methods and models for knowledge conversion and sharing; however, none of this models has yet been applied to the context of serious games and simulations.

As a consequence of this recognized gap in the available literature, as well as of the need for organizations to develop a series of knowledge management systems and practices for the sharing and reusing of knowledge generate through games, the following research question has been formulated:

What are the necessary requirements for games to foster the development, as well as the reuse, of tacit knowledge?

Primary scope of this thesis project has thus been to determine what games' elements represent a fundamental requirement for the generation of both explicit knowledge and tacit skills. In addition to this, the research has taken into consideration different groups of actors (game designers, participants/players, project team members, managers), and attempted to verify whether any dissimilarities exist among these groups in the way of perceiving games' requirements, and their impact on knowledge creation and sharing. Finally, in the light of the obtained results, suggestions have been proposed on the most appropriate knowledge management systems and procedure to use in the context of serious games and simulations.

The research has been carried out in the form of an embedded, single-case study: the main unit of analysis - and client - was ProRail, the government organization which manages the maintenance and extensions of the national railway network infrastructure, the allocation of rail capacity, and the traffic control. The embedded units of analysis were instead represented by different games employed within the organization (OV-SAAL, Ketensimulatie, ERTMS). Once the games have been identified, other research methods have been applied within the case study framework. First, an in-depth literature review was performed, in order to examine which theories, among the existing ones, would have been the more suitable for framing the problem at hand. Then, semi-structured interviews were performed on a sample of 19 respondents belonging to the four identified groups of actors. The first few interviews were used as a basis for building the constructs used in the Q-sort methodology, a technique based on submitting to the interviewee a set of statements, which she is afterwards asked to rank from 'most agree' to 'most disagree' according to a predetermined normal distribution. The statements, in this specific case 40, were crafted in a way to represent as many game elements as possible, while at the same time linking said elements to the quality of the obtained results, and/or to the possible generation of knowledge.

By performing both semi-structured interviews and Q-sort technique, it was possible to gather a substantive amount of both qualitative and quantitative data. The analysis of such data was execute by means of different tools. First, the semi-structured interviews were tran-

scribed and coded on the basis of a coding scheme. Then, the coded transcripts were analyzed with the objective of finding recurring references to contextual factors and game characteristics which influence the output of the game, both in terms of expected results and generated knowledge. After this qualitative analysis, four contextual factors and twelve game features were identified, while five different categories of knowledge were recognized as resulting from the participation in the games. Further analysis was then performed, with the objective of verifying whether certain contextual factors, game characteristics or types of knowledge were observe by just some specific groups of actors. The process resulted in actually identifying some dissimilarities among the actors' responses.
In order to confirm and clarify the results, a quantitative analysis was executed on the obtained Q-sorts. The results of the Q-sort were coded as vectors representing the value that each respondent (observation) assigned to each statement (variable). Once created a data set, many different inquiries were performed in order to unravel trends and difference among the respondents. At first the statements were ranked on the basis of their total score, enabling the identification of aspects generally considered more or less relevant. Then, for each statement, average and variance were calculated. The observations were later divided on the basis of the role of the interviewee (game designers, managers, etc.), organization of belonging, and acse study (i.e. game) the respondents took part it. For each group in each division, the centroids were calculated and confronted with the total average of the sample. This juxtaposition brought to light further revelations concerning the perception of different games' elements, especially depending on the role performed by an employee. To conclude the quantitative analysis, two algorithms were applied to the gathered data, with the objective of revealing possible hidden correlations among the variables (statements), or latent similarities among the observations (interviewees). In order to accomplish the first, the Principal Component Analysis method was applied, both through XLSTAT (an Excel add-in) and R Studio. This technique, however, lead to inconclusive results: this could be motivated by different reasons, one being the high ratio between number of variables and number of observations, or a second the too diverse content of the statements. To find out the latter, instead, the k-means clustering algorithm was implemented (once again both in Excel and R-Studio): the results showed a division of the respondents into four different cluster, or classes, which almost perfectly corresponded to a division per role. The surprising output consist in the fact that, with regards to other divisions (per organization, per game/case study), the clusters resulted quite variegated, indicating that the role of the respondent might have the biggest influence on the way of perceiving games, their role within the organization, and related KM practices.

As a conclusion of the above described analysis, three main objectives were accomplished: 1) the identification of game requirements and contextual factors which influence, positively or negatively, the processes of knowledge sharing and knowledge generation; 2) the classification of generated knowledge into five categories; 3) the recognition of similarities and dissimilarities, among actors performing different roles, in the way of perceiving and evaluating the previously identified elements. All the obtained results were attentively described and displayed in tables. The main outcome of this thesis project consists in the individuation of game elements which are essential requirements for the generation of knowledge, in particular tacit skills and know-how. Additionally, discordances among different groups of actors/roles in the perception of each requirement are identified and registered.

Completing this dissertation report, recommendations for ProRail, the customer of this thesis project, have been outlined. The previously described insights, obtained from both the quantitative and qualitative literature, were combined with theories from available literature in order to define suggestions for a knowledge management framework for serious games and simulations. First, two existing theories were merged and applied to the current situation of ProRail, with regards to knowledge management for games: 1) Nonaka's SECI model, also known as Knowledge Spiral Model; and 2) Blacklers' four categories of knowledge on a cognitive level (embrained, embodied, embedded, encoded). After individuating existing strengths and weaknesses, the resulting combined model was applied once again, this time with the

objective of displaying the advantages of possible future improvements. Finally, as a sum of all the formerly performed investigations, an hybrid knowledge management framework has been proposed. The suggested framework, result of the joint efforts of different TU Delft researchers and ProRail's employees, is presented in the second-last chapter of this dissertation in the form of a set of recommendations for ProRail. Due to time and resource constraints, it was in fact not possible for the author to further expand on the subject, in addition to answering to the main research question. It is hoped, however, that the proposed framework will be used as a groundwork for future studies, and that ProRail will find it useful, as well as all the previously described results, for prosecuting and improving the management of knowledge created and transferred through games and simulations.

ACKNOWLEDGEMENTS

The accomplishment of this thesis project signs the end of an incredible experience, the conclusion of two of the most extraordinary years of my life. It was an amazing, yet sometimes rough, journey, during which I learned more that I could have ever expected. I did not only advanced in my academic career, but I first and foremost became a different and better person. I learned new languages, I met amazing people from all over the world, I realized the value of my roots, of treasuring old friends and family, and I got many steps closer to become a young professional. Not a day goes by without me feeling grateful for the incredible opportunity that I had in TU Delft, because here I found another home.

I want to express my gratitude for the help received during this research to my supervisors and to the members of my Graduation Committee: Alexander Verbraeck, Scott Cunningham, Udo Pesch, Jelle van Luipen. I could have never completed this project without their experience and insights, that guided me throughout the almost seven months of this research. My appreciation goes as well to Bill Roungas, who followed me in my everyday activities, and allowed me to co-author two academic papers. I am immensely thankful to Jelle van Luipen, and ProRail in general, for having given me the opportunity of working on my project in real organization. It was an experience I will always cherish.

I am grateful for the valuable and constant cooperation, guidance, and support of Julia Lo and Femke Bekius, whose advises were crucial in many moments of difficulty or frustration. I thank them in particularly for always reminding me, through the competence and dedication they put into their work, the meaningfulness and significance of my project. I feel so glad to have encountered, during the execution of this research, so many genuinely passionate people. Their enthusiasm and commitment has been inspiring to me. I would like to thank all of those who gave me the opportunity of interviewing them. Knowledge management was an argument that I knew very little of, when I first initiated my study. It is largely thanks to the experience, availability, and willingness to share of the people I got in contact with that I learned to appreciate the value of knowledge, and the fundamental importance of personal interaction.

On a more personal level, all of this would have never happened if I had not had the support of my family, that believed in me and in my dreams, and allowed me to undertake the wonderful adventure that were my two years in TU Delft. I will be forever grateful for this opportunity, especially knowing all the sacrifices that it cost. Endless love goes to my sister, who was always there with me, even with thousands of kilometers between us.

I am truly grateful for all the friends, close and faraway, who have in a way or another shared with me this wonderful journey, and to my boyfriend, for the help and support he has given me during this thesis project.

To the conclusion of an adventure, and to new ones yet to come!

I wish you a good reading,
Rachele

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NNC National Network Controller . . . 38
NPTC National Passenger Traffic Controller . . . 38
PCA Principal Component Analysis . . . 29
RPTM Regional Passenger Traffic Controller . . . 38
ERTMS European Rail Traffic Management System . . . 4
RNC Regional Network Controller . . . 38
RPTJC Regional Passenger Traffic Junction Coordinator . . . 38
RPTMPC Regional Passenger Traffic Material and Passenger Coordinator . . . 38
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SSE Sum of Squared Errors . . . 30
ERA European Union Agency for Railways . . . 36
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1 INTRODUCTION

This first chapter will serve the scope of the presenting the main concepts which will be at the center of this research. The general scope of the study will also be introduced, followed by an explanation of the reasons that make the considered problem relevant under many different perspectives.

1.1 KNOWLEDGE AND ORGANIZATIONS

Knowledge is a key resource of potential advantage for any kind of company or organization [Ichijo and Nonaka, 2006]. Many studies have recognized the fundamental role of knowledge, even arriving to the point of defining it "the only meaningful economic resource" [**?**]. Therefore, the processes by which knowledge is created or collected, transfered and employed must be adequately administered [Quintas et al., 1997].

An adequate management of the knowledge possessed by an organization grants it the opportunity of recognizing and rediscovering its assets, and utilize them to their highest potential. Knowledge Management (KM) is the set of systems, measure and practices which permits the release of such a potential by means of "identifying, capturing, evaluating, retrieving, and sharing all of an enterprise's information assets. These assets may include databases, documents, policies, procedures, and previously uncaptured expertise and experience in individual employees" [Duhon, 1998].

1.1.1 Knowledge Management

KM can be considered as the process of applying a systematic approach to the acquisition, structure, management, and dissemination of knowledge throughout an organization in order to operate quicker, reuse best practices, and reduce duplicated efforts from project to project [Nonaka and Tekeuchi, 1995; Pasternak and Viscio, 1998; Pfeifer and Sutton, 1999; Ruggles, 1999].

A more recent definition of KM by Dalkir and Beaulieu [2017]:

Knowledge management is the deliberate and systematic coordination of an organization's people, technology, processes, and organizational structure in order to add value through reuse and innovation. This coordination is achieved through creating, sharing, and applying knowledge as well as through feeding the valuable lessons learned and best practices into corporate memory in order to foster continued organizational learning.

KM is a multidimensional discipline in nature, drawing upon a wide range of different fields, such as: organizational science, cognitive science, linguistics and computational linguistics, information technologies, electronic performance support systems, database technologies, anthropology and sociology, education and training, storytelling and communication studies [Dalkir and Beaulieu, 2017].

Benefits and Drivers of KM

KM generates many benefits for organizations [Alavi and Leidner, 2001; Lucena, 2016; Liebowitz and Megbolugbe, 2003], such as: enabling better and faster decision making; reusing ideas,

documents, and expertise; sharing relevant information in a fast and flexible manner; building up standard, common practices and procedures; spreading rare skills and expertise; improving employees' engagement and communication; discovering and categorize knowledge; defending valuable knowledge; and creating an environment where new knowledge can be developed. In particular, this research project would focus on the relevance of KM as an instrument for eliciting, categorizing and reusing tacit knowledge.

KM covers a fundamental role in organization, due to four major business drivers [Dalkir and Beaulieu, 2017]: 1) the globalization of business, which implies that companies are becoming every day more global, multilingual, and multicultural; 2) the rise of lean organizations, in which knowledge workers are required to work faster and smarter, adopting an increased pace and workload; 3) the phenomenon of "corporate amnesia", caused by the increased mobility of workforce, which in turns generates problems of knowledge continuum and consistency for companies and firms; 4) progresses in Information Technology (IT), that did not just make connectivity universal, but have also entirely altered expectations (everyone is expected to be "on" at all times).

Challenges of KM

As there are so many aspects contained in the discipline of KM, there are as many issues related to it, which makes it critical for an organization to correctly approach it [Alavi and Leidner, 2001; Lucena, 2016; Liebowitz and Megbolugbe, 2003]. Such challenges can be classified into three main categories:

- Information ⇒ Today's enormous amounts of data are becoming more and more complicated to transform into practical information. With regards to this issue, the main scope of modern KM practices is to prevent users from being overloaded by unnecessary data, while guaranteeing privacy and security, and maintaining information updated.
- Management ⇒ With regards to the managerial perspective, KM measures have to motivate people, business units and departments to share knowledge, while at the same time stimulate individuals to learn from shared knowledge. One way to do so is to manifest the business value of knowledge, and bringing together employees from different business units or hierarchical levels.
- Technology ⇒ Concerning this element, KM needs to establish infrastructure requirements, sustain technological advancement, and ensure security and safety of data access.

1.1.2 Relevance of tacit knowledge

One of the biggest concerns in KM is generated by the type of knowledge that needs to be collected or shared: explicit knowledge is way easier to be managed than implicit one. Implicit, or tacit knowledge is however often the most valuable one, since it is the product of the interaction between several complex elements, such as experience, context, values, intuition, know how. There is in fact no way of putting the knowledge gained through years of experience in a document, which upon reading it a beginner becomes an expert.

Knowledge, and especially tacit knowledge, is recognized to be one of the most valuable asset for any kind of company or organization [Nonaka and Tekeuchi, 1995; Grant, 1993; Spender, 1993]. Although crucial to organizational decision-making, tacit knowledge has shown resistance to be operationalization and has been sporadically subject of scientific inquiry [Brockmann and Anthony, 1998]. To quote Rao [1994], "despite widespread agreement among organizational researchers that intangible resources underlie performance differences among organizations, little empirical evidence exists in the literature" and there is a "need to know much more empirically about the nature of tacit knowledge for it to become a theoretically coherent and convincing construct" [Jensen, 1993].

Technology may simplify and assist the storing of explicit knowledge, however, tacit knowledge lies in people's minds, and its employment is only dependent on individual resolutions

and relations[Cross and Baird, 2000; Fahey and Prusak, 1998; Hinds and Pfeffer, 2003; Lucas, 2005].

1.1.3 Information Technology for Tacit Knowledge Sharing

One dominant controversy among researchers, nowadays, regards whether IT could play a role in sharing tacit knowledge among individuals.

Some, earlier than the social web era, claim that tacit knowledge sharing through IT is too limited, if not definitely impossible to attain [Haldin-Herrgard, 2000; Hislop, 2002; Johannessen et al., 2001; Haldin-Herrgard, 2000].

Others dispute that IT can speed and simplify the processes of tacit knowledge sharing, even though it may not be as comprehensive as face-to-face interactions [Falconer, 2006; Lopez-Nicolas and Soto-Acosta, 2010; Chatti et al., 2007; Sarkiunaite and Kriksciuniene, 2005; Harris, 2009; **?**; Hildrum, 2009; Murray and Peyrefitte, 2007; Hisyam Selamat and Choudrie, 2004; Marwick, 2001]. However, these studies do not take into consideration the notion of the "degree of tacitness" or "the degree of explicitness", which is more meaningful when examining the type of knowledge shared in a specific context [Chua and Ngee, 2001; Chilton and Bloodgood, 2010; Ambrosini and Bowman, 2001]. Moreover, constraining tacit knowledge sharing to mere tacit-tacit conversion (socialization [Nonaka and Tekeuchi, 1995]) may not be a good examination of tacit knowledge sharing phenomenon through IT assisted communications. Every knowledge (including explicit knowledge) has components of tacit dimension [Polanyi, 1966; Hislop, 2002]. Therefore, every tacit-tacit as well as tacit-explicit conversions and vice versa could be regarded as a tacit knowledge sharing phenomenon [Marwick, 2001].

It can be argued then that, nowadays, face-to-face communication can no longer be the principal way of tacit knowledge sharing, especially since experts, as in happens in large organization, are not always geographically co-located, but they still need to exchange their experiential tacit knowledge. Therefore, the use and optimization of IT for facilitating tacit knowledge sharing is today almost inevitable [Sarkiunaite and Kriksciuniene, 2005]. IT certainly can enable individuals to share their tacit knowledge (or at least the knowledge with low to medium degree of tacitness) by supporting various conversions of tacit-explicit knowledge, although it may not be as rich as face-to-face interactions [Ambrosini and Bowman, 2001; Panahi et al., 2012].

1.1.4 Innovative Tools and New Challenges for KM

Additionally, in latest years corporations,irrespectively of their size, have been increasingly using serious games in order to evaluate and ascertain impactful business decisions and strategies [Roungas et al., 2017], making serious games a popular and effective tool for the most different purposes (e.g. learning, training, decision making) [Crookall, 2010].The expanding adoption of these innovative instruments poses however new challenges and obstacles. In particular, many firms started wondering how to handle the information acquired through these particular tools, and how to draw value out of it. There is however a fundamental issue that needs to be clarified in order to answer to such doubts, and that has not been yet confronted by literature: how do games precisely generate tacit knowledge, and why?

This problem gives origin to a whole new array of uncertainties. Organizations have now in fact to understand what are the organizational aspects influenced by such practices; whether this influence is beneficial or not; and whether the generated knowledge can be effectively codified and shared throughout the organization.

1.2 PROBLEM STATEMENT

As it appears from the issues listed in Section 1.1.1, the challenges related to KM are so many and so variegated that it would be impossible for a single study to deal with all of them.

Consequently, it is a critical task for any kind of organization to always try to find more efficient ways of exchanging knowledge. Furthermore, in the contemporary, digitally interconnected world, creating and sharing information became a consistent part of everyone's life. KM is thus relevant not only for improving firms' performances, but also for enhancing communication and eventually achieving wellbeing in the society as a whole. As Roungas et al. [2017] affirm, in fact, that knowledge management and reuse is not, and should not be, of academic interest only. The performances of any kind of organizations of a corporation largely relies on how it approaches the management of both new and pre-existing knowledge [Markus, 2001], with particular regards on context-depending skills, or "know-how".

1.2.1 Scope of the Research

In the light of understanding the great relevance of KM in any organizational context, as well as recognizing the importance of the new challenge posed to KM by the application of serious games (from now on referred to as just 'games'), the following objectives have been drawn for this thesis project:

- Understanding which processes or elements of the game are responsible for the arising of such knowledge, and in particular tacit skills;
- Understanding actors' needs regarding knowledge sharing and acquisition within the context of games;
- Deriving the requirements of games that would lead to the development of a Knowledge Management Framework (KMF) for the acquisition and dissemination of knowledge;

The combination of such objective brings to the following Research Question, which this study will try to answer to.

What are the necessary requirements for games to foster the development, as well as the reuse, of tacit knowledge??

This research has been carried out within the organizational frame of ProRail - the Dutch governmental organization that takes care of maintenance and extensions of the national railway network infrastructure, of allocating rail capacity, and of traffic control, which also sponsored the study. The games taken into consideration for this study were thus some the games carried out within ProRail itself, in sight of the organization's needs and the research objectives.

In particular, the study will focus on three games:

1. Infrastructural change (OV-SAAL);
2. Increase in schedule frequency (Chain simulation (Ketensimulatie));
3. Safety system enhancement (European Rail Traffic Management System (ERTMS)).

The games were selected on a basis of different criteria, such as: purpose, type, number of actors involved, contextual factors, value for the organization, people available for interviews. The selection criteria, along with an explanation of their relevance, will be better explained in Section 5.2.

1.3 RELEVANCE OF THE PROBLEM STATEMENT

1.3.1 Academic Relevance

The problem is relevant from an academic perspective since much is known about the separate topics of tacit knowledge and serious games, but no information is available on any type of relationship between these two subjects. The literature is in particular very scattered and not integrated with regards to the issue of generation of knowledge from serious games. Results from queries in some of the most important academic search engines, such as Scopus and Google Scholar, can prove the lack of previous research on the subject. The query *creation AND tacit AND skills AND serious AND games AND simulations* has 0 results, while the most generic query *tacit AND skills AND serious AND games* just encounters 1 academic paper. As a conclusion, it can be affirmed that the field of study related to the generation and the enhancement of tacit skills thanks to the use of serious game is still an unexplored area, and thus worth of further research.

1.3.2 Managerial Relevance

In addition to the lack of literature on the subject, another element which gives relevance to the presented problem statement is its importance within any organizational environment. As proved by several studies, an effective knowledge management is fundamental for any kind of organization. This study therefore tackles an existing, unsolved problem which affects all firms making use of serious games or simulations for the most different purposes. This study will thus provide a methodology for uncovering tacit skills generated by games, as well as understanding which games' aspects are responsible for the generation of such skills. Once discovered and categorized, both explicit knowledge and tacit skills can be more effectively reused and disseminated in the organization.

1.3.3 Relevance for ProRail

Being ProRail a governmental firm, it has no competition in its market, and it is therefore non relevant to enhance its competitive advantage. Uncovering which skills are generated by games, and afterwards reusing them in order to improve business processes within an organization, can certainly serve to the scope of improving a firm's position in the landscape of a competitive market. However, it depends on which specific processes within a company the uncovered skills are applied to; they could in fact serve as well for improving the decision making process, the recruitment of new employees, the relationship with customers, or the effectives of security measures. All of these areas are common to any kind of organization. In particular, the elicitation of the necessary requirements for managing both explicit knowledge and tacit skills developed within games will allow ProRail to:

- develop, on the basis of the final requirements, an effective Knowledge Management Framework for the storing and reusing of data and information generated by games;
- understand the relation between game characteristics and the creation of tacit skills;
- create value from the uncovered of tacit skills.

1.4 APPLIED METHODOLOGY

The methodology applied will composed of different research methods. The case study approach will be used to define the main framework of this research. ProRail will represent the main unit of analysis, while the games will be studied as embedded units of analysis. Such structure can be described as a embedded, single-case study.

Within the case study framework, a series of research methods will be employed in order to uncover different research objectives. First, a review of the available literature will be carried out, in order to base future work on a solid body of knowledge regarding both knowledge, knowledge management,and serious games. The analysis of available literature will also serve the scope of making sure this research is confronting a problem which has never been confronted by existing literature, or that at least has not been already solved. In short, to make sure not to "reinvent the wheel". Additional scope of the literature review will be evaluating which methodologies would better fit the research objective. As a result of such inquiry, two methodologies were selected to represent the main tools of analysis:

- Semi-structured interviews;
- Q-Sorting.

Semi-structured interviews will be used in a first, exploratory stage, with the purpose of providing an initial understanding of the games, and starting the process of eliciting constructs related to the relation between games and the generation of tacit skills. In a later stage, the interviews will be paired with a slightly more quantitative approach: the Q-sort methodology. Q-methodology (also known as Q-sort) is the systematic study of participant viewpoints. It is used to investigate the perspectives of participants who represent different stances on an issue, by having participants rank and sort a series of statements. Both research methods are qualitative in nature, even though the Q-sort method allows the collection of data into a numeric data set, which can be thus analyzed with quantitative tools. A more specific overview of the sub-questions is provided in Chapter 3, while an explanation of how each research methods will serve to the objectives' achievement is presented in Chapter 4.

1.5 THESIS STRUCTURE

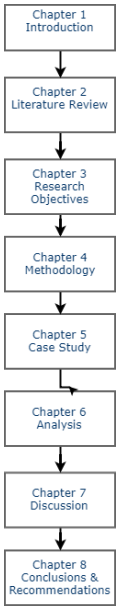


Figure 1.1: Thesis Structure

The research report will be divided into 8 chapters. Chapter 1 will serve as an introduction to the subject and the research objectives. Chapter 2 will be mainly dedicated to literature review and building a solid background on core concepts, which will lead to the identification of a Problem Statement. Chapter 3 will define the main Research Question and the Sub-Questions. Chapter 4 will describe the methodology and the tools used to build the analysis. Therefore, the case building will be presented: the unit(s) of analysis (one or multiple games) will be identified, as well as the knowledge-generating processes within them. Chapter 5 and 6 will focus on the description and analysis of results. The main finding consists in the identification of an hybrid KM framework, described in Chapter 7, for the management and reuse of knowledge acquired through serious games. Chapter 8 will be dedicated to conclusions and recommendations.

2 LITERATURE REVIEW

In the next chapters the main concepts related to knowledge, KM and serious games will be presented and explained.

2.1 A DEFINITION OF KNOWLEDGE

In information theory, data is usually defined as symbols without any meaning or value: it can be described as any distinction, any perceivable difference [Hilbert, 2016].

Information is a "difference which makes a difference" [Bateson, 1987]: if some kind of symbol shows a difference (for example either 1 or 0), but this does not represent any surprise, it does not reduce uncertainty, and therefore is no information. Information can be extracted from data by 'compression', which essentially takes out all redundant data and leaves only those differences that effectively reduce uncertainty. The remaining quantity is called the "entropy of an information source" [Shannon, 1948].

In the general epistemology, knowledge is often defined as "information that have been organized" [Rowley, 2007] or "as actionable information". While "information is to be interpreted as factual knowledge, on the other hand, establishes generalizations and correlations between variables. Knowledge is, therefore, a correlational structure" [Saviotti, 1998]. Adopting a strict computer science definition of knowledge, knowledge implies a step-by-step recipe of doing something, a deterministic algorithm [Brookshear, 2009]. If there is knowledge, there is a deterministic process or procedure that delineates how things go from one stage to another one. Such deterministic process might be unknown (i.e. 'tacit'), but it is still deterministic.

2.2 CLASSIFICATION OF KNOWLEDGE

2.2.1 Ontological Dimension

A first classification of knowledge is the ontological one. Such classification, as presented in Table 2.1, defines different types of knowledge based on their nature or context [Nonaka, 1994]. The knowledge possessed by an organization can in fact reside at different levels: in the individuals' minds, or shared among business units and departments.

In this research project, a simplified categorization will be used, making a simple distinction between individual and collective. Collective knowledge can be intended as either hard data, or as a "'flow' emerging from interaction" [Lam, 2000]. Depending on the processes that transform individual knowledge into collective, the latter can result greater or smaller than the sum of individuals' knowledge [Glynn, 1996].

2.2.2 Epistemological Dimension

Knowledge can also be categorized from an epistemological point of view [de Jong et al., 1988; Messick, 1984], which implies that elements of the knowledge base are characterized by the function they fulfill in the performance of a target task [de Jong and Ferguson-Hessler, 1996].

Individual knowledge	Information believed by an individual as justified truth and stored in memory in a cognitive structure through a cognitive process called learning
Group knowledge	Knowledge held by a group of individuals (e.g. organization departments)
Organizational knowledge	Knowledge held by an organization
Inter-Organizational knowledge	Knowledge held at an inter-organizational level (e.g. knowledge held between an organization and its suppliers)

Table 2.1: Ontological dimension categories

On the epistemological dimension this research will mainly take into consideration the existence of two types of knowledge - tacit and explicit - as recognized by Nonaka and Tekeuchi [1995].

On one hand, explicit knowledge is knowledge that the knower can make explicit by means of a verbal statement: "Someone has explicit knowledge of something if a statement of it can be elicited from him by suitable inquiry or prompting" [Dummett, 1975]. Tacit knowing, on the other hand, encompasses a variety of phenomena, such as the ability to recognize something (e.g. a person's face) even though one cannot describe in context-independent terms (e.g. without saying, "I know that Bob looks like this") how one recognizes it. The cognitive element of tacit knowledge refers to an individual's mental models consisting of mental maps, beliefs, paradigms, and viewpoints, while the technical component consists of concrete know-how, crafts, and skills that apply to a specific context [Alavi and Leidner, 2001].

Tacit knowledge is very hard to be elicited, stored or transmitted, even though it often is the most valuable one: it is in fact generated throughout every kind of process or activity, and it can be very difficult to identify, as it is the results of different factors and it is highly context-dependent. Researches in the field of management and reuse of implicit knowledge are quite recent, as awareness regarding this particular aspect of knowledge has just been raising in the last decade or so. A quick analysis of the results for the query "implicit", "knowledge" and "management" on the search engine Scopus shows that just a few academic papers were published before the year 2000, while a sudden growth in publications took place in the following years. Nevertheless, the total amount of documents found by the search engine, 1513, is still relatively low. If, instead, we just substitute the word "implicit" with "explicit", the number of results rises to 4290. This demonstrates that many approaches have been developed for explicit knowledge management, while engaging with implicit knowledge is still an open challenge.

The explicit-tacit distinction is widely used. However, some classify knowledge as: declarative (know-about or knowledge by acquaintance [Nolan Norton Institute, 1998]), procedural (know-how), causal (know-why), conditional (know-when), or relational (know- with) [Zack, 1998].

By combining the epistemological and the ontological dimension it is possible to define four distinct categories of knowledge (Figure 2.2). These conceptual distinction were firstly identified by Collins [1993], and subsequently revised by Blackler [1995] with the purpose of depicting different 'images' of knowledge within organizations.

		Ontological Dimension	
		Individual	Collective
Epistemological Dimension	Explicit	EMBRAINED KNOWLEDGE	ENCODED KNOWLEDGE
	Tacit	EMBODIED KNOWLEDGE	EMBEDDED KNOWLEDGE

Table 2.2: Cognitive Level: Categories of Knowledge [Lam, 2000]

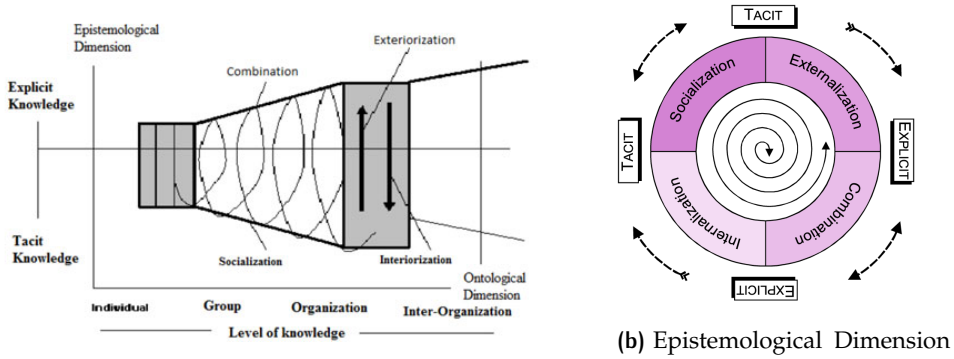
- **Embrained knowledge** (individual-explicit) rests on the individual's conceptual skills and cognitive abilities. It is based on abstract theoretical reasoning ('knowing') [Lam, 2000].
- **Embodied knowledge** (individual-tacit) is more practical, action oriented ('doing'), it is developed through experience, and it has a firm automatic component [Spender, 1996]. Moreover, it is context dependent: it becomes relevant in practice, "in the light of the problem at hand" [Barley, 1996]. In other words, it is impossible to distinguish the creation of this type of knowledge from practical application.
- **Encoded knowledge** (collective-explicit), from time to time also defined as information, is expressed and transferred through symbols and signs. It can be codified, collected, categorized, put into instructions, manuals, written procedures. It is easy to transfer within an organization, especially by means of IT and ICT. It is however a simplified and limited version of the knowledge it aims at capturing, therefore it is not suitable for seizing individuals' skills and know-how.
- **Embedded knowledge** (collective-tacit) consists in 'communities of practices' [Brown and Duguid, 1991a], organizational routines and common standards. This particular type of knowledge is built up through social interaction, it is contextual and relation-specific [Lam, 2000]

2.2.3 Focus of the Research

This research will primarily take into consideration the explicit-tacit dichotomy, focusing in particular on tacit knowledge. Regarding the ontological dimension, individual knowledge will be the main unit of analysis. The reason for this choice is that group or organizational knowledge is hard to define and measure, and the spectrum of this project is not wide enough to allow a thorough assessment of knowledge possessed by entire departments, or by the whole organization. However, it can be affirmed that this research will ultimately aim, at least in part, at promoting and supporting the generation and sharing of knowledge at an departmental/organizational level. To individuate those games' requirements that foster the generation of knowledge represents in fact a step towards the identification of the requirements for a KMF dedicated to serious games and simulation. The development of such a framework would in turn increase the sharing of all kinds of knowledge throughout the organization, from 'know-how' to raw data.

2.3 KNOWLEDGE CREATION PROCESS

As Nonaka [1994] explains, a spiral arises in the moment in which the interplay between tacit and explicit knowledge is augmented dynamically from a lower to a higher ontological level (see Table 2.1). The spiral is formed by four modules of knowledge conversion, in which the knowledge is transformed from one type to another. The types of knowledge conversion are described by Takeuchi [2006]: by moving through the spiral, the interaction between tacit and explicit is amplified.



(a) Spiral of Organizational Knowledge Creation [Nonaka, 1994]

(b) Epistemological Dimension of Knowledge Creation [Takeuchi, 2006]

Figure 2.1: Modules of Knowledge Creation and Conversion

2.4 KNOWLEDGE ACQUISITION

In contrast to a few decades ago, when finding sources of information was the main issue for both companies and individuals, today's information society requires companies and individuals to create and employ mechanisms to search and retrieve relevant data from the vast quantity of available information and mine it into knowledge, which can be used to take the most suitable decisions [Montoyo et al., 2012]. Because digital data are so easily shared and replicated, it enables a tremendous reuse opportunity, accelerating investigations already under way and taking advantage of past investments [Lynch, 2008]. As a result, the amount of data and information available for organizations analysis is exploding [McAfee and Brynjolfsson, 2012].

2.4.1 Tacit Knowledge Acquisition

Eliciting tacit knowledge is one of the main challenges that most organization are facing nowadays: to extract this particular dimension of knowledge can be expensive, and requires highly qualified people to develop some applicable methodologies which could be used successfully [Cao and Compton, 2005]. Such difficulties are due the fact that experts, in most domains, find it difficult to explain what they do or even why they do it [Lucena, 2016]. Moreover, they could consider very complicated explaining and justifying their decisions, practices, and sequence of steps in a specific task execution. The reason for this lies in the nature of implicit knowledge, which is mostly composed by insights, intuitions, hunches, inherent talents, skills, experience, know-who, know-why, and working experience (see Figure 2.2) which are embedded within the minds of domain experts [**?**Khalifa and Shen, 2006; Kotiadis and Robinson, 2008; Vandenbosch and Higgins, 1996].

2.5 KNOWLEDGE SHARING

Many organizations are nowadays having trouble in providing its members access to the information required to perform their tasks. In fact, even if the needed knowledge exists in the organization, sometimes the people who have it just refuse to share, or people who should learn from shared information are not motivated to do so, or employees who are looking for information do not even know where to find it. For these and other reasons, promoting a knowledge-sharing behavior has started to be one of the most relevant concerns for many knowledge managers [Holder et al., 2006].

When newly acquired knowledge possessed by an individual, a group or a department is shared with the rest of the staff, it is challenged, defended, refined and eventually becomes organizational knowledge [Chua and Ngee, 2001]. In other words, the sharing of existing

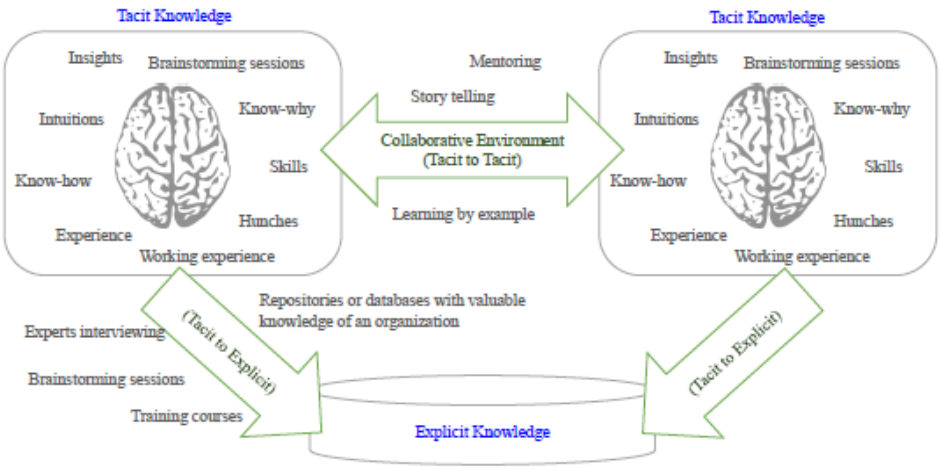


Figure 2.2: Tacit and explicit knowledge acquisition

knowledge leads to the creation of new knowledge. Since this process is highly social in nature [Havens and Knapp, 1999; Garvin, 1993; Nerney, 1997], most knowledge management literature invariably alludes to the importance of social interaction among the members of an organization. Social interaction involves two main components, namely, the types of knowledge shared and the types of communication channels used [Chua and Ngee, 2001].

Panahi et al. [2012] identify five requirements of tacit knowledge sharing:

- social interaction;
- experience sharing;
- observation;
- informal relationship/networking;
- mutual trust.

2.5.1 Social Media for Tacit Knowledge Sharing

Social media can be defined as "collaborative online applications and technologies which enable and encourage participation, conversation, openness, creation and socialization amongst a community of users" [Bowley, 2009], or as a "network technologies based media that support social interaction, social information aggregation and sharing" [Zheng et al., 2010].

This set of different tools has many characteristics that promote, empower and stimulate people to share their knowledge in an easy and effective way, thanks to different components [Panahi et al., 2012].

- User-generated content ⇒ co-creation of the content [Bowley, 2009; Elefant and Black, 2010; Sarkkinen, 2009], users can jointly create, edit, comment, assess and share contents [Lerman, 2007].
- Peer-to-peer communication ⇒ connectivity is the most relevant characteristic of social media, allowing people to effortlessly connect with each other in real-time and worldwide thanks to live chats, video or telephone conferencing, and so on [Bowley, 2009; Matthee, 2011; Mayfield, 2003].
- Networking ⇒ establishing a community of users is another fundamental feature of social media [Sarkkinen, 2009; Lerman, 2007; Mayfield, 2003]. It facilitates people with shared interests and passions to meet each other through an online space, build relations,

discuss without restrictions, and share their knowledge and experiences [Gordeyeva, 2010].

- Multimedia oriented ⇒ this element allows users to collect and distribute a variety of forms of files (text, images, audio or video recordings, and so on) in a straightforward and interactive manner [Canali et al., 2008; Lindmark, 2009].

- User friendly ⇒ social media applications are generally very easily accessible, available for everybody, clearly understandable, personalized and low-cost, if not free [Pavlicek, 2009; Zheng et al., 2010; Li et al., 2010; Wollan et al., 2010,?; Mayfield, 2003; Zheng et al., 2010].

The integration of these characteristics and associated instruments causes social media to be an incredible mean of knowledge sharing. By assisting people in staying connected, communicating with each other, developing trustful relations, social media tools promote the processes of knowledge creation and sharing more effectively than traditional KMSs [Gordeyeva, 2010].

2.6 KNOWLEDGE REUSE

Many are the opportunities that the efficient management and reuse of new or already retained knowledge might generate, and the academic interest towards the topic is rapidly increasing. In general, the knowledge reuse process can be defined by these moments: "capturing or documenting knowledge, packaging knowledge for reuse, distributing or disseminating knowledge (providing people with access to it), and reusing knowledge" [Alavi and Leidner, 2001].
There are three major roles in the knowledge reuse process[Markus, 2001]:

- knowledge producer: who creates and documents knowledge;

- knowledge intermediary: who arranges knowledge for reuse (eliciting it, indexing it, summarizing it, etc.), while playing a part in its diffusion;

- knowledge consumer: the proper knowledge re-user, who captures the knowledge content and implements it in some way.

Roles can be performed by the same individual(s) or group(s), different individual(s) or group(s), or a combination of those [Markus, 2001].
In his research Markus [2001] poses the basis for a "theory of knowledge reusability", with particular emphasis on the role of KM systems and knowledge repositories. Knowledge repositories, often also referred to as organizational memory systems [Ackerman, 1998], or organization memory information systems [Hackbarth and Grover, 1999], have different requirement depending on the type of knowledge re-user.
Additionally, Markus [2001] pointed out three important factors that influence the successful management and reuse of knowledge: a) the costs involved, b) the incentives knowledge producers have to contribute to a KM system that can be used by others, and c) the need to transform knowledge so that it is appropriate for use by others.

2.7 KNOWLEDGE LIFE CYCLE

The knowledge life cycle is the process that knowledge passes through an organization since it is identified, created, captured, shared, transferred, and utilized [McDaniel and Brown, 2001]. Figure 2.3 illustrates the four main phases considered: 1) acquisition; 2) formalization and storage; 3) use; and 4) maintenance. These four phases determine as many quadrants, which comprise smaller steps from the data collection to the decision making support.

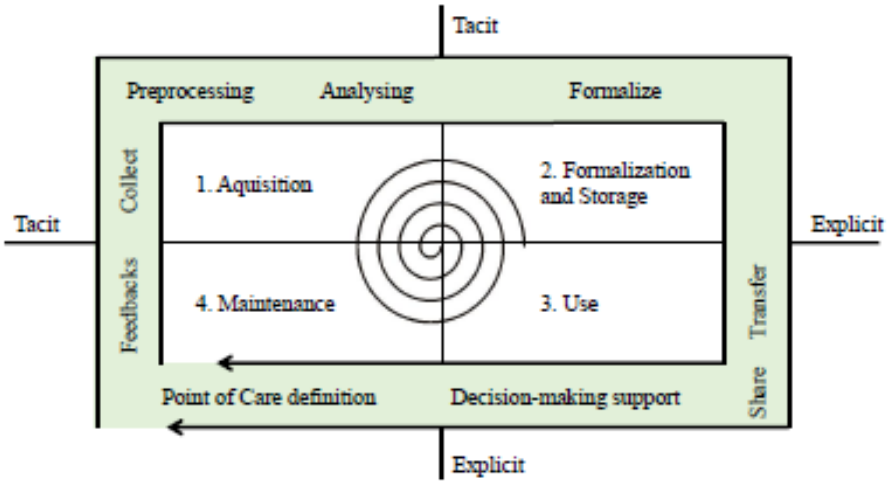


Figure 2.3: Knowledge Life Cycle [Lucena, 2016]

2.8 KM MODELS

Literature offers a variety of KM models. Among the most relevant there are: the model of Organizational Epistemology [von Krogh and Roos, 1995], the Knowledge Spiral Model [Nonaka and Tekeuchi, 1995], the Sense-making KM Model [**?**], the Wiig Model for Building and Using Knowledge [Wiig, 1993], the Boisot I-Space KM Model [**?**], the ICAS model of KM [Beer, 1981; **?**].

This study will focus in particular on the Knowledge Spiral Model. As said in Section 2.2, Nonaka's model examines knowledge from both an epistemological (distinction in tacit/explicit form) and an ontological perspective (different levels of sharing and diffusion: individual/group/organizational).

Nonaka's model defines four modes of knowledge conversion, as illustrated in Figure 2.4:

- Socialization (tacit to tacit) ⇒ process of sharing tacit knowledge through observation, imitation, practice, and participation in a formal and informal community [Takeuchi, 2006]. Some used methods are [Ceptureanu and Ceptureanu, 2010; Hoegl and Schulze, 2005]:
  - face to face communication;
  - video conference tools;
  - informal events;
  - virtual reality tools.
- Externalization (tacit to explicit) ⇒ process of articulating tacit into explicit knowledge through dialogue and reflection [Nonaka, 1994; Takeuchi, 2006]. Some of the used methods are [Hoegl and Schulze, 2005]:
  - process capture tools;
  - expert systems;
  - experience workshops;
  - experience reports;
  - experts interviews;
  - discussion platforms.

- Combination (explicit to explicit) ⇒ process of integrating concepts into a knowledge system [Takeuchi, 2006]. It implies Systematizing and applying explicit knowledge and information [Nonaka, 1994]. It can be done through:
  - communities of practice;
  - systemic knowledge tools;
  - web forums;
  - best practice databases.
- Internalization (explicit to tacit) ⇒ process of embodying explicit knowledge into tacit knowledge [Nonaka and Tekeuchi, 1995]. Examples are:
  - collective knowledge;
  - research services;
  - notes database.

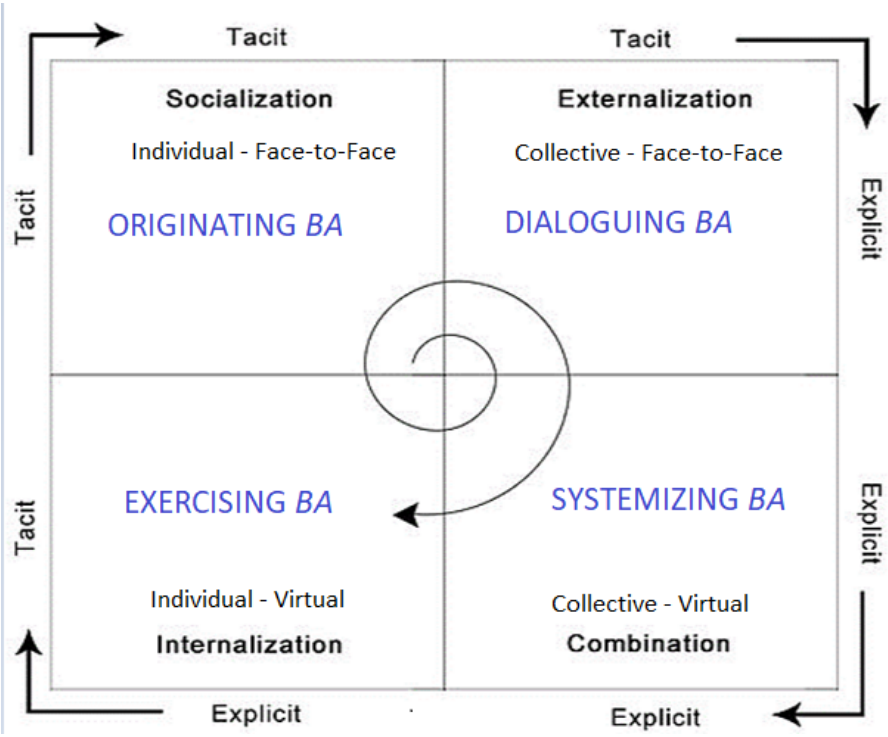


Figure 2.4: Nonaka's SECI Model, adapted from Nonaka and Konno [1998]; Nonaka [1994]

Extremely relevant for the scope of this study are the processes of Socialization and Externalization, which represent an attempt of capturing the intrinsic value of tacit knowledge. As Davenport et al. [1998] point out that: "tacit, complex knowledge, developed and internalized by the knower over a long period of time, is almost impossible to reproduce in a document or a database. Such knowledge incorporates so much accrued and embedded learning that its rules may be impossible to separate from how an individual acts". Socialization implies achieving a reciprocal understanding by way of sharing mental models, deliberating in a cooperative way, training or coaching interactions, etc. [Dalkir and Beaulieu, 2017]. Externalization, instead, makes tacit knowledge discernible, converting it into explicit. Once made concrete and invariable, knowledge can be shared more smoothly and efficiently throughout the organization [Dalkir and Beaulieu, 2017]. Internalization is also fundamental: it translates or assimilates shared and/or individual expertise and knowledge into individual mental models. Once incorporate within one's self, newly generated knowledge is thus applied by employees who develop it, deepen it, and rethink it within their own current tacit knowledge framework.

In 1998 a third, more challenging, cultural hypothesis was annexed to the SECI debate. A new concept, the Japanese philosophical notion of *Ba*, was proposed by Nonaka and Konno [1998]. This idea previously exclusively existed in the deep roots of Japanese society and culture, which linked it to the physical, relational and spiritual elements of 'place', or perhaps more broadly 'context'. Four different conceptions of *Ba* are delineated, one for each quadrant of the SECI model, creating together the 'spiral' of knowledge. Figure 2.4 displays the four different *Ba*:

1. The Originating *Ba* ⇒ an intangible space where individuals are able to share feelings, emotions, and experiences.
2. The Dialoguing *Ba* ⇒ a space where tacit knowledge is conveyed through dialogue and metaphor creation, and recorded in its explicit form.
3. The Systematizing *Ba* ⇒ a virtual place, where explicit knowledge is recombined thanks to IT into new formats and designs.
4. The Exercising *Ba* ⇒ where explicit knowledge is turned into tacit knowledge.

2.9 KM SYSTEMS

KM systems represent a valid tool for leveraging knowledge both internally within an organization and externally to shareholders and customers; it is a source of value for any kind of company's intangible assets [Rubenstein-Montano et al., 2001]. "Any misalignment between an enterprise's knowledge and the KM systems it adopts generates problems of inefficiency (i.e., under-use of KM systems) and ineffectiveness (i.e., using unsuitable KM systems), which in turn adversely affect the enterprise's operational performance" [Centobelli et al., 2018].

KM systems can be defined as:

- IT-based systems aimed at facilitating different stages and processes of KM: data mining, learning tools, databases, discussion forums, expert systems, and so on [Alavi and Leidner, 2001];
- Procedures, practices and cost-efficient software products enhancing the integration of knowledge between people, processes, technology, and structure of an organization (e.g., brainstorming, knowledge networks, email systems, communities of practice, best practice, lessons learned, knowledge maps, storytelling, databases, document management systems, content managements, and expert systems) [Fink and Ploder, 2009].

There are three common applications of IT to organizational knowledge management initiatives [Alavi and Leidner, 2001]:

- the coding and sharing of best practices: transfer of internal best practices [O'Dell and Grayson, 1998; KPMG, 1998];
- the creation of corporate knowledge directories: since a great portion of the knowledge possessed by an organization does not get systematized, acknowledging and measuring a firm's internal expertise is one of the most important functions of KM [Ruggles, 1999];
- the creation of knowledge networks [Ruggles, 1999].

2.10 KM FRAMEWORKS

The effectiveness of a Knowledge Management System (KMS) in achieving its objectives is the result of different aspects: organizational culture (willingness to share), processes and environments (for sharing, collaborating, learning), technological infrastructure (for conveying

codified knowledge). Technology, if correctly applied, can be an incredibly valuable tool in designing, aligning and supporting the process of transferring and sharing knowledge, but it needs to be compatible with all the other factors.

The combination of the actions that can be possibly performed on knowledge within an organization (creating, capturing, synthesizing, accessing, storing and so on) and the enablers of said actions (people, processes, technology, governance) defines a particular KMF. All of the cited activities assume managerial implications at all organizational levels and function: this suggests that KM programs must have coherence across a number of dimensions, such as organizational structure and culture, people, processes, technology [Quintas et al., 1997].

Regardless the type on KMF applied, there is a managerial need to define decision-support frameworks that can enable managers to understand how knowledge assets interact each other and with organizational performance in order to support the achievement of company's strategic objectives [Schiuma et al., 2012].

The available literature provides many examples of KMF [Holsapple and Joshi, 1999; Lai and Chu, 2000; Liebowitz and Megbolugbe, 2003; Stankosky, 2005]. Newman et al. [2000], for instance, define a "classification framework", which has the main objective of helping individuals identifying and differentiating among the roles different tools can play in a knowledge management system. Other models,instead, mostly focus on processes [Davenport, 1994; Garvin, 1995; Lehtimaki, 1991; Ostroff and Smith, 1992], that are considered to be facilitators in the development of management practices [Ferreira and Pilatti, 2013]. In another study, Rubenstein-Montano et al. [2001] discern three distinct types of KMFs:

1. *prescriptive* (task-oriented): specifies different ways to undertake KM activities;
2. *descriptive*: characterizes or describes KMSs;
3. *hybrid*: a combination of the two.

Regardless of the organization or the specific games they use, a KMF is composed of some common building blocks that eventually contribute towards building a KMS [Roungas et al., 2018]. Namely, these blocks are:

- The type of the KMS. Currently there are two distinct types of KMSs, *Codification* and *Personalization* [Roungas et al., 2017]. *Codification* collects and makes available for reuse all forms of seized knowledge. *Personalization*, instead, resides in the the transfer of knowledge that has been previously gained by means of face-to-face individual or collective conversations and brainstorming sessions; it encourages interaction and the sharing of expertise among employees in a more intimate way. Most of the shared tacit knowledge is exchanged through *Personalization*.

- The purpose of the KMS. A KMS can been used for one or more purposes, like own-project improvement (root-cause analysis), cross-project improvement, organizational culture improvement, and network improvement.

- The intended users of the KMS. Any individual or group employed or even associated with the organization is a potential user of the KMS.

The KMF that is being developed at the Dutch railway infrastructure manager ProRail focuses on codification, in which knowledge from games can be reused and analyzed. Mainly research games (that explore and/or test a future state of the railway system) will currently be incorporated in the KMF. Currently principal stakeholders such as game designers as well as project team members are most likely to be the users of the KM.

2.11 SERIOUS GAMES AND SIMULATIONS

2.11.1 What are serious games?

The idea of using games for purposes other than fun was first formulated in the book *"Serious Games"* by **?**: "We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement." The educational purpose of Abt's serious games does not necessarily have to be in the game's design, but can be assigned to the game by the context it is used or embedded in. The term 'serious game' as it applies to digital games was coined by Ben Sawyer in his 2003 paper on the potential of using digital games for policy making [Sawyer, 2003].

Serious games are a subgroup of simulations and are also known as simulators, human-in-the-loop, participatory simulations, or just games. Many definitions exist that describe a game [Garris and Ahlers, 2002; Vogel et al., 2006], but mostly a definition along the following lines is chosen: that it is goal-directed, a competitive activity (against the computer, another player, or oneself) and conducted within a framework of agreed rules [Lindley, 2004]. In addition, games constantly provide feedback to enable players to monitor their progress towards the goal [Prensky, 2003].

	Serious Games	**Entertainment Games**
Task vs rich experience	Problem solving in focus	Rich experiences preferred
Focus	Important elements of learning	To have fun
Simulation	Assumptions necessary for workable simulations	Simplified simulation processes
Communication	Should reflect natural (i.e. non-perfect) communication	Communication is often perfect

Table 2.3: Difference between entertainment games and serious games [Susi et al., 2007]

Serious games have become a popular and effective tool for purposes like learning, training, and decision making [Crookall, 2010]. For thousands of years playing games was considered a way of passing time and relaxing. Nevertheless, around the 1950s gaming began to draw attention as a feasible mean of analyzing and solving several different types of social issues [Klabber, 2007]. In his book, Klabber [2007] also defines games as a "social systems", made of "interconnected actors, rules and resources". Figure 2.3 clarifies the position of serious games within the framework of educational concepts.

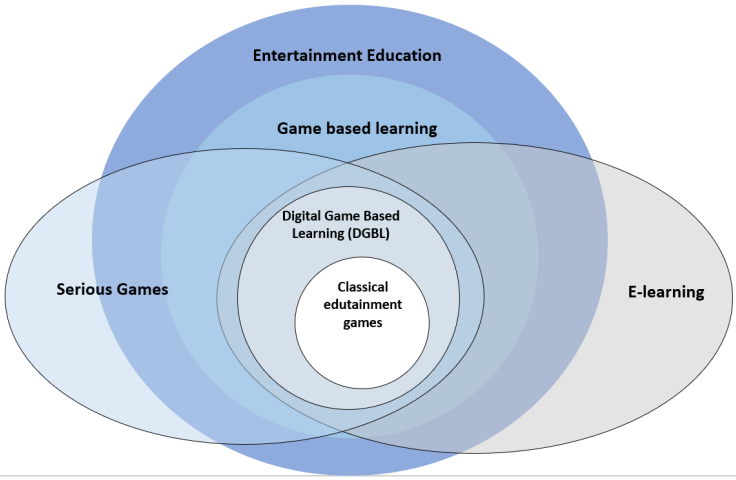


Figure 2.5: Relation between serious games and similar concepts, adapted from [Breuer and Bente, 2010]

Entertainment education can be described as "any attempt to make learning (more) enjoyable, no matter if media-based, mediated or within a classroom setting" [Breuer and Bente, 2010]. Game-Based Learning is a subset of this including the use of any type of games (e.g. board games, card games, sports or digital games) for learning/educational purposes. Serious games, however, also have application fields outside of education and learning (art, therapy, advertising etc.). Digital game-based learning (DGBL) is the section of serious games, which incorporates education/learning as the main or sole purpose. E- Learning is different from this categorical system as it does not imply any coupling of entertainment and education, but a combination of (digital) media and learning. While serious games can belong to the e-learning methods, not all e-learning systems are supposed to be entertaining (e.g. podcasts of lectures or computer-based online examinations) and not all serious games are learning games.

2.11.2 Categories of Games

This research will focus on simulation games, or gaming simulations: interactive environments which simultaneously model a technical system through simulation and a social system with role-play participants [Grogan and Meijer, 2017]. Gaming methods are a subset of research games.

Knowledge Type	**Knowledge Beneficiary**	
	Participant	Principal
	Teaching	Research
Generalizable	Experiential learning	Hypotheses generation and testing
	Dangerous tasks	Artifact assessment
	Policy	Design
Contextual	Organizational learning	Interactive visualization
	Policy intervention	Collaborative design

Table 2.4: Canonical applications of gaming methods knowledge [Grogan and Meijer, 2017]

2.11.3 Games Elements

A simulation can be described as a model of the real world through the depiction of state and state transitions that determine dynamic behavior [Zeigler et al., 2000].

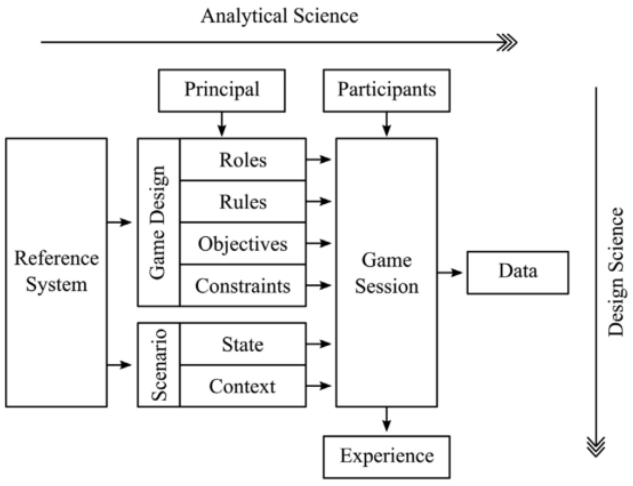


Figure 2.6: Elements of a research game [Grogan and Meijer, 2017]

A game "is an activity where one or more players make decisions to achieve potentially conflicting objectives with limited resources"[Abt, 1970]. Integrated, a simulation game or,

instead, gaming simulation, aims at constructing a replicative model of the real world where human actors are able to recreate, at least in part, behaviors by the means of specific roles [Duke and Geurts, 2004]. This integrated, interactive model empowers players to take actions, learn, investigate, create, and examine through a combination of formal rules based on logic, and natural laws and role-play built on experience, instinct, and interpretation. The reference system consists in the real-world context which has been selected as subject of the research. The game principal is instead the researcher, or investigator, who designs a game in pursuit of research objectives. Participants are reference system experts or proxies who interact as role-players [Grogan and Meijer, 2017].

2.11.4 Learning Outcomes in Serious Games

There are several types of learning outcomes deriving from serious games. Such outcomes can be mainly grouped in four categories, following the taxonomy developed by Wouters et al. [2009]:

- cognitive;
- motor skills;
- affective;
- communicative.

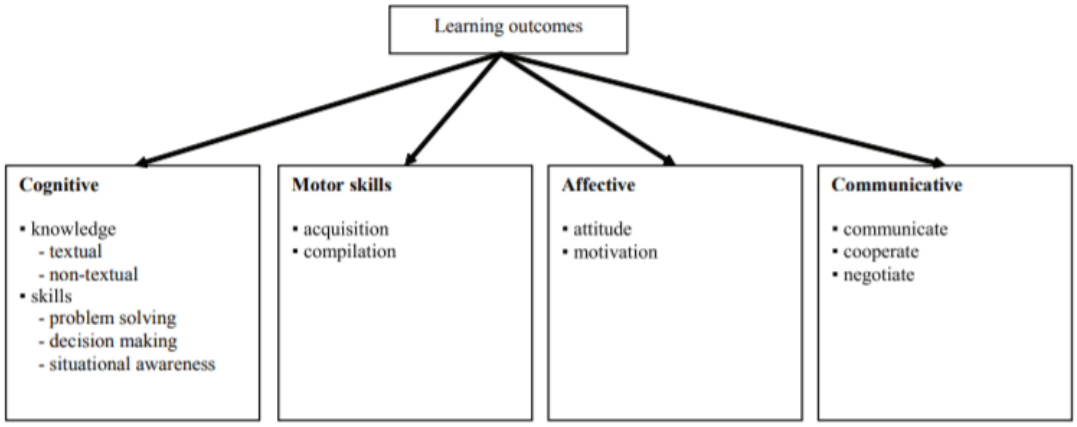


Figure 2.7: A taxonomy of learning outcomes from serious games [Wouters et al., 2009]

Focus of this research will be in particular cognitive learning outcomes, which can be divided into knowledge and cognitive skills. Knowledge refers to encoded knowledge reflecting both text-oriented (e.g., verbal knowledge) and non text-oriented knowledge (e.g., knowledge in the form of an image). Several types of encoded knowledge can be discerned such as declarative (explicit knowledge of facts) and procedural (tacit knowledge of how to perform a task). A cognitive skill, instead, is related to more complex cognitive processes [Wouters et al., 2009]. In problem solving, for example, learners have to apply knowledge and rules to solve new problems. In complex and dynamic situations people are sometimes forced to make decisions under time-pressure. Such decision making skills require situational awareness, that is, the ability to attend to and perceive the relevant information in a situation, comprehend this information and predict how the situation may develop [O'Brien and O'Hare, 2007].

2.12 CONCLUSIONS ON LITERATURE

Throughout all the processes listed in section 2.11, from game design to game sessions, both explicit and implicit knowledge is generated. Explicit knowledge is displayed in the form of

databases, graphs, videos, reports, or any other physical/visual exhibit of information, and is therefore relatively easy to capture, store and share.

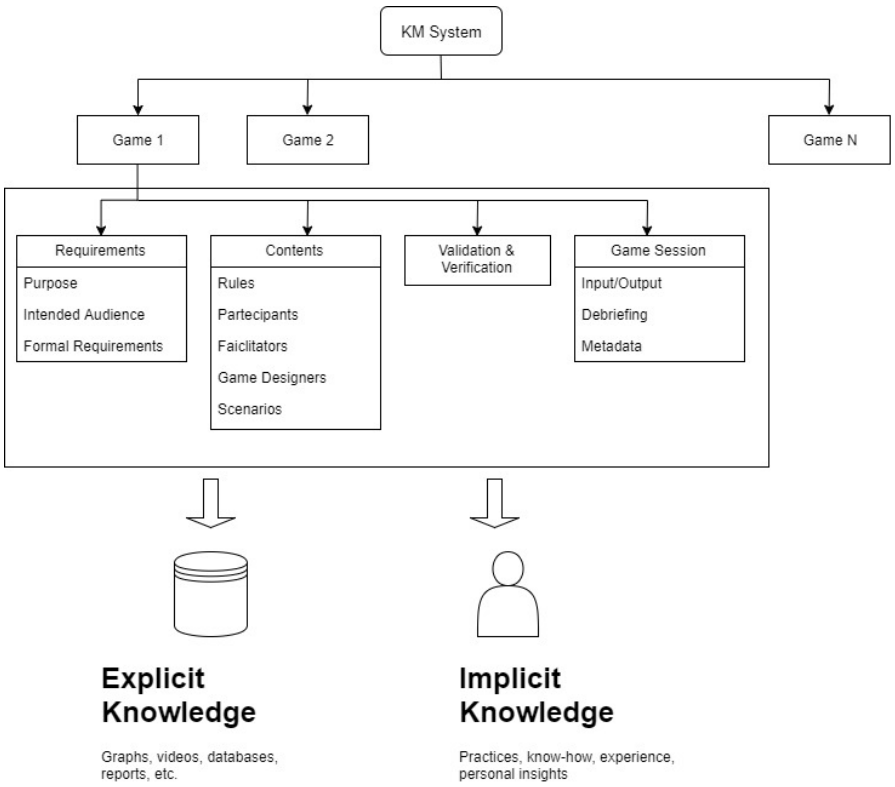


Figure 2.8: Type of Knowledge Generated through Serious Games

Implicit knowledge, on the other hand, despite being created throughout all kinds of processes and activities, is way harder to be individuated and organized. As in the famous iceberg metaphor, it represents the 'unseen' part of knowledge, composed by un-codifiable intangible assets, such as skills, expertise, experience, know-how. As an attempt of enhancing the sharing of implicit knowledge within organizations, in recent years we are witnessing the wide adoption of Web 2.0's social software tools (blogs, microblogs, wiki, forums, shared calendars, etc.) complementing (or even replacing) existing enterprise applications [Di Iorio et al., 2013]. This trend is justified by the improved immediacy with which information can flow among the members of the organization and, by a better support of agile, emergent cooperation models that re-shape the practices and the processes within organizations, allowing their continuous refinement and alignment with the organizations' missions and evolving know-how [Di Iorio et al., 2013].

In any case, independently from the structure, it is paramount for a KMS to be effectively utilized by users, who are necessary for the creation of new knowledge and the reuse of existing one. There is in fact a causal relationship between knowledge contribution and reuse [Markus, 2001]. Moreover, the success of a KMS is built upon the credibility of the primary source of information: a person who aims at using knowledge previously acquired shall be confident of the expertise of the knowledge contributors, and thus trust their respective findings [Watson and Hewett, 2006]. Finally, a KMS has to be properly and consistently indexed [Markus, 2001], so that knowledge contributors can be confident that the time spent contributing to a KM system is not wasted and their input will be easily accessible and truly used [Roungas et al., 2017].

As for the previously given definition, KMS can be described as organizational or technological tools supporting the integration of knowledge between people, processes, technology, and structure of an organization. If we transfer this interpretation to serious games and simulations, we can affirm that, within an organization, a single KM system can, and needs to,

manage knowledge acquired through different games, or tools. These can be greatly different in terms of contents, inputs and outputs, functionalities, but they all usually share a common structure, or architecture:

- game requirements ⇒ depend on the client, e.g. purpose, intended audience;
- game elements ⇒ rules, scenarios, participants, facilitators, game designers;
- game validation ⇒ whether the "right game" is being created[Balci, 2003]);
- game verification ⇒ whether the game is being created "in the right way" [Balci, 2003]);
- game session ⇒ game instantiation, characterized by input, output, debriefing, etc..

All the aspects and stages of the application of a game need to be documented, and both qualitative and quantitative data for each activity have to be measured and stored. Even though different games might be extremely dissimilar, they are all based on the same pillars which allow comparison among them: metadata, input and output data (quantitative and qualitative), and debriefing [Roungas et al., 2017].

2.13 FINDINGS

In conclusion, the main findings on the previously presented literature review are the following:

- Employees' know-how contributes to the performance of the firm through the level of creativity in problem solving which, in combination with comprehensiveness and consensus, is the key contributing factor to the level of new knowledge created by the firm, which in turn has a positive influence on innovative output [Soo et al., 2002];
- Developing serious games that can actually meet the client's (in this case "learner"'s) requirements/expectations is a problem that has been tackled by many researchers [Yusoff et al., 2009; De Freitas and Jarvis, 2006], as well as developing frameworks for games' evaluation [Mayer et al., 2014]. However, there are no studies regarding what tacit skills are generated by game, and how..
- Every knowledge (including explicit knowledge) has components of tacit dimension [Polanyi, 1966; Hislop, 2002]. Therefore, every tacit-tacit as well as tacit-explicit conversions and vice versa could be regarded as a tacit knowledge sharing phenomenon [Marwick, 2001];
- The degree of explicitness of knowledge shared is negatively correlated to the media richness of the communication channels used [Chua and Ngee, 2001];

As a result of the presented findings, the next chapter will introduce the main research question for this study, as well as the sub-questions in which it will be partitioned.

3 RESEARCH OBJECTIVES

3.1 KNOWLEDGE GAP

The main knowledge gap identified in the literature is the lack of research on the relationship between serious games and the knowledge - tacit or explicit - that they generate. The is in fact a missing link between two very large bodies on knowledge. On the one hand - as the analysis of available literature proved - there is an incredibly high number of researches on organizational knowledge, knowledge management practices and knowledge management systems, which particularly stresses out the fundamental role of tacit knowledge in enhancing a firm's capabilities. On the other hand, many studies have proved the value and the practicality of games for the most different organizational purposes, in particular for learning and decision making [Wouters et al., 2009; Connolly et al., 2012; Breuer and Bente, 2010]. In conclusion, while it is clear why knowledge - in particular tacit knowledge - and serious games can have a positive impact on a firm under many different aspects, it is not so clear why do games actually produce tacit skills, and how.

What this study aims at verifying is whether games are truly a source of knowledge, both explicit and tacit. In the case they are, this research will try to uncover through which particular processes - or elements - such knowledge is generated, and how. Disclosing the intersection between generation of knowledge and games processes will help organizations better understanding how these innovative tools are actually beneficial, and will hopefully allow to employ them in an even more efficient and effective manner. Furthermore, the individuation of the types of knowledge generated by games, and of the needs in terms of information exchange of all the involved actors, will direct towards the definition of both the qualitative and technical requirements for a knowledge management framework. Such framework will grant an improved knowledge management: from easier acquisition of knowledge, to more rapid dissemination and reuse throughout the organization.

3.2 MAIN RESEARCH QUESTION AND SUB-QUESTIONS

In conclusion of the insights offered in section 2.12, and as said in the previous section, the main objective of this research is to define the requirements of a knowledge management framework which will allow the maximum knowledge acquisition and reuse from serious games and simulations. In particular, the project will be carried out as a case study, whose protagonist will be ProRail, the Dutch governmental task organization that takes care of maintenance and extensions of the national railway network infrastructure, of allocating rail capacity, and of traffic control.

The main research question for this graduation project is therefore formulated as follows:

What are the necessary requirements for games to foster the development, as well as the reuse, of tacit knowledge?

The research question (RQ) can then be split into more specific sub-question (SQs) that will gradually build up to a final solution:

SQ1: What are the games' element or processes which are central in the generation of tacit knowledge?

By answering to this question, the objective is to define what exactly are the game requirements, intended as game characteristics (roles, rules, scope, constraints, participants, context, data, etc.), which are correlated with the generation of tacit knowledge.

SQ2: What are the dissimilarities - with respect to different actors and/or roles - in the consideration of the most relevant aspects for knowledge generation and sharing?

SQ2 aims at assessing whether there are any differences among the aspects considered relevant by different actors, or groups of actors, with regard to both games' requirements and types of generated and shared knowledge.

SQ3: How do such differences, if present, affect the needs of the different actors in terms of knowledge sharing and acquisition during the different game processes?

The answer to SQ3 builds on her previous one: once eventual differences and/or dissimilarities, concerning the said aspects, among actors are identified, it will be possible to understand how such differences might affect KM processes and practices.

SQ4: What measures can be proposed for the improvements of knowledge generation, sharing and reuse process for serious games and simulation?

Finally, SQ4 intends to combine the results from the previous sub-questions and, on their basis, develop a model for increasing tacit knowledge generation, sharing and reuse within the context of serious games and simulations.

The next chapter will provide a description of the methodology selected as more appropriate to answer to the RQ and the SQs.

4 METHODOLOGY

In this chapter, the research methods applied throughout the project will be presented. Their advantages and limitations will be explained, as well as the reason why they were considered appropriate for their specific objective.

4.1 TYPE OF STUDY

This research has an exploratory nature and it follows a qualitative approach, with the use of both primary and secondary data. The qualitative approach is due to the fact that the research question is oriented to cases or phenomenas, seeking patterns of unanticipated as well as expected phenomena [Stake, 1995]; as opposed to a quantitative study, which seeks out a relationship among a small number of variables. In order to answer to the different research sub-questions, the research makes use of a combination of different research methods. However, the different methods used will be shaped in the "case study" framework, according to the guidelines provided by Yin [2009]. Case studies are typically considered the preferred strategy "when the investigator has little control over events, and when the focus is on a contemporary phenomenon within some real-life context" [Yin, 2009].

4.2 ELICITATION OF TACIT KNOWLEDGE

In their paper, Ambrosini and Bowman [2001] put the basis for a methodology which tries to inquire in the elicitation of tacit knowledge in organizations. Their research has the scope of evaluating the tacit knowledge present in an organization in order to assess success factors, and finally enhance competitive advantage. Being ProRail - subject of this case study - a governmental organization with therefore no competition, this purpose seems not to be useful anymore. However, there is more than one reason for evaluating tacit knowledge within an organization. First of all, the elicitation of tacit knowledge or skills is fundamental in general for the progress of any kind of organization or society whatsoever. Second, many organizational variables can depend on tacit knowledge, such as operational efficiency, degree of innovation, quality of the work environment, decision making processes, etc. It follows that understanding how tacit knowledge influence an organization is crucial for recognizing its strengths and weaknesses.

As an assumption to their research, however, Ambrosini and Bowman [2001] decide to refer to tacit knowledge as "tacit skills". The definition of 'tacit' skills may encompass a range of different degrees of tacitness. As two anchor points we can have 'explicit skills', i.e. skills that can easily be communicated, codified and shared, and, tacit skills that are totally unavailable, that are not accessible to the knowers because they are too deeply ingrained. In between these two points, it is possible o individuate at least two other degrees of tacitness: tacit skills which are unarticulated, but that could be promptly articulated by questioning organizational members about how they do what they do. Such skills, according to Berry's research on expert's knowledge [Berry, 1987], are tacit but have been acquired explicitly. They have turned into tacit over time. Another type of tacit skills are those that could be accessed, but that cannot be articulated through words. They could however be articulated through other means, for instance through the use of metaphors and storytelling. Because of the lack

of empirical knowledge on tacit skills, trying to operationalize the 'most tacit' tacit skills is unlikely to be a realistic endeavour. However, attempting to operationalize tacit skills that are not yet articulated, but that could be attained by asking the right question, or conveyed by way of different channels than ' formal words' may be achievable. Hence we shall concentrate our attention on B and C in Figure 4.1.

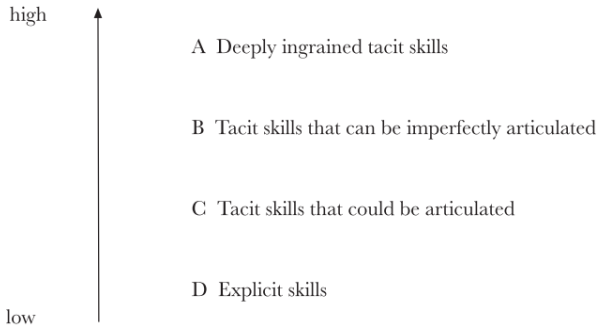


Figure 4.1: Degrees of tacitness

The notion of the "degree of tacitness" or "the degree of explicitness" was considered more meaningful by many researches, especially when examining the type of knowledge shared in a specific context [Chua, 2001; Chilton and Bloodgood, 2010].

As mentioned earlier, there have been very few attempts to empirically research tacit skills, and there is therefore no 'ready' methodology for their analysis. The methodology proposed by Ambrosini and Bowman [2001] is closely related to social science, in particular for studying intangible phenomena, which in this case would be represented by tacit skills.

4.2.1 Philosophical viewpoint

Knowledge is often defined through an hierarchical perspective, according to which data are raw numbers and facts, information is processed data, and knowledge is described as verified information [Machlup, 1980; Dretske, 1981]. However, many researches have shown that fundamental to adequately discerning between information and knowledge is not the content, structure, correctness, or utility of the considered information or knowledge. Rather, knowledge is information retained in the mind of individuals: "it is personalized information (which may or may not be new, unique, useful, or accurate) related to facts, procedures, concepts, interpretations, ideas, observations, and judgments" [Alavi and Leidner, 2001]. Tuomi [1999] observes in fact that knowledge exists which, once expressed, communicated, and arranged, becomes information which, when assigned a fixed representation and standard interpretation, becomes data. Decisive to this assertion in the belief that knowledge does not exist outside of an agent, the so called a 'knower': "it is indelibly shaped by one's needs as well as one's initial stock of knowledge" [Fahey and Prusak, 1998; Tuomi, 1999]. Knowledge is therefore the result of cognitive processing provoked by the influx of new stimuli. Following this reasoning, it can be affirmed that information is converted to knowledge once it is processed in the mind of individuals and knowledge becomes information once it is articulated and presented in the form of text, graphics, words, or other symbolic forms [Alavi and Leidner, 2001]. A significant implication of this view of knowledge is that for individuals to arrive at the same understanding of data or information, they must share a certain knowledge base.

The philosophical perspective in line with interpretation is called *social constructivism*: it in fact argues that all knowledge depends on the knower and is context specific [Berger and Luckmann, 1966]. This implies that meaning cannot be 'objective' in the positivist sense, meaning is constructed by people. As a consequence, a method needs to be found which would allow to capture the constructed reality of individuals, that is what drives them in making sense of the world around them. Thus, the main focus has to be on the reflection of what they make of what is there: 'if men define situations as real, these are real in their consequences' [Thomas and Thomas, 1928].

4.3 PROPOSED METHODOLOGY

This section will provide an overview of the selected research methods for the achievement of the research objectives.

In brief, the study as a whole will be structured as a case study, with multiple units of analysis represented by different games. The case study will then be characterized by the application of various research methods. The main ones will be semi-structured interviews and Q-Sorting, which will be combined for the elicitation of constructs on games' requirements for the generation on knowledge. The causal mapping technique will represent a complementary tool - after the first preliminary interviews - for defining the set of statement which will be used in the Q-Sort technique.

4.3.1 The case study

The main research methods applied in this study is represented by the case study. In particular, the adopted type of design will be: embedded, single-case study. ProRail would represent the main unit of analysis, while the embedded units would be represented by different games within the ProRail framework.

ProRail offers a perfect opportunity for analyzing current techniques of reuse of knowledge generated by simulations and serious games. In addition to being the main Dutch governmental organization for maintenance and extensions of the national railway network infrastructure, allocation of rail capacity, and traffic control, ProRail is also a strongly innovative company, characterized by constant tension towards new technological instruments.

The Dutch railway system is in fact a highly complex and heavily utilized network [Goverde, 2005], and improvements in capacity management and traffic control are becoming increasingly difficult to implement because of the large interconnectedness of all processes. To cope up with the 50% growth expected for the year 2020, new and smarter ways of managing such problems are key for the success of the Dutch rail infrastructure for society [Meijer, 2012]. For this reason, ProRail started looking into gaming simulation as a tool for enhancing the innovation process: in the year 2009, in fact, together with Delft University of Technology, it started a four-years research and implementation proposal for the large-scale implementation of gaming simulation methodology, which is now in operation and who's this graduation project is part of [Meijer, 2012].

Within the case study, many other research methods will be adopted, depending on the stage of the research. Figure 4.2 presents an overview of the applied methodologies with reference to particular stages and objectives of the study.

4.3.2 Literature Review

In a firs stage, an in-depth literature review will be carried out in order to clearly define the main concepts which will be protagonist of the study. This will allow to understand the state-of-the-art, in terms of research, with regards to both KM and serious games. The review of the existing literature will moreover serve the fundamental scope of proving theories (such as the Nonaka's SECI model), which will represent the basis for analysis the current situation and developing suggestions for the client of this research.

4.3.3 Semi-structured interviews

Interviews in general can be a powerful tool in revealing tacit skills, since they allow the possibility of continuously asking the respondents to reflect on their behaviors, on what they do, and why they do it. This way, aspects that up to that point were tacit (in terms of degrees C and possibly B of tacitness) can be revealed to the interviewer. In the semi-structured

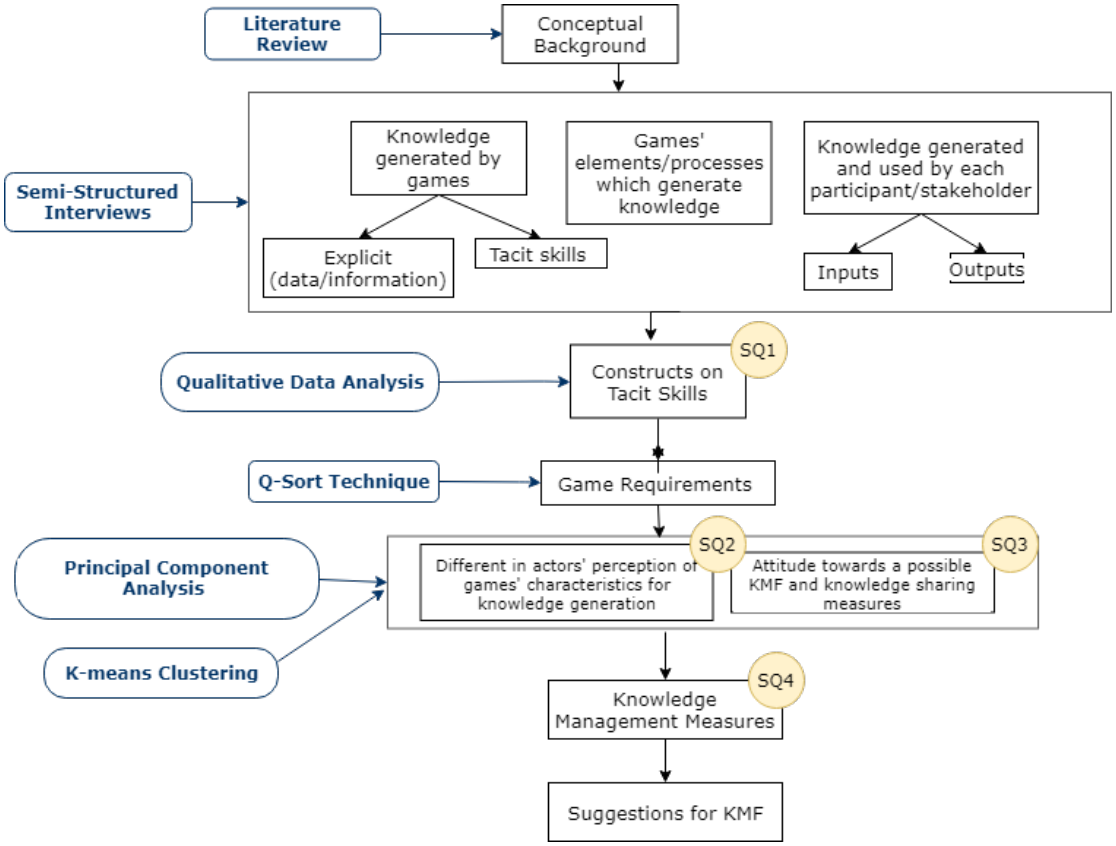


Figure 4.2: Research Flow Diagram

interviews, the purpose and structure of the interview is pre-determined, in the sense that they have a precise scope. However, the interviewees are also asked to tell stories and give examples. There reason for this is that "stories are one of the many forms of implicit communication used in organizational contexts" [Martin, 1982], and people frame their experience through in stories, managing "the collective memory of the organization through storytelling". [Boje, 1991a]. Stories are in fact "contextually embedded" [Boje, 1991b],and they are able to "reflect the complex social web within which work takes place" [Brown and Duguid, 1991b]. In other words, through storytelling, participants can express what is done in the organization, and hence some tacit skills may be uncovered. For example, the participants could be asked to provide examples of situations in which they taught having performed a certain game was useful, or a task for which instead they thought it was counterproductive, and so on.

Appendix A elaborates on the developed interview protocol and on the objectives which each question is focused on.

Advantages of Semi-Structured Interviews

Structured interviews have the risk of resulting in biased, on behalf of the interviewer, statements due to the lack of flexibility [Roungas et al., 2018]. Hence, providing a setup for the interviewees to expand on their answers, and not just answer closed or very structured questions, allows for more rich responses from which the statements for the Q-methodology are expected to be more descriptive.

The main aim of semi-structure is in fact to encouraged the respondents to answer questions by telling stories [Ambrosini and Bowman, 2001]. The story telling allows the interviewees to manage the collective memory of an organization [Boje, 1991a], frame their experiences [Wilkins and Thompson, 1991], and reflect on the complex social web of an organization [Brown and Duguid, 1991b].

Disadvantages of Semi-Structured Interviews

The richness provided by the semi-structured interviews in- creases the risk for statements to overlap or to have strong causal relations (1 to 1, 1 to n, or n to 1). Hence, using causal maps enables the grouping of such statements and thus reducing, among other things, the effect of what in statistics is known as multicollinearity [Roungas et al., 2018].

4.3.4 Q-Sort Technique

The Q Methodology is a research method initially developed by psychologist William Stephenson, widely used in psychology and in social sciences to study people's "subjectivity". 'Q' is used to distinguish this method from 'R' methodology,which is used to refer to traditional statistical methods involving the use of correlation. ('R' is a reference to Pearson's product moment correlation: r). Subjectivity, in the context of Q methodology, represents the communication of an individual's views based on personal opinions and constructs, as opposed to uncovering 'objective' facts [Baker et al., 2016]. As such Q methodology is used to study: "...matters of taste, values and beliefs about which a limited variety of alternative stances are taken" [Stainton Rogers, 1995].

Q studies have four step-wise stages:

1. selecting the 'Q set' of items (usually statements) to be sorted;
2. selecting a sample of individuals or 'P set';
3. the Q sorting process (the ranking of items by respondents) - commonly followed by a brief interview;
4. factor analysis and the interpretation of factors.

Different papers from available literature - Baker et al. [2016]; Watts and Stenner [2005]; van Exel and de Graaf [2005] - will be used as a basis for the execution of this technique.

Advantages of Q-Sort

Another considerable difference between Q and R is that "Q does not need large numbers of subjects as does R, for it can reveal a characteristic independently of the distribution of that characteristic relative to other characteristics" [Smith, 2001].

One of the important advantages of Q-sorting is that questions pertaining to one and the same domain are not analysed as separate items of information but rather in their mutual coherence for the respondent: "[s]ubjective feelings and opinions are most fruitfully studied when respondents are encouraged to order a good sample of items from one and the same domain of subjective interest (instead of just replying to single questions)" [Brouwer, 1999].

In addition to the highlighted benefits, knowledge, and even more tacit knowledge, is characterized not only by its subjectivity but also by its almost completely non-quantifiable nature. Therefore, using a methodology like Q seemed to be the only way forward with this research.

Disadvantages of Q-Sort

Because Q is a small sample investigation of human subjectivity based on sorting of items of unknown reliability, results from Q methodological studies have often been criticized for their reliability and hence the possibility for generalization [Thomas and Baas, 1992].

4.3.5 Principal Component Analysis

The Principal Component Analysis (PCA) technique will be applied for the analysis of the data deriving from the Q-sort responses. PCA is a form of dimensionality reduction: in statistics, machine learning, and information theory, dimensionality reduction is defined as the process of diminishing the number of random variables under consideration by obtaining a set of principal variables, or principal components [Fodor, 2002]. In this specific case, the number of

initial variables is defined by the number of statements contained in the Q-sort.

PCA, invented by Pearson [1901], is a statistical procedure that uses an orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables called principal components. If there are$n$ observations with p variables, then the number of distinct principal components is $min(n-1, p)$. This transformation is defined in such a way that the first principal component has the largest possible variance (that is, accounts for as much of the variability in the data as possible), and each succeeding component in turn has the highest variance possible under the constraint that it is orthogonal to the preceding components.

The objective of PCA would therefore be to find a lower-dimensional surface onto which to project the data. In other words: reducing data from n-dimension to k-dimension by finding k vectors $u^{(1)}, u^{(2)}, ..., u^{(n)}$ onto which to project the data, so as to minimize the projection error. It is important to note how PCA differs from linear regression. The main objective of linear regression, on one hand, is to predict a certain variable y defined by another variable x ($x \rightarrow y$), or a set of variables $(x_1, x_2, ..., x_n)$. PCA, on the other hand, does not aim at predicting a variable; it rather focuses on a set of features (variables), which are all treated equally.

More details on the interpretation of the resulting graph from PCA are presented in the Analysis Chapter.

4.3.6 K-means Clustering

Cluster analysis itself is not one specific algorithm, but the general task to be solved. It can be achieved by various algorithms that differ significantly in their understanding of what constitutes a cluster and how to efficiently find them. Clustering is a method usually applied when, from an unlabeled data set, it is desirable to have an algorithm automatically group the data into coherent subsets or into coherent clusters. The K Means algorithm is one of the most popular and widely used clustering algorithms. It is articulated in 1 first step, followed by an iterative loop, which is repeated until the optimal solution is found. An easy way to understand this process is picturing a bi-dimensional plan which contains a set of points (the observations).

- The first action of the K-means algorithm is to randomly initialize the so-called cluster centroids, whose quantity depends on the number of clusters (groups) that have to be obtained. Afterwards, the algorithm starts with the first iteration of the loop, which is composed by two steps.

Step 1. Cluster assignment: the algorithm goes through all the observations (points) and assigns them to the cluster represented by the closest cluster centroid.

Step 2. Move centroids: the algorithm updates the position of the centroid, by moving them to the average of all the points contained in its cluster.

This process is reiterated until the cluster centroids do not move any further, and the assigned points remained unchanged.

In order to operate, the K-means algorithm needs two inputs. One is a parameter K, which represent the number of clusters, or groups, that want to be find in the data. The second is the data set: in this case, the observations obtained through the Q-sorting.

Defining the number of clusters

The most common way to define the number of clusters K is manually, that is on the basis of further analysis purposes (e.g. market segmentation). However, the Elbow Method [Thorndike, 1953] can help in understanding which number is more appropriate. This methods calculates, for different values of K, the corresponding Sum of Squared Errors (SSE). The

objective is to get to a low value of SSE: this measure reduces as the value of k increases, until it equals 0 when k is the same as the number of observations. In such a scenario, in fact, each observation (or data point) would have its own cluster; moreover it would coincide with the center of the cluster, so there would be no error between it and the centroid. The objective of the Elbow Method is then to facilitate the identification of a small value of k, that would still ensure a low SSE: this is usually represented by the 'elbow' of the curve.

4.3.7 Difference between factoring and clustering

PCA and k-means clustering may seem like similar methods, since they both aim at a reduction on whether variables into factors or observations into clusters. However, there are is a crucial dissimilarity between factoring and clustering. Factoring, or factorization, aims at describing a number, or any mathematical object, as a product of several factors, usually smaller or simpler objects of the same kind. Factor analysis attempts in fact to discover an underlying correlations among variables, in other words a latent structure in the data set. So, while factor analysis groups features into linear combinations, cluster analysis groups cases: observations that are more similar to each other than to other types of cases. In conclusion, it is possible to affirm that both factor and cluster analysis have the scope of reducing the data set, in order to make them more practical to analyze. However, while factor analysis reduces the data on the basis of fewer representative features, cluster analysis reduces them by grouping together observations in a representative manner.

5 CASE STUDY

This chapter will depict the case study framework that was applied to the research. Moreover, the selected embedded units of analysis will be presented and described in their features. Finally, the interviewing process will be presented, together with the definition of the Q- and P-set.

5.1 DESIGN OF THE CASE STUDY

As said in Section 4.3.1, the design employed for this particular research is the one of the embedded, single-case study. Such design implies the following: the main unit of analysis is a single entity, in this case ProRail. Within the main unit of analysis there are however multiple, embedded, sub-units of analysis [Yin, 2009], in this case represented by three different serious games or simulations.

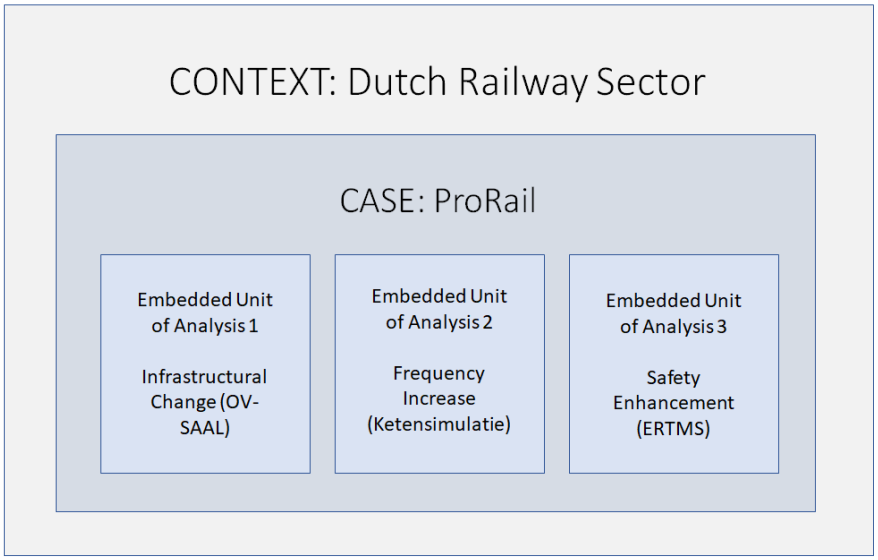


Figure 5.1: Case Study Design

The advantage of an embedded case study methodology is to provide a way of integrating quantitative and qualitative methods into a single research study, while ensuring, through the identification of the sub-units, a more detailed level of inquiry [Scholz and Tietje, 2002; Yin, 2003].

While the reasons for choosing ProRail as main unit of analysis where presented in the previous chapter (Section 4.3.1), the following section describes the selected games, along with the reasons which motivated their selection.

5.2 SELECTION CRITERIA FOR EMBEDDED UNITS OF ANALYSIS

As anticipated in the Introduction chapter, the games were selected on the basis of several diverse criteria. Such decision was made with the objective of having a widest spectrum as possible of games different among each other, so to guarantee a higher external validity to the study. However, the selection was submitted to some limitations.

- The selected games had to be chosen within the range of games applied in ProRail;
- Games from too many years ago could not be selected because of lack of documentation and involved actors to interview;
- The choice was influenced also by the availability and number of possible interviewees.

Apart from said limitations, the games selected for this project were supposed to have the following characteristics:

- Scope: testing;
- Related field: operations, engineering systems and infrastructures design;
- Relevance: non-high decision making;

In addition to specif games' features, other aspects taken into consideration were for the game to:

- Have the highest possible number of involved stakeholders;
- Have encountered particular challenges, or changes, during their design, play or debriefing;
- Be possibly characterized by contrasts among stakeholders' interests;
- Be considered relevant by the organization.

5.3 CASE STUDY: EMBEDDED UNITS OF ANALYSIS

5.3.1 Unit 1: Infrastructural Change (OV-SAAL)

The OV-SAAL game was organized by ProRail in 2013 in order to reach a final decision on the matter of building an infrastructural expansion on the railway network. The solution encountered thanks to the game was eventually provided to the Minister of Infrastructure as a suggestion for the final decision.
The public transport project Schiphol-Amsterdam-Almere-Lelystad (OV SAAL) was part of the project High Frequency Rail Transport Program, whose primary goal was to achieve high frequency rail transport on the busiest tracks in the broad Randstad area, as well as in the SAAL corridor. Good accessibility, both by road and by public transport, is of paramount importance to the economic development of the Amsterdam Metropolitan Area. Some of the reasons for the necessity of an infrastructural change were: the existence of plans for building additional housing in Almere; the growth of the Zuidas in Amsterdam into a work location of international significance; the expansion of Schiphol and Lelystad Airport.

The measures needed with respect to the SAAL corridor in the short, medium and long term had to ensure that sufficient capacity would have been provided, and that a quality improvement in public transport this densely populated area would have been achieved. The government reserved great amount of money (more than €1.4 billion) as an investment for necessary changes in the railway infrastructure. The presence of such high expenditures lead this game to be characterized by many, strong contrasts in stakeholders' interests, in particular among the municipalities which were being considered as possible receivers of the investment.

ProRail, being responsible for taking a decisions on the exact measure to execute, was - both from an economical and political perspective - in a clearly very delicate position. The final decision involved the expansion of station of Weesp from 6 to 8 tracks. This variant provides two extra tracks in Weesp so that the ICs can be used Sprinters in this corridor can pass there. The costs for this measure were estimated at €126 million.

5.3.2 Unit 2: Frequency Increase (Ketensimulatie)

Within the framework of Beter & Meer, RailwayLAB organized four different game sessions (31st of May, 14th of June, 21st of June and 28th of June 2017) in which disruptions were simulated on the A2 corridor (Amsterdam - Eindhoven) in combination with the new higher-frequency timetable for 2018. The aim of the gaming simulation was:

1. to gain confidence of the feasibility of the implementation and management of the new timetable;

2. to measure bottlenecks and learn how to overcome them in case of disruption;

3. to get operational personnel and management familiar with the high-frequency timetable.

The Ketensimulatie was the biggest game ever organized by ProRail and NS, both in terms of number of participants per game session (around 30) and amount of game sessions (more than 4). It represented an incredible technical and organizational challenge for the company, which encountered several difficulties in the execution of this project. The RailwayLAB, which was in charge of the game, can be described as a grouping of employees from the Innovation department of both ProRail and NS.

Figure 5.2 displays how the game sessions were structured: on the ground floor (*begane grond*) there are the NS Regional Operational Centers (*Regionaal Besturig Centra*); on the first floor (*2e verdieping*) there is ProRail traffic control (*Verkeersleiding)*; and on the second floor (*3e verdieping*) the Operational Control Center Rail (*Operational Control Centrum Rail*, national control center for Netherlands) and train drivers (*machinisten)*.

Figure 5.2: Ketensimulatie: game session design

5.3.3 Unit 3: Safety Enhancement (ERTMS)

The ERTMS can be described as set of standards for management and inter-operation of signalling for railways introduced by the European Union (EU), administered by the European Union Agency for Railways (ERA). The primary objective of this project is to endorse interoperability among trains of different European countries. Moreover, other goals of the ERTMS standard are: a considerable enhancement of safety, an increase in the efficiency of train transports, and an improved cross-border connection of rail transport. This can be achieved by substituting former national signalling equipment and operational procedures with a single new Europe-wide standard for train control and command systems.

This game differs from the previous ones for the main fact that is currently ongoing, and will most likely continue for years. The ERTMS standard is in fact expected to be completely operationalized in the whole country by 2025-2030. The Proof of Concept for the ERTMS simulation was concluded during the performing of this research (May/June 2018), and this is also the reason why it was not easy for the author to reach people involved in the project. The peculiarity of this game makes it particularly suitable for the development of a KMF: since its duration is expected to be quite extended, the ability of collecting data, sharing and reusing them in a meaningful and efficient way gains even more relevance than in the previously presented games.

In the Netherlands, the Betuweroute, HSL, Hanzelijn and the tracks between Amsterdam and Utrecht are already equipped with ERTMS.

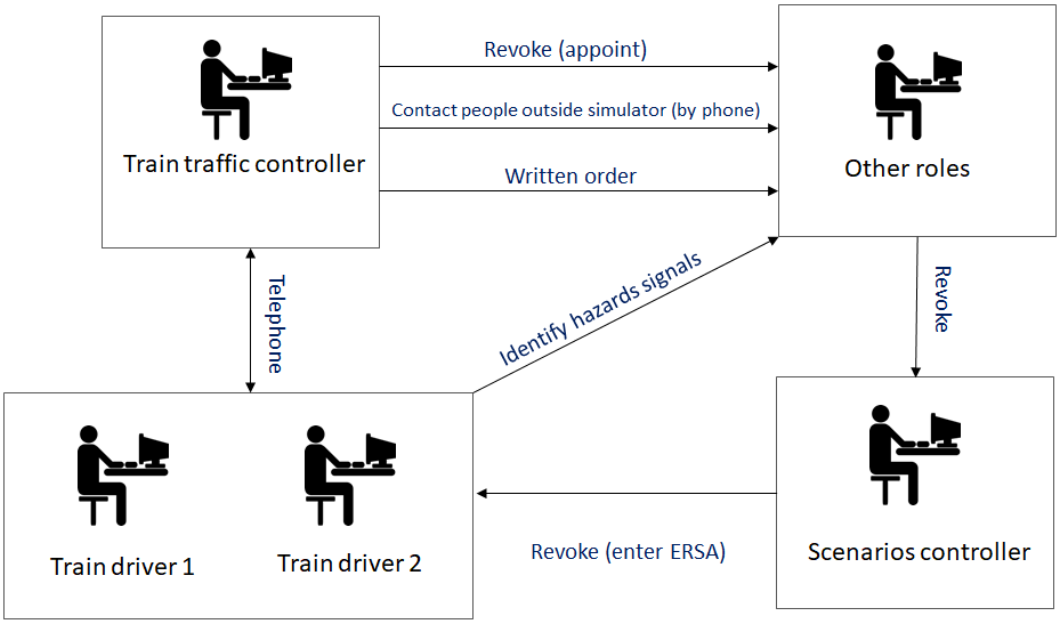


Figure 5.3: Communication scheme for ERTMS simulation [ProRail, 2018]

5.4 GAME FEATURES FOR SELECTED UNITS OF ANALYSIS

Table 5.1 elaborates on the main design characteristics for each game selected as case study. To be taken into account is the fact that the ERTMS game just had one single game session, since, as explained in the previous paragraph, it had just concluded its Proof of Concept phase at the time of the interviews.

Core Aspect	**Infrastructural Change (OV-SAAL)**	**Frequency Increase (Ketesimulatie)**	**Safety Enhancement (ERTMS)**
Purpose	Exploring the impact of implementation of a high-frequent train schedule on the A2 corridor (Amsterdam – Utrecht – Eindhoven)	Exploring the impact of different scenarios on a high frequency timetable	Testing the impact of newly created user processes for ERTMS
Scenarios	Five scenarios, such as No infrastructural expansion, 2. Four additional tracks at Almere station, 3. Additional haul tracks at Weesp station, 4. Four additional tracks between Duivendrecht and Weesp station, 5. Implementation of Europena Rail Traffic Management System ERTMS in all four infrastructural layouts	Seven scenarios spread over four days (1-2 scenarios each game day). such as 1. freight train malfunction between Oud Zaltbommel and Geldermalsen, 2. Fire alarm at train tunnel in Best, 3. power failure at station Den Bosch etc.	Five scenarios to test ten newly created user processes, such as turning train direction at Lage Zwaluwe, entering a non-automatic management shunting area, combining two trains etc.

Core Aspect	Infrastructural Change (OV-SAAL)	Frequency Increase (Ketesimulatie)	Safety Enhancement (ERTMS)
Simulated world	Railway infrastructure on two trajectories: Amsterdam Central Station - Lelystad and Amsterdam Zuid - Hilversum, co-location of operators occurred by seating arrangements (each table was a control center). Current time table.	Railway infrastructure on the A2 corridor Amsterdam – Utrecht – Eindhoven; co-location of operators occurred by seating arrangements (each table was a control center, communications only happening by telephone); three different floors for different organizations (NS, ProRail, Dutch Railways). Higher frequency time table (6 intercity trains per hour instead of 4).	Future railway infrastructure with ERTMS safety system, co-location of operators in same room.
Number of participants	8	between 17 and 23 per game session	3
Number of game sessions	1	4 (1 day each)	2
Roles	Train Traffic Controller (TTC) (2), Regional Network Controller (RNC) (2), National Network Controller (NNC) (1), Regional Passenger Traffic Controller (RPTM) (2), National Passenger Traffic Controller (NPTC) (1)	TTC (6-9), RNC (2-3), NNC (1), RPTM (2-3), Regional Passenger Traffic Junction Coordinator (RPTJC) (2-3), Regional Passenger Traffic Material and Passenger Coordinator (RPTMPC) (3), NPTC (1)	TTC (1), Train Driver (TD) (2)
Type of role	Similar to own (5), prior experience in role (3)	All operators played a role similar to their own in the operational environment, facilitators (ca. 6 per session) covered for other operational roles	All operators played a role similar to their own in the operational environment, one facilitator covered other operational roles
Objectives	Determining own decisions for the next 15 minutes given the status of the system at paused moment	Conducting operator tasks as done in the 'real' operational environment	Conducting operator tasks as done in the 'real' operational environment
Constraints	Separation of train traffic regions: one regional train (2) and passenger traffic center (2) each versus other remaining regional train traffic center (2), exclusion of roles outside the defined infrastructure area, exclusion of train driver	Limitation of a number of simulator functionalities, solved through workarounds	Limitation of a number of simulator functionalities, solved through workarounds

Core Aspect	Infrastructural Change (OV-SAAL)	Frequency Increase (Ketesimulatie)	Safety Enhancement (ERTMS)
Load	Four types of disruptions: 1. Local train delay (+5 min), 2. Freight train delay (+10 min), 3. Corridor train (intercity) delay (+10 min), 4. Disruption as chosen by participants themselves	Scenarios included a various sorts of disruption with a major impact on train traffic operations. This required collaboration between operational roles in applying a disruption mitigation procedure	Scenarios include normal train traffic conditions with no disruption
Situation (external factors)	Presence of observers and video cameras. At the end of each game session the results were discussed and a structured debriefing was carried out to point out most relevant insights gained (with possibility for participants to express their vote for the different observations).	Occasionally presence of observers. A debriefing was held at the end of every scenario.	Presence of an operator acting as observer.A debriefing was held at the end of XX.
Time model	Step-wise (per time periods of 15 min)	Real-time/ continuous	Real-time/ continuous

Table 5.1: Game design requirements of the three case studies

5.5 THE INTERVIEWING PROCESS

The interviews were executed in part as just semi-structure questionnaires, in part in combination with the Q-Sort methodology. The reason for this approach is that the first few interviews were used as a basis for deriving statements - or constructs - on the relation between games' requirements and the development of tacit knowledge/skills, which then defined the Q-set (as explained in Section 5.6.1). All the interviews - whose duration was approximately 40 minutes each, excluding the Q-sorting - were recorded through a smartphone application and then carefully trascribed into a text file. Afterwards, each text file was analyzed to draw out both the game characteristics and the interviewees' viewpoint on the development of tacit knowledge. Such analysis was performed by defining a coding scheme, in order to facilitate the storing and categoriziation of information. A description of the coding scheme development is presented in Section 5.5.3.

5.5.1 Sample Selection

The selection process tried to include in the sample, for each game (i.e. case study), at least one representative for each category of actors: game designer, participants in game sessions, facilitators, stakeholders, members of the project team.

However, the selection process was of course subjected to restrictions:

- Games: interviewees had to be picked among the people who participated in any process related to the chosen games, and not others;
- Language
- Reachability

- Availability

5.5.2 Scope of Questions

The interviews consisted of more than 20 questions, of which more than half aimed at understanding the game characteristics, the role of each stakeholder, and the input and output data. The last seven questions were concerned with the tacit and explicit knowledge produced in, and by, the game. These questions aimed at identifying the challenges each stakeholder faced, the lesson learned from the game, as well as if and how they would do things differently if they were to repeat the game. Results from the initial interviews reveal a varying level of tacit knowledge by each of the principal stakeholders.For instance, the interviewees each found specific certain challenges of the game session memorable, such as the time pressure that was a consequence of the amount of conditions that should be tested, the dynamics of the game in which the participants changed the game rules by adapting the speed of each round and the extent to which the debriefing should be structured. Also, for the game designers from academia the application of the game in a railway domain contributed to a better understanding of train traffic operations. More is discussed about the results of the interviews in Chapter 6.

The first four interviews resulted in building a list of 40 statements for the Q-methodology. In the following interviews, the semi-structured questions were used in combination with the Q-sorting.

The questionnaire was moreover slightly modified for each respondent, depending on her role and level of involvement in the game. In particular, questions about game characteristics were skipped after the first few interviews, since the answer would have been the same for all respondents and it would have not added any further information.

5.5.3 Coding Scheme

One of the main challenges of coding semi-structured in-depth interviews is ensuring inter-coder reliability and inter-coder agreement [Campbell et al., 2013].

- Inter-coder reliability: requires that two or more equally capable coders operating in isolation from each other select the same code for the same unit of text [Krippendorff, 2004; Popping, 2010];

- Inter-coder agreement: requires that two or more coders are able to reconcile through discussion whatever coding discrepancies they may have for the same unit of text discrepancies that may arise, for instance, if some coders are more knowledgeable than others about the interview subject matter [Garrison et al., 2006; Morrissey, 1974].

In order to enhance such features of the coding scheme, Campbell et al. [2013] advise to involve a second coder. In particular, they encourage to adjudicate "the remaining coding disagreements through a negotiation among coders in an effort to establish a high level of inter-coder agreement". For this reason, the interview transcripts were presented to other researchers without the coding scheme developed by the author, in order for them to develop their own coding scheme. The two codes were then compared and the differences assessed. Since there were very few dissimilarities, the original coding scheme was considered valid, and improved with the suggestions given by external coders. It is possible to consult the coding scheme in Annex B.

5.6 IMPLEMENTING THE Q-SORT

As is true of many other qualitative methods (and in response to its factor analytic heritage), Q methodology is primarily an exploratory technique. It cannot prove hypotheses. It can, however, bring a sense of coherence to research questions that have many, potentially complex and socially contested answers (Stainton Rogers, 1995).

5.6.1 Defining the Q-set

The Q set is the collection of 'heterogeneous items' which the participants will sort [Watts and Stenner, 2005]. Regardless of the research question, the Q set should always aim at being largely representative of the opinion domain under analysis, in order to represent all possible points of view. For this reason, the generation of potential statements cannot be theory-driven, it would happen in the design of a questionnaire or a test.

the final Q set can be elicited from any number of sources: by extensive reference to the academic literature (which generally identifies and breaks down a subject matter into its key 'themes'), from both literary and popular texts (magazines, television programmes, etc.) from formal interviews, informal discussions and often via pilot studies. Generally speaking, however, a Q set of somewhere between 40 and 80 statements is considered satisfactory [Stainton Rogers, 1995; Curt, 1994; van Exel and de Graaf, 2005].

5.6.2 Defining the Kurtosis

The score sheet for the Q-sort methodology is represented by a continuum ranging from 'most agree' to 'most disagree', and in between a distribution that usually takes the form of a quasi-normal distribution [van Exel and de Graaf, 2005].

The kurtosis of this distribution relies upon the controversiality of the topic: in case the engagement, concern or awareness of the respondents is expected to be low, or a relatively small part of the statements is expected to be particularly important, the distribution should be steeper in order to leave more room for uncertainty, indecisiveness or error in the middle of the distribution; in case respondents are expected to have strong, or well articulated opinions on the topic at issue, the distribution should be flatter in order to grant more room for strong (dis)agreement with statements [van Exel and de Graaf, 2005]. Usually, respondents are requested to adhere to the distribution provided. In this case, the involvement of the participants is expected to be characterized by an intermediate level of interest: the steepness of the kurtosis will therefore be moderately abrupt.

The range of the distribution depends on the number of statements and its kurtosis: according to Brown [1980], Q sets should contain contain 40 to 50 statements, and employ a relatively flattened distribution with a range of -5 to +5.

5.6.3 Defining the P-set

The P-set can be defined as the total amount of respondents. The Q-sort methodology does not require a very wide sample of interviewees: in keeping to smaller numbers, in fact, an emphasis on quality is maintained, pattern and consistency can still be detected within the data [Watts and Stenner, 2005]. In some occasions, like in the context of this study, it may be logical to strategically sample participants, especially if they seem likely to express a particularly interesting or pivotal viewpoint. Respondents for this Q-sorting study were therefore selected on the basis of their involvement in the games under analysis, in particular the preferred roles were: game designer, game leaders, project team members' or debriefing leaders. Some players were also selected as respondents, in order to include in the sample all the roles involved in the game processes.

The next chapter will present the results obtained from the execution of the semi-structured interviews and Q-sorting technique.

6 ANALYSIS

This part of the report will display the results of the previously introduced research methods, as well as the instruments and tools that have been used for the qualitative (semi-structured interviews) and quantitative (Q-sorts) analysis.

6.1 ANALYSIS OF SEMI-STRUCTURED INTERVIEWS

A total of 20 semi-structured interviews was performed, in order to achieve different objectives. As already explained in Chapter 3, such objective are:

- A first, more generic scope was represented by getting a deeper understanding of the context, of the games' characteristics and contextual factors which influenced the games under analysis. Table 5.1 displays in fact aspects such as: scope of the game, roles performed during the game play, type of rules, number of accomplished game sessions, umber of participants per session, and so on.
- A second objective was to develop a *discourse*, or set of statements, on the relations between game elements and results, as well as knowledge generation and/or reuse. The resulting set of statements was then translated into the Q-set used for the Q-sort technique.
- The third and main purpose of the analysis of the semi-structured interviews was to uncover which game features are considered more relevant for the generation of knowledge - especially tacit. Moreover, the qualitative analysis lead to the identification of other two crucial elements: a) contextual factors that have a strong influence on a game's outcome; b) types of generated knowledge. A deeper analysis then allowed to
- Fourth and last, a deeper examination of the performed semi-structured interviews aimed at discerning dissimilarities with regards to actors performing different roles (i.e. game designers, project team members, participants, managers) in the perception of said elements, as well as in their attitude towards the possible use of a KMS and/or KM practices.

The interviewee set was composed by 19 respondents, out of which the first 4 where used for developing the constructs (statements) afterwards employed in the q-sorting. The composition of the sample was the following:

- 7 game designers;
- 6 project leaders/project team members;
- 4 participants;
- 2 project/department managers.

In reference to the case study:

- 8 respondents for OV-SAAL game;
- 8 respondents for Ketensimulatie;
- 3 respondents for ERTMS.

With regards to the organizations:

- 8 respondents from ProRail;
- 6 respondents from NS;
- 1 respondent from TU Delft.

The following three sections will present the obtained results with regards to: identified contextual factors which affect gaming processes and output; game's characteristics which are fundamental for the generation of new knowledge; types of knowledge developed through games. More details on the analysis can be found in Annex E.

6.1.1 Contextual Factors and their Impact

First, contextual factors which affect game's processes and outcome are identified through the analysis of the transcripts of the semi-structured interviews. Once individuated, the total amount of respondents who consider a certain response relevant is calculated, and the effect of said factor is explained.

Contextual factor	**Number of interviews in which it appears**	**Impact (+/-)**	**Explanation**
F1.Time pressure	11	+/-	This factor has a very direct and negative effect on game processes. A restricted time-frame forces game designers and project team members to accelerate the development of simulators and other technical aspects (e.g. coupling of different system). On the other hand, they are pushed to carry out fewer testing sessions and anticipate the actual game sessions even if the simulator is not ready. This leads to repeated crashes of the system which can cause biased behaviors in participants in the following game sessions. In one case, however, a respondent recognized time pressure as a positive, stimulating factor.
F2.Pressure from external actors (for obtaining a solution suitable to their interests)	8	-	Certain games can involve a high number of different parties (e.g. municipalities, ministries, other organizations, etc.), which can try to pull results in their directions. This can happen due to several reasons (presence of big investments, political pressure, etc.). Whatever the reasons, this kind of pressure has a negative impact on the game processes: if there are conflicts among stakeholders, often they will completely conceal their ultimate objectives, afraid that - by revealing them - will lose the opportunity to get what they want. This makes it hard to define the research question and desired structure the results.

F3.Managerial guidance and involvement (follow-up measures)	5	+	The involvements of middle/high-level management has a positive impact on the game processes, since all the employee involved feel that what they are working on is relevant and valued by the organization as a whole. On the other hand however, it follows that a lack of managerial involvement and guidance can have a bad influence on the game processes, and in particular on the application of measures based on the game's result. In short, the game would identify existing problems, but such problems would then not be dealt with, there would be no follow-up measures, or a thorough track-and-trace policy.
F4.Pressure for proving value of the game as a testing, learning or decision making tool	1	+/-	This factor is one of the least relevant, however it can have very different effects: from pushing the game designers to create an effective and realistic game, to putting even more pressure on the realization of the game design.

Table 6.1: Contextual factors identified and their effect

Deeper insights on these results can be gained by analyzing the composition of respondents who observed each factor (see Annex E.1). By doing so, it is possible to understand whether a particular contextual factor was associated with a specific game, or group of actors. It is interesting to notice how each contextual factor is acknowledge by a great variety of both roles and games.

F1. Among the 11 respondents who admitted to feel the pressure of time restrictions, 5 participated in the OV-SAAL game, 5 in the Ketensimulatie game, and 1 in the ERTMS simulation (even thought the number of interviewees from ERTMS is way lower than the first two games, this can be explained by the fact that they amount to just 3, against the 8 of OV-SAAL and Ketensimulatie, respectively). Also the roles result quite variegated, with the presence of game designers, project team members, managers and participant. However, it can be relevant to note how the highest percentage is represented by game designers (4 out of 11).

F2. The same is valid for pressure deriving from conflicting stakeholders' interest: 5 respondents from OV-SAAL, 3 from Ketensimulatie and 1 from ERTMS. The roles are also here variegated (2 managers, 2 participants, 2 designers, 3 project team members).

F3. With regards to managerial involvement, instead, it is possible to observe a higher concentration of game designers (3 out of 5 interviewees), while the rest are project team members. Such a results is understandable, due to the fact that managers themselves would not be able to notice an eventual lack of engagement from the managerial layers, and participants are not really involved in the follow-up measures that would accompany issues detected during the game.

F4. This last factor, as it might be expected, was just observed by game designers, whose main function is to build suitable and effective games.

6.1.2 Game Requirements

After the identification of the contextual factors, an analysis of the game characteristics that are considered to mainly influence game output (both in term of results and knowledge creation) was executed. The same procedure was followed as in the previous case: game characteristics

were individuated through an analysis of the transcripts of the semi-structured interviews, they were more clearly defined, along with their effect, and the amount of respondents who cited them was calculated as a percentage of the total.

Game Characteristic	**Number of interviews in which it appears**	**Impact (+/-)**	**Explanation**
C1.Structured and concrete results	4	+	If the results of one or multiple game sessions are not concrete, and possible quantitative, they might be attacked by parties who are not satisfied with said results: they could criticize the analysis procedure or the people accountable for them. Moreover, whenever results exceed the expected output (not in terms of quality, but rather in quantity or variety), it might be difficult for the organization to create value out of them (e.g. a particular solution for an infrastructure might be the best, but it was not foreseen and it might now be too complex, or different from the expected ones, to be even taken into consideration; or it might take to long to make this new option run throughout the whole organization to get approval)
C2.Unexpressed and/or conflicting stakeholders' interests	4	-	If all the stakeholders do not express their interests and expectations, both related to the game design and results, the risk is that design options, as well as the research questions and the variables to be tested, will remain uncertain and unclear until the very last day. It is therefore in everybody's interest to align interests and expected output as soon as possible in the game design process.

Game Characteristic	Number of interviews in which it appears	Impact (+/-)	Explanation
C3.Structured debriefing	4	+	If a debriefing is simply organized as an open discussion, participants might feel more free to come up with suggestions and personal opinions. However, this is not always desirable, especially if personal opinions and suggestions start to drift away from the scope of the game (e.g., in case of a game for the definition of a new infrastructure: new design options could come up, which were not expected as a results, leading to the problems explained in C1). It is important, in leading a debriefing, to keep in mind the main objective of the game: is it to test something? Or is it to design something? In case the game is trying to develop a new solution, a more open discussion might certainly be more proficient. However, if the main objective is to test already existing solutions, it might be wiser to carry out a structured and well-defined debriefing, in which participants and stakeholders can express their opinions, but always within the frame of the main scope. Moreover, an open discussion can still be part of a structured debriefing, but it might be accompanied by more concrete, or quantitative, measurements of participants' reactions and feelings (i.e. pre- and post-debriefing interviews, surveys, scorecards, list of lessons learned, video recordings).
C4. Presence of a project manager	4	+	Many respondents have identified as an added value to the whole gaming process the presence of a managerial figure which would be solely focused on managing all aspects related to games, that are currently taken care of by people who cover other roles, such as game designers or project team members. A game project manager could in fact attend to procedures such as: planning all the game-related activities and establishing a time-line, choosing participants and getting them off their work shifts to be available for the game sessions, managing eventual missing players, finding the right spaces and infrastructures for the game sessions, etc..
C5.Simulator validated beforehand (for digital games)	4	+	It appears like, in many game sessions, the software was not actually ready for the simulation, and this created problems of system crashes and duplication of efforts (e.g. if the system crashes while the game is being played, and it is then restarted from the initial point, participants will already now what is going to happen and they will react differently, leading to a biased game result).
C6.Strict rules (vs. loose rules)	2	+	Stricter rules ensure a higher validity of results.

Game Characteristic	Number of interviews in which it appears	Impact (+/-)	Explanation
C7.High variety of roles (parties) involved in game design	11%	+	It is important to involve in the game design process as many stakeholders as possible. Moreover, in the specific case of the railway sector, it seems very relevant to include the operational personnel, who represent, in the end, the people who will actually work every day on the to-be-designed infrastructure or timetable.
C8.High complexity of the game's scope	2	-	An excessively complex scope should be avoided for any type of game. Most of the times, in fact, games are organized in a time-restricted manner; if the game's scope is too broad, problems might arise, such as technical complications (system crashes, simulation software not ready), organizational issues (getting many participants off their shift in their actual job, finding and organizing gaming spaces, scheduling game sessions). Sometimes, the number of game sessions which is actually possible to run, due to time and cost budget, might also not be enough to thoroughly answer to all the research questions.
C9.High variety of roles (parties) involved in game play	1	+	As for the game design process, it is fundamental for the generation of knowledge to also involve as many different actors as possible in the game sessions. The presence of such a diversity of roles is in fact a driver for communication and exchange of ideas, practices and "know-how" which would otherwise never happen in real-life, where the actors work in very segregated environments.
C10.Analog games (vs. digital games)	1	+/-	Analog games appear not to be the preferred ones in case of testing purposes, in particular due to their limited resemblance to reality (step-wise vs. continuous), and the high chance of encountering changes during the game session. However, digital games are not always more effective or useful than analog game, even though they can express a way higher level of complexity. What defines the usefulness of the game is in fact the variable that needs to be tested or measured. Moreover, being far more complex, digital games require higher investments in terms of software development, organization of game sessions (setting up gaming spaces), management of participants (finding participants and making them free from their job for the game day), and management of the debriefing (especially with high numbers of players).

Game Characteristic	Number of interviews in which it appears	Impact (+/-)	Explanation
C11.Amount of aspects taken into consideration in the game design	1	+	Some respondents stated that a game is not really useful if it does not take into account all the possible aspects related to a particular real-life situation (e.g. in case of a new infrastructure for a station, reliability and maintenance in addition to the tracks' design and the timetable). If not all of these elements are considered, then the game will not bring much added value to the work of a dedicated project team that has been working for years of the problem under analysis.
C12.Timing of the game	1	+	The timing of a game is also a characteristic that has to be taken into account beforehand. If a game is done too early, it might point out problems that the organization is not ready to deal with yet. On the other hand, if it is done too late, or too close to the deadline for a necessary solution, it might call the attention on issues that are too complex to be solved in time. Game planning is fundamental in order to avoid problems that might occur during the game sessions or the debriefing.

Table 6.2: Relevant game characteristics and their effect

As already done for contextual factors, it it important to examine the composition of respondents who observed each game characteristic, in order to evaluate whether there are dissimilarities in the way of perceiving games' features - and their effect on games' results and knowledge output - on the basis of covering different roles, or having participated in different games (more details are contained in Annex E.2).

C1. This games' characteristic was detected by different types of actors (managers, game designers, participants). However, the majority of the people who perceived the importance of structured and objective results belong to the first embedded case study unit, the OV-SAAL game. This is explained by the fact that the OV-SAAL game was characterized by not only the involvement of very influential and powerful stakeholders (Minister of Transports, multiple municipalities in the Netherlands), but also by highly conflicting interests among such stakeholders. Having all the actors very prominent monetary concern with the regards to the results of the game, it appeared crucial to the people involved in it to achieve a very concrete, as quantitative as possible, outcome, in order not to foster any recrimination regarding the validity of the reached conclusions.

C2. As in the previous case, also for this feature a majority of respondents from the OV-SAAL game can be detected. The explanation for this can be linked to the one of C1, actually being the cause of it: OV-SAAL was, out of the three examined case studies, the game distinguished by the higher disagreement and dissension among stakeholders, which called for the need of objective and structured results, as well as for the realization of the importance of displaying every actor's needs and expectations as soon as possible in the gaming process.

C3. This game characteristic was recognized by the same number of respondents from OV-SAAL and Ketensimulatie; the roles of the interviewees also do not add much information, since they are quite diversified.

C4. One remarkable aspect is that this feature was observed almost only in employee who participated in the Ketensimulatie game, plus one who took part in the OV-SAAL game. The Ketensimulatie was a very large game, with both a elevated number of participant per game session (around 20 players), and a high number of game sessions. This explains why people who were involved in such a great organizational and technical effort perceived the need for a project manager figure, who can take care of all aspects not directly related to game or infrastructure design. Moreover, giving even more relevance to this conclusion is the fact that the three respondents who identified this necessity are all game designers: a group of actors who had to take over, during the game processes, many responsibilities that were not exactly related to their job function, but rather to the role of a project manager (establish a time schedule for the game-related activities, finding participants, arranging their shift, organizing gaming spaces, and so). The same can be said for other respondent, a high-level manager who took part in the OV-SAAL game and had to perform similar tasks.

C5. This game requirement was recognized as significant by almost solely respondents who took part in the ERTMS game (3 out of 4 interviewees, the other one being from the Ketensimulatie game). Another meaningful aspect is that 3 out of 4 respondents were project team members. Such a composition can be explained by two considerations: first, the ERTMS game has so far just completed the phase of Proof of Concept, which implied a few 'failed' or attempted simulations, with system crashes and problems in coupling different operational systems; second, all the employee interviewed for the ERTMS were project team members.

C6. The two respondents who gave relevance to this game features are interestingly both game designers, and both took part in the OV-SAAL game. This is coherent with the fact that the OV-SAAL game was analog, characterized by a step-wise time model (each scenarios was played for 15 minutes, then the game would stop and start again for the next disruption) and not very strict rules, neither for the game play nor the debriefing. It is then comprehensible how game designers who experienced issues during these two processes are firmly aware of the importance of establishing clear rules so that the game will not generate unexpected problematic situations.

C7. As already explained for C1 and C2, the OV-SAAL game was distinguished by many actors involved in the whole gaming process, as well as many conflicts in stakeholders' interests and desired outcomes. This can clarify why the only two respondents who mentioned this game characteristic as relevant both participate in the same game, OV-SAAL. It is however surprising that they had very opposite opinions regarding the effect of the presence of many actors/stakeholders involved in the game design: one, a manager, considers it to be a positive addition to the designing process, since it helps capturing as many aspects of the real situation and incorporate them in the game. The other one, a game designer assigns to this feature a negative connotation, believe it generates confusion and hinders the process of definition of the objectives. Different actors means in fact different roles, which in turns entails different objectives, and therefore different expected results from the game.Nevertheless, interaction among different stakeholders and actors is a fertile source of knowledge: interaction, exchange of practices, know-how, awareness of others' needs and tasks (see C1).

C8. Not surprising is instead the observed composition of respondents who recognized the significance this game requirement: two game designers, who took part in the Ketensimulatie game. As mentioned for C4, the Ketensimulatie was in fact a very large and complex simulation: is it thus easy to understand how the game designers who took part in it believe that a too complex scope can in the end undermine game processes.

C9. The presence of multiple and differentiated roles during the game sessions was recognized by a participant of the Ketensimulatie.

C10. This game requirement was identified by a gamed designer who participated in the OV-SAAL game, whose analog nature created some problems, as explained in the previous paragraphs (C6).

C11. A project team member who also took part in the OV-SAAL game stated the fundamental importance of considering as many aspects as possible in the game design, in order to make the game resemblant to real life (especially significant in the case of simulation of railway infrastructures which are going to be built years after the execution of the game).

C12. Finally, this last characteristic was pointed out by a game designer who participated in the Katensimulatie.

6.1.3 Generated Knowledge

Once understood which game requirements are fundamental for a positive game outcome, as well as for the generation of new knowledge, it is important to identify and describe which types of knowledge are exactly developed through games. The applied procedure is the same as in the previous sections: transcripts are meticulously analyzed, patterns among the respondents are individuated, the knowledge types are restricted to a limited amount. Table .... provides a description of the identified types of knowledge, together with the percentage of interviews in which each category appears.

Type of generated knowledge	**Number of interviews in which it appears**	**Description**
K1. Knowledge about game processes	7	Many respondents have recognized how, just being part of a game - especially in the game design, game play or debriefing - helped them to gain insights, in a fast and dynamic manner, in how to manage all processes related to games (e.g. finding participants, setting up gaming spaces, defining different stages of game design, organizing the debriefing, etc.)
K2. Knowledge about operational activities	10	Participating in a game related to railway operational activities helps people not usually involved in operational aspects for their everyday job understanding how things work (what is the decision-making process involved in the creation of a new station; what are the necessary actions in order to manage personnel such as train drivers and traffic controllers;how do different operators in the railway sector communicate; how is it defined how many new tracks should be built, and where; and so on)
K3. Knowledge about technical aspects (simulation tools and softwares)	7	Participating in a game's design foster the creation of skills such as: how to develop and construct a realistic, effective and efficient simulation software, how to couple different systems in order for them to work together in a simulation as they do in real life (e.g. train drivers, train traffic controllers). Moreover, knowledge is gained, in some cases, on specific softwares or paradigms (such as ERTMS, for the ERTMS simulation).
K4. Knowledge about inter-actor relations	4	Understanding of how to manage actors with very different interests and expectations (both during the game design and the analysis of the game's results), how to supervise interrelations among participants during game play,

Type of generated knowledge	Number of interviews in which it appears	Description
K5.'Organizational view'	11	Respondents admitted to have gained, through games, a wider and more 'organizational' perspective, a deeper understanding of the risks that are shared among different business units and departments, as well as of the dependencies among different roles and operators (getting to know each-others roles, tasks and needs).

Table 6.3: Types of knowledge generated by games

A few impressive insights can be gained by looking at the roles and games of the respondents for this table (Annex E.3).

K1 Knowledge regarding game processes was acquired by all types of actors and in all of the games. It can therefore be concluded that, taking part in any kind game or simulation, by performing any type of tasks, it is possible for a person to build up, or enhance, her or his expertise concerning how to define, execute and bring to completion all game-related activities (from defining scenarios accordingly to many actors' perspectives, to arranging gaming space or picking participants for the game sessions).
This particular knowledge may be defined as embodied: individual and tacit.

K2 It possible to observe a majority of game designers (5 out of 10) among the respondents who acknowledged to have gained insights regarding operational activities (in addition to all the other roles). The interesting aspect of this result resides in the fact that game designers do not know a lot about the operational activities performed by the organization. Games thus allow them to have a better understanding of operations and their functioning, helping them to design every time better games and simulations.
It is difficult to give a single definition to knowledge regarding operational activities: it is in fact partially embrained (explicit and individual, e.g. users' processes for operators), and partially embodied (tacit and individual, such as all of those procedures that are the result of practice and experience, and are not written down in manuals).

K3 On the other hand, knowledge concerning more technical aspects of the game - such as simulation softwares - was mainly attained by project team members (4 out of 7, followed by 2 game designers and 1 participant). As a reflection of what has been explained in the previous paragraph, it appears also in this case that actors acquire skills and know-how which are complementary to their official job function: while game designers learn about train drivers and train traffic controllers, infrastructure designers discover new information on systems coupling and simulators.
With regards to a classification of this specific type of knowledge, the same is valid as for K2.

K4 The only outstanding detail, with regards to the composition of the interviewees who mentioned this particular type of knowledge is the fact they the participate, for the most part (3 out of 4) in the OV-SAAL. This, once again, is explained by the involvement in the game of several different stakeholders with significant power and conflicting interests.
This peculiar knowledge can be categorized as embedded, therefore tacit and collective, because developed through and thanks to the interaction of multiple actors.

K5 This particular aspect of knowledge, which might be defined as embedded (tacit and collective) is the most frequently nominated in the semi-structured interviews, without differences among diverse groups of actors. Its distinctions from other knowledge aspects is not motivated by its content, but rather by its nature.
Regarding a classification of this aspect, the same is valid as for K4, since it cannot be formulated into words and can only be generated through communication and cooperation among a variety of actors with different roles and perspectives.

Interestingly, it seems like games do not generate knowledge only on an individual level (see K1), but also - and mainly - at a "organizational" level. This can be deduced from the fact that the knowledge every actor gained it is not directly useful for their jobs, but it helps improving the efficiency and effectiveness of the organization as a whole, improving its performances. Moreover, since ProRail's functions are so deeply connected and co-dependent on the service provided by other organizations in the railway sector, such as NS (which took part in 2 out of the 3 games analyzed), it could be said that knowledge is even generated at an "inter-organizational level". The knowledge generated in this particular perspective is not really technical in nature, but can be considered more of an understanding, a state of awareness of the tasks and needs of people working in different departments and organizations, who are supposed to virtually work together, but that actually barely even meet in real life. Through games, they are able to interact, communicate, learn from each other, and ultimately enrich their skills and know-how.

- Game designers learn about operations, and about how operators think and work. Therefore, thanks to this deeper understanding, they are able to design games which are not only closer to reality, but also to the learning and training needs of train drivers, train traffic controllers, and other operators.

- The same is valid for infrastructure designers, which have high-level expertise in their field, but never get really in contact with the people who actually use and work every day n the infrastructures they designed.

- Participants, who usually perform operational activities related to the railway sector, can through games learn from each other, discover the functioning of other roles connected to theirs, train on their particular tasks, and, most importantly , they can express their opinion and ideas and have them heard by managers, infrastructure designers and game designers.

6.2 CONSIDERATIONS FROM ANALYSIS OF THE SEMI-STRUCTURED INTERVIEWS

1. Contextual factors can have a heavy impact on a game's results, as well as on generated knowledge. Factors such as time pressure, conflicting stakeholders' interests, or the pressure of proving the value of using games as testing/decision-making tools can negatively affect game processes. On the other hand, a firm, steady managerial guidance can help in making the most out of gaming and simulations, by facilitating many of the activities involved. For these reasons, when planning a game, it is fundamental not to just consider technical or organizational requirements, but also possible influencing contextual factors.
   Moreover, the analysis of the performed interviews showed that contextual factors do not have different weights depending on the actors' roles or job function, and -surprisingly - neither on the game itself.

2. The most significant game requirements identified by the accomplished qualitative analysis are: structured and concrete definition of desired results; unexpressed stakeholders' interests and expectations; presence of a project manager; and validation of the simulator before the starting of game sessions (for digital simulations). Other important characteristics to be considered are: adoption of strict rules during the game play; high variety of actors/roles present in both game design and game sessions; type of game (analog or digital); complexity of game's scope; number of real-life aspects taken into consideration during the design process.
   Unlike in the case of contextual factors, the analysis of composition of the respondents who valued each characteristic showed some dissimilarities among groups. In particular, game designers appear to recognize greater influence to features such as presence of a

project manager, adoption of strict rules, and type of game (digital preferred to analog for testing purposes). Project team members, on the other hand, rather acknowledged the relevance of validating the simulation software beforehand, as well as amount of real-life aspects taken into account for the game design. Finally, participants focused more on the amount and variety of roles represented in the game sessions.

3. Regarding the types of knowledge generated in the games under analysis, five main categories are mentioned by the interviewees: 1) knowledge about game processes (tacit and individual); 2) knowledge about operations (individual, partially tacit and partially explicit); 3) knowledge about technical aspects of gaming, such as simulation softwares (individual, partially tacit and partially explicit); 4) knowledge about inter-actor relations (tacit and collective); 5) knowledge as better "organizational view" (also tacit and collective). The first and fourth types were observed in the transcripts of respondents covering all kinds of roles. The second, instead, was mainly recognized by game designers; the third by project team members; and the fifth by a higher percentage of participants.

To conclude this section, it can be affirmed that some fundamental dissimilarities have been encountered in the way different groups of actors conceive games' features and knowledge produce through gaming and simulation. This consideration may be taken into account in following stages, especially in the process of defining a KMF for serious games. If different actors are interested, and consider relevant, not only certain elements of games, but even just some specific categories of knowledge, this statement might be crucial for defining the intended user of each KMS employed.

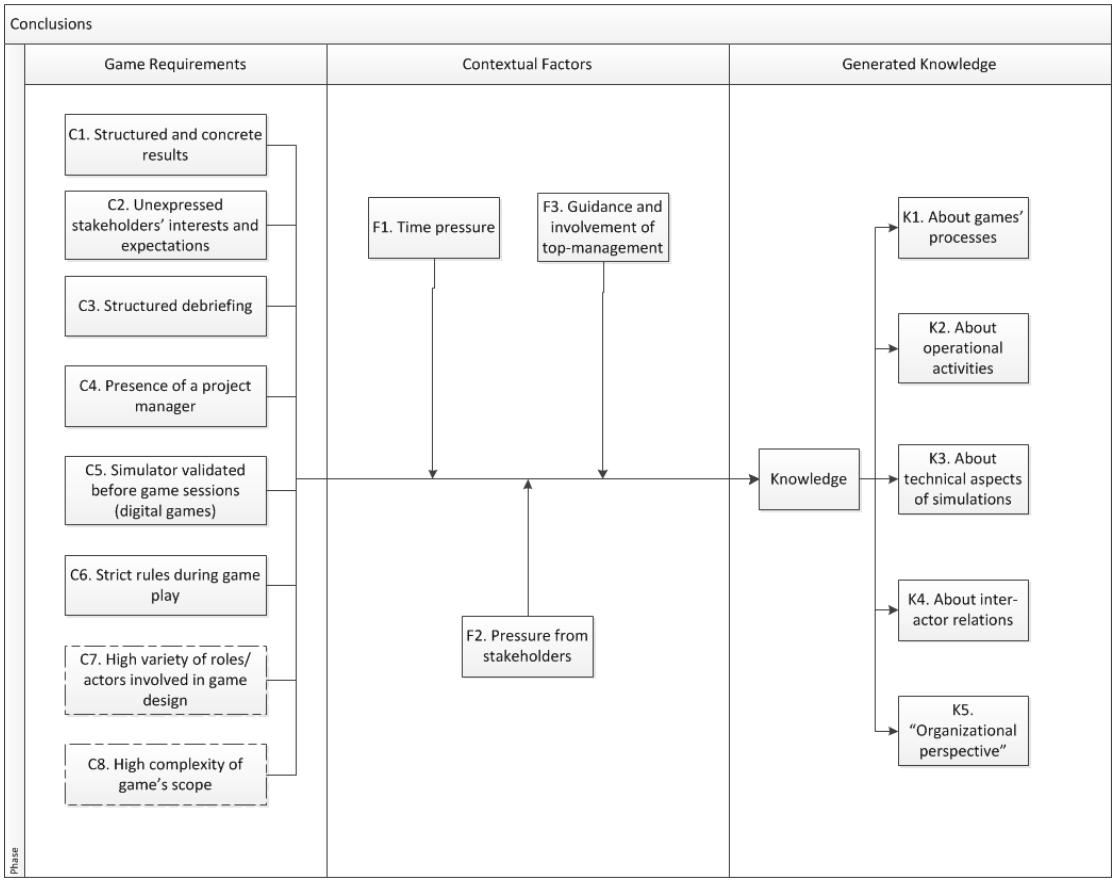


Figure 6.1: Diagram of the conclusions obtained from the analysis of the semi-structured interviews

Figure 6.1 display the findings of the analysis of the semi-structured interviews in a model-like diagram. The point of reference for the development of this scheme was the model created by Grogan and Meijer [2017], showed in Section 2.11.3 of the Literature Review. In this case,

however, the contextual factors are considered moderating variables, by influencing the magnitude of the effect that the independent variables (game requirements) exert on the dependent variable (generated knowledge, in this case tacit). Game characteristics 9, 10, 11, and 12, as well as contextual factor 4, were not considered in the visual model, since they were just acknowledged by one interviewee each.

6.3 ANALYSIS OF Q-SORT RESPONSES

The analysis of the Q-sorts was accomplished by utilizing different tools and programs. The results of the Q-sorts were stored, after each interview, in an Excel file. First, for each statement the total score, average and variance were calculated. Second, the statements were ranked in accordance with their total score, and the results were analyzed and commented. Then, the average and variance of each statement were used to better understand the obtained ranking, and to compare results among different groups (interviewees divided per different role and different game/case study). Then, a Principal Components Analysis (PCA) was performed in order to spot the eventual presence of clusters among the respondents, or any particular strong correlation among the variables. Finally, the k-mean clustering technique was applied to in order to confirm, or disprove, the results obtained with the PCA. Both PCA and k-mean clustering were executed through a Excel add-in tool, XLSTAT, and double-checked in R Studio.

6.3.1 Total Score Ranking

Table 6.4 shows the ranking of the statements with regards to their total score, as the sum of the points obtained in every Q-sort, from the highest to the lowest scoring statement.

Statement	**Score**
12.Games allow for a better understanding among participants of each other roles and tasks.	49
13.Games allow to better understand the reasons of certain actions performed by participants in real life.	40
35.I think it would be useful for game designers, project teams, and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)	39
11.Games allow to test situations which would not be possible to test in real life.	36
2.It is important to have a structured debriefing in order to have valuable and useful results.	35
6.Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.	30
15.The organization as a whole gains through games a better understanding of operations and their functioning.	30
18.Games are useful for the organization for understanding participants' needs (e.g. for the railway sector: operators, train traffic controller, train drivers).	27
24.Games generate a positive environment for people to work in together, especially if they come from different organizations or context.	26
19.Games allow the identification of procedures which are not standard (documented/ described), but are the result of experience and contextual factors.	22
4.The needs of each stakeholder involved in the game should be analysed before the beginning of the game design process.	20

Statement	Score
38.The process itself of designing and playing a game - especially for more complex, digital simulations – helps the organization (project team members, management, game designers) advancing its organizational and technical skills.	20
16.Games bring together actors that would not interact so closely in real life (e.g. representatives of municipalities or ministries, members of project team, train traffic controllers, game designer, etc.)	17
1.Insights from game players or participants should be incorporated at an early stage in the game design process.	16
10.Participating in the game improves participants' ability to cope with unexpected changes in their day-to-day working activities.	9
28.I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.	8
22.The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.	7
7.Games represent a unique occasion for participants (e.g. train drivers, train traffic controllers) to come in contact with the designers (e.g. of the infrastructures).	3
31.I think a game is more effective if there is a variety in participants' roles and expertise.	3
9.In order to be helpful and have valuable results games should be characterized by a balance between number of possible scenarios and accuracy of data.	2
17.Games can help organizations implementing new infrastructure designs.	1
32.I believe that the more times a game session is repeated, the accuracy and validity of the results increase.	1
3.I would like to have a way to consult results as well as access documentation from previously played games.	-2
39.Games are drivers of technological innovation for the organization.	-3
33.I think that games' results (both qualitative and quantitative) would be more useful if organized in a structured database (e.g. combination of repositories of data, videos, forum for questions, etc.)	-2
34.In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game	-5
30.A higher number of participants ensure a better validity of results.	-9
29.The results of a game are valuable as long as the game takes into consideration as many aspects related to the problem as possible (e.g. in the design of a new infrastructure such aspects would be: logistics, maintenance, reliability, etc.).	-12
40.Games are drivers of technical advancements (e.g. developing a software for the game play).	-16
14.Games serve as an occasion for participants to evaluate each others' work.	-18
20.Games' biggest value is in explaining experts' role and tasks to the not experts.	-21
25.Games have value as a learning tool just for people with a low expertise (beginners or other stakeholders who are not involved in the project team or design process).	-30
23.The complexity of a game is directly correlated to the value and utility of its results.	-31
37.Digital games and simulations are better than analog games for testing purposes.	-35

Statement	Score
5.Game designers are mainly concerned in designing a game which can obtain measurable quantitative results.	-35
8.I believe that, in games, strict rules and high validity of results are more useful than loose rules and more space for personal interaction (open discussion, face-to-face interaction).	-40
26.Games related to a particular field (e.g. logistics) are not useful for people with high expertise in that same field, unless they represent a level of complexity which could just be digitally tested.	-42
36.Analog games should be preferred for learning purposes, while digital games for testing purposes.	-42
27.Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).	-46
21.Games should just be used for learning purposes or for explaining complex design to non-experts, but not for decision making.	-48

Table 6.4: Total Score Ranking

Observations

It is interesting to note how the highest-scoring statements are not at all related to games' technical aspects. The aspects which are generally considered more important are instead more social, or interactive, in nature (statement 12, score 49; statement 6, score 30; statement 24 score 26; statement 16 score 17): collaboration among different parties and roles, relevance of facing conflicts in stakeholders' interests, strength of games and simulations as a meeting point, where operators can meet game designers and infrastructure designers, and decision-makers can talk face-to-face with train drivers and train traffic controllers. In addition to these elements, respondents seemed to highly value the role of games as instruments for gaining a better understanding of operations (statement 13, score 40; statement 11, score 36), statement 15, score 30; statement 19, score 22; statement 38, score 20).

Surprisingly, statements that correlate technical aspects of the games to the utility and/or validity of results scored quite low. Elements such as number of participants (statement 30) or amount of aspects taken into consideration when designing a game (e.g. not just infrastructures, but also reliability, maintenance, and so on, statement 29) obtained a total score of just, respectively, -9 and -12), positioning in the lower half of the ranking.

Another unexpected results is that, in opposition to the preliminary findings obtained by the analysis of the semi-structured interviews, games seem to be not considered drivers of innovation and technological advancement (statement 39, score -3; statement 40, score -16); or at least, this aspect appears to be secondary to others. Moreover, games are apparently not believed to have a restricted audience, or target group: statements such as " Games' biggest value is in explaining experts' role and tasks to the not experts" (number 20), or "Games have value as a learning tool just for people with a low expertise (beginners or other stakeholders who are not involved in the project team or design process" (number 25), or "Games should just be used for learning purposes or for explaining complex design to non-experts, but not for decision making" scored very low, respectively -21, -30 and -48, lowest score in the ranking. Statement 26, "Games related to a particular field (e.g. logistics) are not useful for people with high expertise in that same field, unless they represent a level of complexity which could just be digitally tested" was one of the lowest scoring ones, with a total of -42. The very low general score of these statements shows how games are perceived to be as a very broad and adaptable tool, which can be useful for every type of actors, from operational personnel to policy makers, from game designers to project team members, from middle to top management. Of course, depending on the party, they will serve different scopes and produce different results.

Another interesting element to consider: some of the lowest scoring sentences in the ranking are related to the type of game (analog/digital), and to the game's scope (testing, learning, decision making). Based on these results, the complexity of a game seems not to be relevant at all in the achievement of its objectives (statement 23, score -31). Digital games, in fact, despite having the possibility of being far more detailed, realistic, and accurate than analog games, seem not apport any particular added value, not even when talking about testing purposes (statement 37, score -35). The strictness of rules is also not considered positively correlated to the validity of the results, while loose rules combined with more room for personal interaction appear to be relevant (statement 8, score -40).

Finally, it is important to acknowledge the scores of statements that contained references to a possible KMF, or to more general KM measures. Statement 39, "I think it would be useful for game designers, project teams, and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)" was the third highest scoring statement (score 39), followed by statement 2 in the fifth place, " It is important to have a structured debriefing in order to have valuable and useful results" (score 35). On the other hand, statements more directly correlated to a possible repository or database for games did not score high in the ranking: statements 3 ("I would like to have a way to consult results as well as access documentation from previously played games"), 33 ("I think that games' results (both qualitative and quantitative) would be more useful if organized in a structured database (e.g. combination of repositories of data, videos, forum for questions, etc."), and 34 ("In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game") can be find around the middle of the ranking, with respective scores of -2, -4, and -5. This, however, does not mean that, if implemented, such KMS would not be used or appreciated by the employees, but simply that - at least with regards to this specific sample and case studies - there are other measures which are considered more important, such as face-to-face interaction, discussions, structured debriefing.

Comments to the observations

It is very important to consider how the analysis of this ranking can just lead to a certain accuracy of the observations. One fundamental element to take into consideration is the fact that the scores do not really express the absolute significance of a statement - and therefore of a certain game's aspect, but they rather give an indication of a "scale" of significance: in short, how relevant is an element considered to be in comparison to the others. Moreover, the study was limited to just one typology of games (testing), and the sample was limited due to time and workforce restrictions to just 16 respondents.

In order to better understand the results of the q-sorts, however, it is not possible to restrict the analysis to the total score. Another important feature to evaluate is the variance of each variable (statement) within the total amount of observations (respondents). After considering this aspect, a more thorough analysis of the data will be carried out (Principal Component Analysis, PCA; k-means clustering, others), in order to pinpoint the presence of similarities or differences in the way of perceiving games - and in particular the relation between their characteristics and the generation of knowledge - among different groups.

6.3.2 Variance

It is interesting to see how some of the statements with the highest variance are also some of the highest or lowest scoring in the general ranking (statement 11, score 36; statement 14, score -18; statement 15, score 30; statement 29, score -12). This can mean that, although the majority of the interviewees strongly agrees or disagrees with these statements, there is a small percentage of respondents who firmly feels the opposite way.

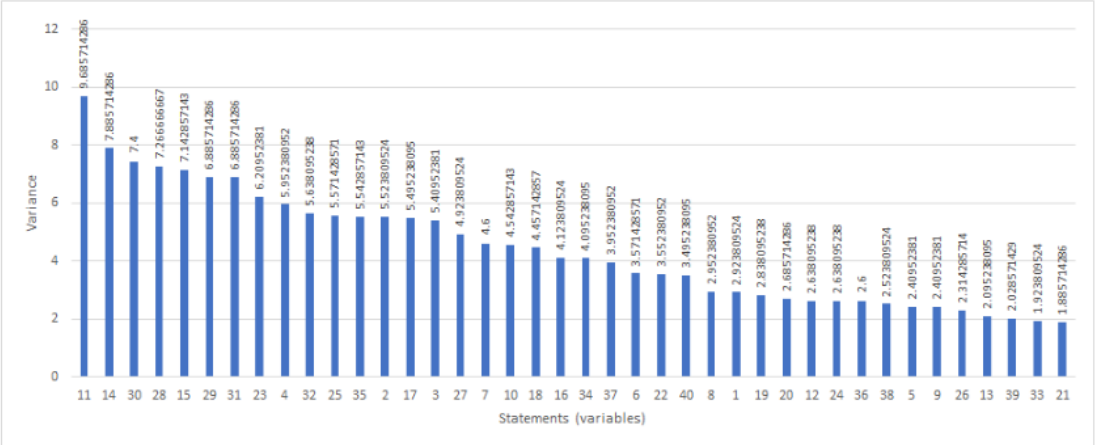


Figure 6.2: Observed variance of statements

6.3.3 Difference Between Group Centroids and Total Average

This section provides insights on similarities and dissimilarities among different sub-sets of the interviewees. The respondent were arbitrarily grouped with regards to their role, subsequently to the case study they took part in, and finally to the organization of belonging. For each division, and for each group, the average was calculated, defining thus the centroid, a 40-dimensional vector representative of a certain category (e.g. game designers, or ProRail's employees, and so on). The total average of the sample was then subtracted from the vector, in order to obtain the distance of the centroid from the total average. After carrying out this procedure for all the sub-sets, the different groups were confronted. The insights obtained are presented in the following sections. More details are contained in Annex G.

Division per Role

The list below (where the abbreviation statement (st.) is used to indicate the exact considered statement) expands on the greatest dissimilarities among different categories of actors.

- Participants and managers
  - **KMF and KMS** ⇒ Both participants and managers revealed a negative opinion regarding the possibility of consulting documentation from previously played games (st. 3). However, managers acknowledge the relevance of being able to examine video or audio recordings from previous game sessions and/or debriefings (st. 34).
  - **Involved actors** ⇒ Regarding this aspect, the two groups showed very different beliefs: both agreed that insights from players (participants) should be incorporated in the game design process (st. 1). However, they also both disagree on the fact that stakeholders' interests should be examined before designing the game (st.t 4). The two perspectives start to step away on statements regarding the number and variety of roles involved in the game play. Participants, in fact, consider that the diversity of actors participating in the game is directly correlated to the game's effectiveness (st. 31). Managers seem not to agree with this point of view; however, in contrast with participants, they consider more relevant the role of game as an occasion for bringing together actors that would never interact in real life (st.16).
  - **Game's technical aspects** ⇒ Both groups agreed on the necessity for games to include as many aspects as possible related to the real-life situation to be simulated, so to ensure a certain level of validity (st. 29). Strong disagreement between the two roles can be detected concerning the type of game, and the accuracy of inputs. While participants showed to firmly prefer digital games to analog (st. 27), and to value high accuracy of input data (st. 28), managers tended to disagree with these points.

  - **Role of games within the organization** ⇒ Participants displayed a firm consideration of games as a positive environment for operators to share opinions, learn from each other, show concerns and give suggestions (st' 6, 12, 14). Managers, however disagreed also with these statements. They were instead more incline towards the idea of games as a tool for helping the organization developing new infrastructures (st. 17), for understanding operators' needs (st. 18), and individuating practices which are not standard, or contained in a manual (st.19). It is nevertheless fundamental to note how, on the other hand, the participants - which are almost solely operators, and whom said statements are therefore directed to - tended to disagree with the managers, showing a big gap in the organization's comprehension of game dynamics.

- Game designers and managers
  - **KMF and KMS** ⇒ Game designers shower greater interest than other categories of actors in the possibility of consulting documentation from previously played games, both in form of raw data and video/audio recordings (st. 3, 34)
  - **Involved actors** ⇒ Game designers, in contrast with the previously considered categories, showed not to believe in the importance of incorporating the participants' insights in an early stage of the game design (st. 1). They however agreed - once again in contrast with participants and managers - with the assertion that stakeholders' needs and interests should be taken into account and analyzed before starting the game design process. Together with managers, they recognized the relevance of games for bringing together actors that would not interact in real life (statement 16), while dissented on the allegation that the effectiveness of a game is directly correlated with the diversity of roles involved in it (st. 31).
  - **Game's technical aspects** ⇒ As for the managers, and in contrast with participant, game designers did not recognize digital games as superior to analog (st. 27), and did not agree with the affirmation that the precision and correctness of data is fundamental for the game's scope and validity of results (st.28). However, they disagreed with the manager category on the assertion that the more aspects related to a real life situation are incorporated in a game, the higher is its accuracy and effectiveness (st.29).
  - **Role of games within the organization** ⇒ Game designer tended to differ from managers with regards to this specific matter, while they were more likely to agree with participants (st. 6, 12, 14, 17, 18, 19). The only exception concerns the belief that games represent an occasion for participants to better understand each other's roles and tasks (st. 11).

6.3.4 Division per Case Study

This section provides instead a summary of the greatest discrepancies identified among Q-sort respondents, this time grouped on the basis of the case study, i.e. game, they took part in. It is relevant to note how, in this particular division, it is impossible to find general trends (e.g. interviewees from one game mainly agreeing or disagreeing with interviewees from another game). This might be due the fact that each game was characterized by certain particular circumstances, issues, and contextual factors, bringing employees who took part in them to have very distinct perspectives. However, the lack of an identifiable tendency to agreement or disagreement in this particular division could be a very interesting point. It might in fact mean that, despite circumstantial game's features, divergences in opinion are more linked to a certain employee's role, job function, department, or organization, rather than the game itself.

One significant aspect is represented by two statements concerning the application of KM measures to games. Respondents who took part in the first game sessions of the third case study (Safety Enhancement (ERTMS)), displayed a greater interest in the possibility of consulting documentation from previously played game sessions (st.3), as well as in the institution

of post-debriefing session for discussing the 'lesson learned' (st.35). Such a feedback is particularly interesting, since the suggestions for changes in KM practices sought by ProRail are mainly thought for the ERTMS case study. The Safety Enhancement game is in fact planned to last for a few years, and it would therefore greatly benefit from the presence of a KMF that would gather both qualitative and quantitative data from all the executed game processes.
Annex E reports in details the other identified dissimilarities in responses for the division by case study.

6.3.5 Division per Organization

With regards to the division of respondents on the basis of their organization of belonging, very strong dissimilarities have been identified between ProRail's and NS's employees. TU Delft was in this case omitted because it was represented by only one interviewee, and it would have therefore created a very skewed graph (Figure E.3, Annex E).

The list below provides an explanation of the most considerable discrepancies identified.

- **Game's technical aspects** ⇒ With regards to technical game features, both organizations showed to consider quite fundamental certain characteristics. However, they tend to give more consideration to different aspects. ProRail's employees regarded as fundamental strict rules and high validity of results over personal interaction among participants (st.8) and number of scenarios (st.9). They moreover agreed with the assertion that a higher number of game sessions results in a higher legitimacy of the results (st.32). Respondents from NS, on the other hand, gave priority to the presence of a structured debriefing (st.2), and to the participation in the game of people with a certain level of expertise (st.22). It appears like employees from NS have a higher consideration of the human element in games. This might be due to the company's mission and values.Within the railway branch, in fact, ProRail and NS, despite deriving from one unique original institution, have now quite different scopes as organizations. While ProRail's objective is to ensure safety and security of the railway network, manage traffic control, and maintain railway infrastructure, NS focuses mainly on guaranteeing a good and satisfying service to clients, i.e. train travelers.

- **Role of games within the organization** ⇒ Also in this case, employees from ProRail and NS showed to have very dissimilar perspective. The former agreed on the value of games as a tool for understanding operators' needs (st.18), as well as for helping the organization to design new infrastructures (st.17); however, they disagreed on the affirmation that games represent a positive environment for collaboration among people coming from different organizations (st.24). The latter, on the other hand, displayed the exact opposite opinion on these matters. NS's employees moreover seem to consider games as an occasion for operators to understand each other's tasks and needs (st.12), statement which respondent from ProRail strongly disagreed on. Also concerning these elements, it seems like NS's employees gave higher consideration to the human element.

- **Type of game** ⇒ With regards to the dichotomy digital/analog game, ProRail's employees disagreed with all the statements concerning the eventual superiority of one type of game or the other for certain specific scopes, such as learning, decision making, etc.. Interviewees from NS, however, showed to believe in a higher effectiveness of digital games (st.27), as well as on the assertions that analog games are better for learning purposes (st.36), while digital games are more suitable for testing (st.37).

6.3.6 K-means Clustering

This section presents the results obtained by submitting the available data set of Q-sort responses to a particular clustering algorithm: K-means clustering. As for the PCA, this clustering technique was applied through different instruments and programs: at first, the Excel

add-in tool XLSTAT was used; then, the method was additionally run in R Studio, in order to check the truthfulness of the results.

As explained is Section 4.3.6, the main input to be provided to the k-means clustering is the number of clusters in which the observations will be divided into. There is not a universally valid rule for deciding this number, however the Elbow Method can give an important indication. The resulting graph from the Elbow Method applied to the data under analysis is portrayed in Figure 6.3.

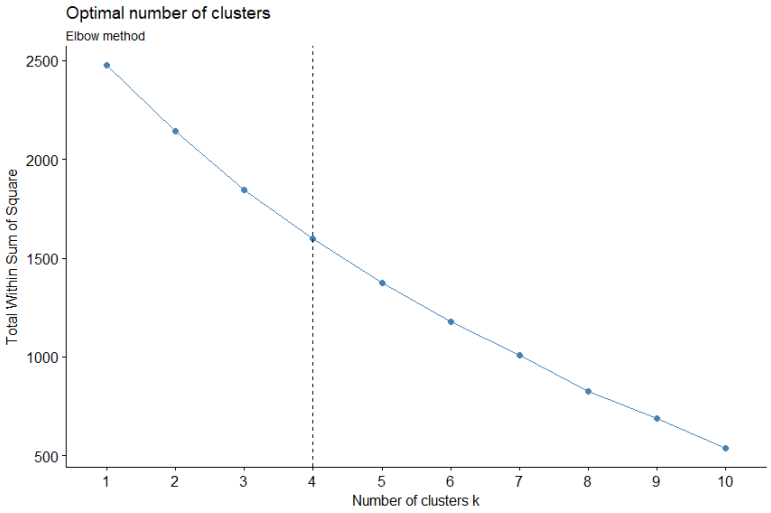


Figure 6.3: Elbow Method for the definition of the number of clusters

As it is possible to deduce from the plot, the value K indicated as the optimal number of clusters is 4. Once obtained this information, the k-mean clustering algorithm was run on the Q-sort observation, which brought to the results presented in Table 6.5.

Class	Observations	Main Composition
Class 1	1OmPR 7OmPR 15EtPR 11KpNS	Managers
Class 2	2KdNS 3KdNS 8KdPR 5KdNS 12EtPR	Game Designers
Class 3	4OtPR 9OdTU 13EtPR	Project Team Members
Class 4	6KpPR 10Oo pNS 14KpNS	Participants

Table 6.5: Results of k-mean clustering ($k = 4$)

In order to better understand the output of the clustering process, it might be helpful to get a better insight into the identification code of the interviewees. Each observation is in fact identified through a sequence of number and letters, of which:

- The initial number (varying from 1 to 15) simply defines the order in which the respondents were interviewed.

- The capital letter in the second position stands from the case study the interviewee took part in ("O" is for OV-SAAL (Infrastructural Change), "K" is for Ketensimulatie (Frequency Increase), "E" for ERTMS (Safety Enhancement)).
- In the third spot, in lowercase, a letter specifies the role of the interviewee in a certain game ("d" stands fro game designer, "p" for participant, "t" for project team member, and "m" for manager).
- Finally, the last sequence, composed by two letters in uppercases, is an indication of the organization the respondent belongs to ("PR" means ProRail, "NS" means NS, and "TU" means TU Delft).

In the light of the above, it can be affirmed that the obtained results are quite revealing. By looking at the composition of the four classes, in fact, it is possible to notice how each cluster is composed for the major percentage by a specific type of actors. Class 1 contains the only two managers of the sample, who account for half of the group; Class 2 is almost exclusively composed by game designers; Class 3 is consists of mainly project team members; while Class 4 only includes participants. It is very interesting to note how, despite the discrepancies detected in Section 6.3.3 with regards to both the division per organization and per case study, the classes defined thanks to the k-means algorithm result mixed with respect to these two divisions. Only for Class 2 it can in fact e registered a majority of respondents who took part in the second embedded unit of analysis, Frequency Increase (Ketensimulatie).

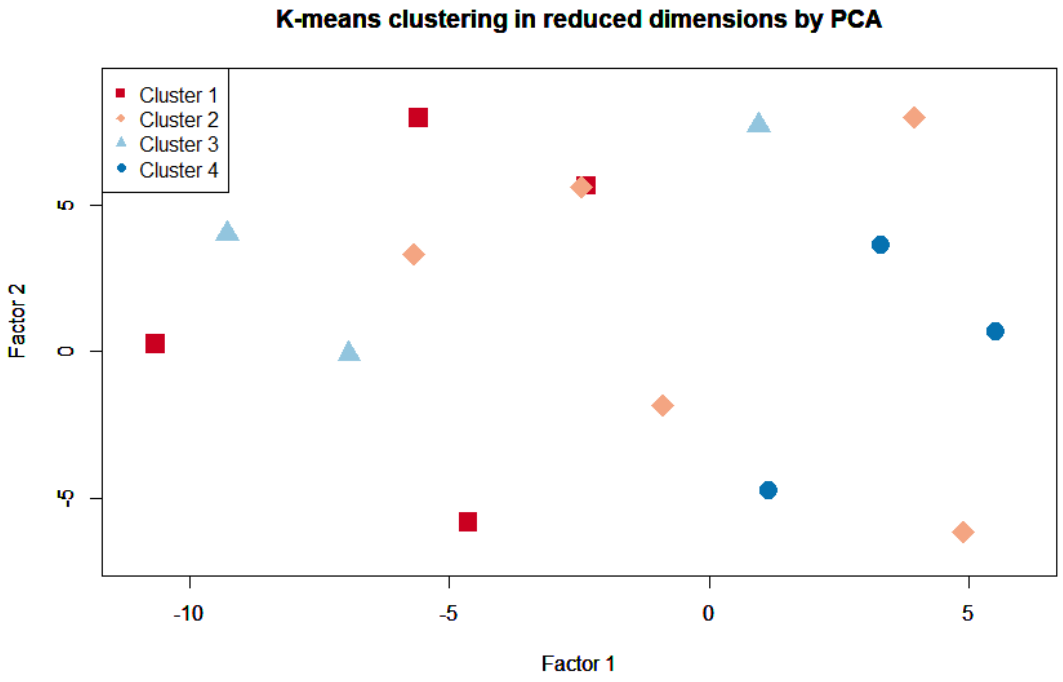


Figure 6.4: Visualization of k-means clustering results by PCA

By looking at Figure 6.4 it appears almost impossible to assign the observation to a cluster or another. The reason for this output is the fact that it would be impossible to visualize the clusters in a 40-dimensional space. PCA, however, allows to visualize the observations by reducing the space from from 40- to bi-dimensional. This result is achieved by representing the clusters through the two principal components (eigenvectors) which explain the highest percentage of the variance: in this case 29%. Figure 6.5 depicts the explained variance for each eigenvalues. As it is possible to observe, there is no predominance of certain factors over others, hence the low value of explained variance. Table **??** displays the eigenvalues, as well

as the explained variability (both for each eigenvalue and cumulative) .

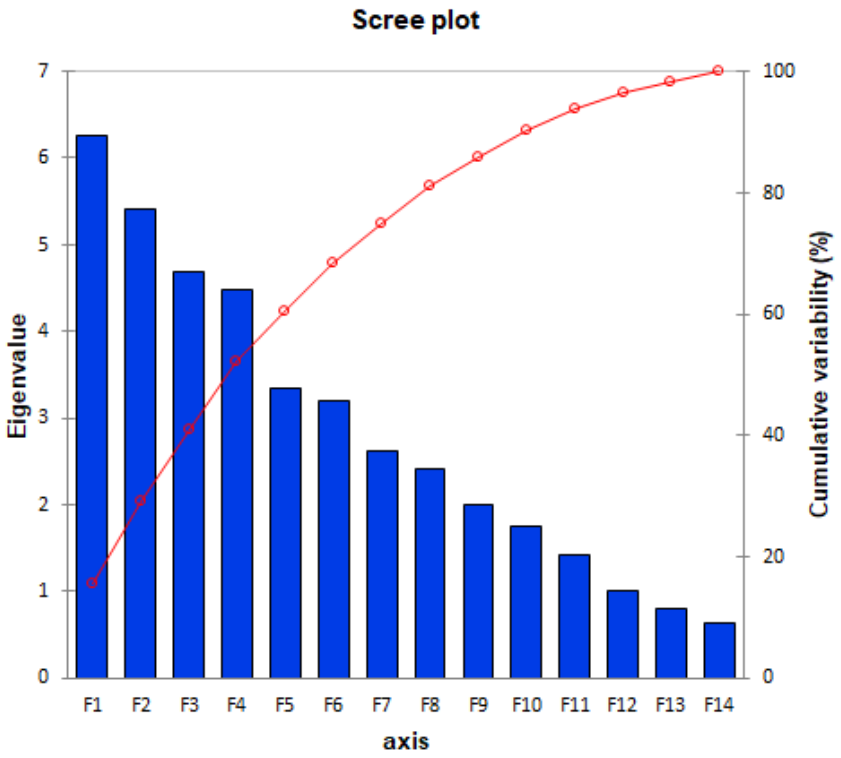


Figure 6.5: Explained variance for each factor

Discrepancies among Clusters

In order to get more insights in the differences among the identified clusters, it is possible to consult the value of the 'distance between centroids' (d). As explained in Section 4.3.6, the centroids serve the role of a 'representative' for the whole cluster they belong to: they are the 'central object' of the class determined by the algorithm. As a consequence, it is possible to define a matrix which identifies the respective distances between centroids: this can help in understanding which groups, or classes, are more or less similar (in terms of closeness) to each other. By looking at the distance between centroids matrix it results that:

- The closest groups seem to be Class 1 and 3 ($d = 9.819$), respectively the managers and the project team members.
- Class 3 and 4 - project team members and participants - registered instead the furthest distance among centroids ($d = 14.142$)

A better understanding of the discrepancies among clusters can be gained by looking at the graph and table displayed in Annex H. The list below presents a summary of the greatest differences in opinions among classes.

- **Class 1 (Managers) and Class 3 (Project Team Members)**
  - **Role of games within the organization** ⇒ As explained in the previous paragraph, respondents belonging to Class 1 and 3 tended to agree on several assertions. With regards to games' function, for instance, they both acknowledge the relevance of games as a meeting point for actors that would usually work in very distant environments (st. 7), as powerful tools for better understanding the reasons behind

certain non-codified operational procedures (st. 13, 15), as well as effective testing instruments (st.11). There are however some points of disagreement. While representatives of Class 1 believe that games are fundamental for understanding operators' needs and skills (st. 18, 19), members of Class 3 rather recognize game play as a way for operators to improve their ability to cope with unexpected changes in their day-to-day activities (st. 10).

- **Games' technical features** ⇒ More discrepancies between the two clusters can be detected with regards to this aspect. Members of Class 1 seem to disagree with the assertion that digital games are more effective for testing, while analog games for learning (st. 36), as well as with the allegation that games are drivers for technical advance within the organization (st. 40). Representatives of Class 3, however, recognized such statements as valid; they however did not consider relevant for games to take into consideration as many aspects related to the problem as possible, such as - in the design of a new infrastructure - logistics, maintenance, reliability, etc.(st. 29). The two classes shared a common view on the importance of the accuracy of input data (st. 28): while this elements was highly valued by members of Class 4, it was regarded as subordinate by all the other clusters.
- **Roles involved in game processes** ⇒ Contrasting opinions have been registered also in this category of statements. Representatives of Class 3, in fact, gave high relevance to the presence of many different actors during the game play (st. 31); while members of Class 1 did not recognize the value of diversity among participants. Both clusters, however, agreed on the necessity of incorporating insights from operators in an early stage of the game design (st. 1).
- **KMF and KM practices** ⇒ Class 1 and 3 displayed concordant opinions concerning these aspects. While they showed interest in the possibility of consulting audio/video recordings from previously played games organized in a repository or database (st. 33, 34), they demonstrated no enthusiasm for the possibility of organizing post-debriefing sessions for discussing lessons learned (st. 35), as well as for the possibility of accessing data and/or documentation of previous games (st. 3).

- **Class 3 (Project Team Members) and Class 4 (Participants)**
  - **Role of games within the organization** ⇒ With respect to this issue, respondents belonging to Class 4, in contrast with those of Class 3, demonstrated to consider games as a highly relevant occasion for participants (operators) to gain a better understanding of each other needs and tasks (st. 12), as well as to give feedback to each other (st. 14). At the same time, however, interviewees from Class 4 do not agree with the assumption that the organization gains through games a greater comprehension of operational activities (st.15), or that games help the organization designing new infrastructures (st. 17). These affirmations are instead strongly agreed with by members of Class 3. Such difference are understandable by looking at the main composition of the two classes. Class 4 consists for the most part of participants, who are dedicated to operational activities, and are not in charge of developing and implementing changes in the railway branch. It is therefore quite clear why they would be perceive games as a tool for aggregation, communication, and knowledge exchange among participants, rather than as instruments created by the organization for testing new infrastructures, timetables, and security systems, or helping with decision-making processes.
  - **Games' technical features** ⇒ Many discrepancies between the two classes can also be found here. In particular, respondents from Class 4 proved to prefer strict over loose rules, with a consequential decrease of room for free interaction, (st.8), digital games over analog (st.27), the highest possible number of aspects taken into consideration in the game scenarios (st.29), and extremely accurate inputs (st.28). On the other hand, respondents belonging to Class 3, while holding different opinion with regards to all said elements, regarded the amount of games sessions (st.32) as a very important aspect for the validity of results.

  - **KMF and KM practices** ⇒ As it could have been expected, members of Class 4 - which as previously stated is mainly composed by participants - demonstrated, in contrast with members of Class 3, a very low interest in the development of a repository for games (st.33), as well as in the possibility of consulting data from previously played games (st.34). However, interestingly enough, respondents belonging to Class 3 (i.e. project team members, for the most part) displayed a negative attitude towards the possible institution of post-debriefing sessions for discussing lessons learned (st.35), either among project team members, or with other actors (game designers, managers)

- **Other significant differences among classes**

Figure 6.6 displays other significant discrepancies in the responses of the different classes.The selection of the statements was executed on the basis of the variance: the presented ones registered in fact an above average variance. The reported statements are characterized by contrasts not only between two specific classes, but among all of the four clusters. For this reason, the author opted for a visual representation. The identified differences regards four main themes.

  - **Role of games within the organization** ⇒ Class 1 and 3, and Class 2 and 4 showed similar opinions with regards to this aspects. The assertion that games serve as an occasion for participants to evaluate each other's work (st. 14) was agreed on by Class 2 (game designers) and 4 (participants), while disagreed on by Class 1 (managers) and 3 (project team members). The four groups had instead exactly specular opinions on the assertion that the organization might gain through games a better understanding of operational activities (st. 15). Concerning other statements, it is interesting to note how, for instance, Class 1 (managers) believe that games help the organization understanding operators needs (st. 18), while both participant, who are mainly operators, and project team members strongly dissented. More disagreement can be found also with regards to statement 17 (*"Games help organizations implementing new infrastructure designs"*) which was considered as truthful by project team members, but not by participants. Finally, while Class 2 (game designers) seemed to believe that games are drivers for technical advancements (st. 40), Class 1 (managers) disagreed with this assumption.
  - **Games' technical features** ⇒ Concerning technical aspects, opinions are quite differentiated among classes. Class 1 (Managers) and 4 (Participants) seem to believe that a high amount of real-life aspects taken into consideration increases the accuracy and value of the results (st. 29). Class 1 also agrees with the statement that the general complexity of the game helps in this perspective (st. 23), while all other classes disagree. Members of both Class 1 and 3 (Project Team Members), however, think that a high number of game sessions can also serve such purpose (st. 32). With regard to the type of game, Class 4 appears to be the only one considering digital games more useful than analog ones (st. 27). It is interesting to note how representatives of Class 2 (Game Designers) did not consider relevant any of these features.
  - **Actors involved in the game processes** ⇒ Quite large discrepancies can be detected also regarding this element. While Class 3 (Project Team Members) and 4 (Participants) agree on the positive impact of the participation of many different roles during the game play (st. 31), Class 1 (Mangers) and 2 (Game Designers) showed a contrasting opinion. Representatives of Class 2 are the only ones who tend to consider of games as a meeting point for actors and stakeholders who would never normally interact (st. 16). Members of Class 1 and 3, however, recognize the value of games in bringing operators into contact with figures such as game and infrastructure designers (st. 7). Class 2 is the only one that displayed interest in analyzing in an early stage, and incorporating into the game design the needs of each stakeholder (st. 4).

– **KMF and KM practices** ⇒ Finally, with regard to KM aspects, members of Class 2 (Game Designers) were the only ones showing enthusiasm for the possibility of consulting documentation from previously played games (st. 3). However, also Class 1 and 3 declared their interest for accessing audio or video recordings from past game sessions or debriefing (st. 34).

One interesting aspect to be noted is the fact that five of the statements which registered the highest amount of variance - and thus discrepancies among classes - were regarded as highly correlated in the PCA. Table F.1 reports the values of the correlation (r) among the statements, which are all concerned with the role of games within an organization. Together with the insights gained through the analysis of the clusters' composition, this might suggest a systematic disagreement, among different groups of actors, with regards to the purpose and function of games in a company.

Table 6.6 expands on said discrepancies, specifying the response of the different classes to each statement. The responses for each group are also displayed graphically in the graph portrayed in Figure 6.6 Both the graph and the table are a section of the ones presented in Annex H, containing the other (less) relevant differences.

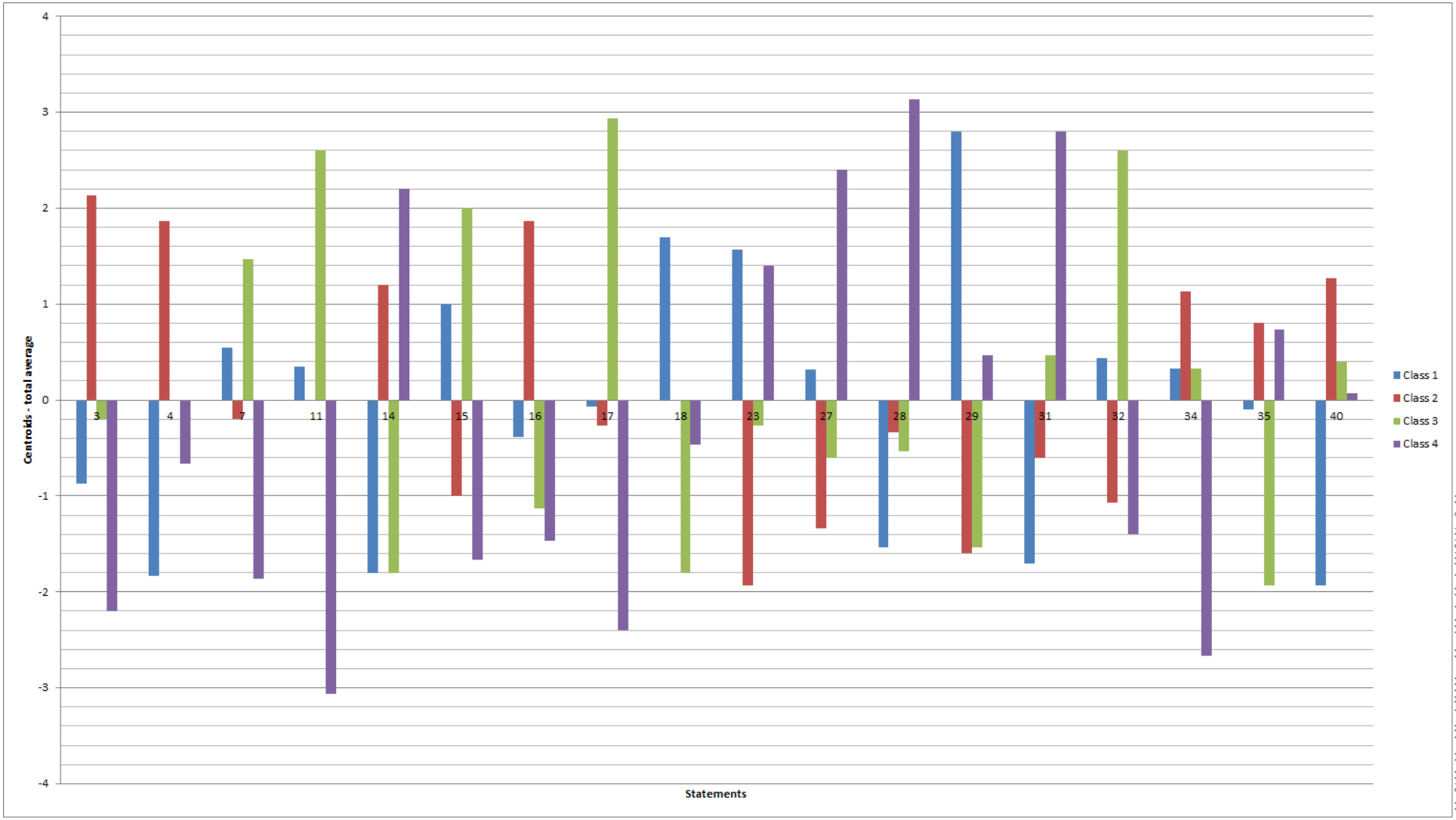


Figure 6.6: Graph: Greatest Discrepancies among Classes

Game Aspect	Statements	Class 1	Class 2	Class 3	Class 4
Scope	11. Games allow to test situations which would not be possible to test in real life.	AGREE	NEUTRAL	STRONGLY AGREE	STRONGLY DISAGREE
	14. Games serve as an occasion for participants to evaluate each others' work.	DISAGREE	AGREE	DISAGREE	STRONGLY AGREE
	15. The organization as a whole gains through games a better understanding of operations and their functioning.	AGREE	DISAGREE	AGREE	DISAGREE
	17. Games help organizations implementing new infrastructure designs.	SLIGHTLY DISAGREE	SLIGHTLY DISAGREE	STRONGLY AGREE	STRONGLY DISAGREE
	18. Games are useful for the organization for understanding operators' needs.	AGREE	NEUTRAL	DISAGREE	DISAGREE
	40. Games are drivers for technical advancements (e.g. developing a software for the game play)	DISAGREE	AGREE	AGREE	SLIGHTLY AGREE
Technical Feat.	23. The complexity of a game is directly correlated to the value and utility of its results.	AGREE	DISAGREE	SLIGHTLY DISAGREE	AGREE
	27. Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).	SLIGHTLY AGREE	DISAGREE	DISAGREE	STRONGLY AGREE
	28. I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.	DISAGREE	SLIGHLTY DISAGREE	DISAGREE	STRONGLY AGREE
	29. The results of a game are valuable as long as the game takes into consideration as many aspects related to the problem as possible (e.g. in the design of a new infrastructure such aspects would be logistics, maintenance, reliability, etc.).	STRONGLY AGREE	DISAGREE	DISAGREE	AGREE
	32. I believe the more times a game session is repeated, the accuracy and validity of the results increase.	AGREE	DISAGREE	STRONGLY AGREE	DISAGREE
Involved Actors	4. The needs of each stakeholder involved in the game should be analyzed before the beginning of the game design process.	DISAGREE	AGREE	NEUTRAL	DISAGREE
	7. Games represent a unique occasion for operators (e.g. train drivers, train traffic controllers) to come in contact with the designers of the infrastructures.	AGREE	SLIGHLTY DISAGREE	AGREE	DISAGREE
	16. Games bring together actors that would not interact so closely in real life (e.g. representatives of municipalities or ministries, members of project team, train traffic controllers, game designer, etc.)	DISAGREE	AGREE	DISAGREE	DISAGREE

Game Aspect	Statements	Class 1	Class 2	Class 3	Class 4
	31. I think a game is more effective if there is a variety in participants' roles and expertise.	DISAGREE	DISAGREE	AGREE	STRONGLY AGREE
KM Measures	3. I would like to have a way to consult results or access documentation from previously played games.	DISAGREE	STRONGLY AGREE	SLIGHTLY DISAGREE	STRONGLY DISAGREE
	34. In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game.	SLIGHLTY AGREE	AGREE	SLIGHLTY AGREE	STRONGLY DISAGREE

Table 6.6: Table: Greatest Discrepancies among Classes

Other differences identifiable through the analysis of transcripts are: project team members gave more relevance to games' characteristics such as the number of aspects taken into consideration when designing a game (C11, see Section 6.1.2; the presence of a project manager who is just focused on the game (C4); or the validation of the software before starting with the actual game sessions (C5). Participants, on the other hand, attributed more influence to the presence of a high variety of actors during the game play (C9).

Even though managers and project team members result to be closer than other groups according to the k-mean clustering algorithm, they still differ in many aspects, which are traceable by looking at the analysis of the transcripts. Game designers are almost uniquely interested in fact in games' features such as: the strictness of rules (C6, Section 6.1.2), the complexity of the game's scope (C8), whether the game is analog or digital (C10), or the timing itself of the game (C12). Managers, instead, demonstrated to give particular attention to elements such as: obtaining quantitative, concrete results (C1), solving unexpressed conflicts in stakeholders' interests (C2), and the value of a structured debriefing (C3).

6.4 CONSIDERATIONS FROM THE ANALYSIS OF Q-SORTS

- As explained in Section F.1, the PCA did not lead to any particular conclusion on the eventual presence of dissimilarities among groups. This might be due to several reasons:
  - Actual lack of a common shared view, among employees and within groups of actors (game designers, participants, etc.) on the function and value of games in an organizational perspective;
  - Large number of variables (statements), in addition of the amount the games' features taken into consideration, which makes it very hard for the algorithm to identify meaningful clusters of variables (factors), that could in turn explain dissimilarities among respondents.
  - Limited sample of interviewees, due to time and resource restrictions.
- On the other hand, insights gained by the qualitative analysis of the semi-structured interviews actually appear to be in line with the results of comparing the centroids minus total average for each statement among groups (Section 6.3.3), as well as with the outcome of the k-means clustering technique. It can therefore be affirmed that there seem to be some substantial and concrete dissimilarities, among different groups of actors, in the way of perceiving not only gaming *per se*, but also the knowledge eventually generated by gaming and simulations. This in turns means that different approaches

might be necessary for the specific characteristics, needs, and expectations of each group of actors.

6.5 CONCLUSIONS OF THE ANALYSIS

The analysis of both the transcripts of the semi-structured interviews and the Q-sort responses lead to the uncovering of several findings.

- First of all, it was possible to determine - thanks to the qualitative analysis of the semi-structured interviews - which are the game elements and contextual factors that more intensively influence the game's output, as well as the generation of new knowledge. Moreover, it was possible to categories the different types of knowledge developed and reused thanks to games. Eight game characteristics were therefore identified, together with three main contextual factors, and five categories of generated tacit knowledge:
  - **Game Characteristics** ⇒ 1) structured and concrete results; 2) unexpressed stakeholders' interests and expectations; 3) structured debriefing; 4) presence of a project manager; 5) simulator validated before the game sessions (for digital games); 6) strict rules during the game play; 7) high variety of roles/actors involved in the game design; 8) high complexity of the game's scope.
  - **Contextual Factors** ⇒ 1) time pressure; 2) pressure from stakeholders; 3) guidance and involvement of the top management.
  - **Knowledge Categories** ⇒ 1) knowledge about game processes; 2) knowledge about operational activities; 3) knowledge about technical aspects of simulations; 4) knowledge about inter-actor relations; 5) stronger 'organizational perspective'.

  A further investigation of the roles and job function of the interviewees for each element identified uncovered the presence of certain trends among the responses. In particular, the examination of the composition of the respondents who valued each game characteristic showed some dissimilarities among groups. Game designers displayed greater interest for features such as presence of a project manager, adoption of strict rules, and type of game (digital preferred to analog for testing purposes). Project team members, on the other hand, regarded more relevant the validation of the simulation software beforehand, as well as the amount of real-life aspects taken into account for the game design. Finally, participants gave more attention to the number and variety of roles represented during the game sessions. The identification of such discrepancies gave way to the thought that the perception of games - of their elements, scope, and generated knowledge - might be influenced by the role covered by the individual, in this case a certain employee. However, this consideration could not just be deduced from the qualitative analysis of the semi-structured interviews, and it was thus further investigated by quantitatively examining the Q-sort responses.

- Second, the analysis of the Q-sort responses led to even more interesting findings:
  - The ranking of the statements based on their overall score displayed that respondents, in general, tended to consider more relevant non-technical aspects such as: collaboration among different parties and roles, importance of facing conflicts in stakeholders' interests, strength of games and simulations as a meeting point, where operators can meet game designers and infrastructure designers, and decision-makers can talk face-to-face with train drivers and train traffic controllers.
  - The analysis continued by arbitrarily grouping the respondents in sub-sets based on their role (managers, participants, project team members, game designers), organization of belonging (ProRail, NS), and case study (embedded unit of analysis 1, 2, 3). Then the difference between the centroids - for each sub-set - and the total average of the sample were calculated and compared, in order to expose different reactions to the proposed statements. This procedure helped revealing the presence

of systematical differences among groups, in particular with regards to the division by role and by organization.

- In order to demonstrate this conclusion and grant it validity, both the PCA and the k-means clustering algorithm were performed on the available data set. While the PCA did not lead to any conclusive results (for reasons better explained in Annex G), the k-means algorithm showed interesting findings. The resulting clusters, in fact, displayed a mixed composition with regards to organization of belonging and case study/game. However, each presented class was almost entirely composed by members who covered the same role within the game they took part in. Such discovery confirmed the hypothesis developed after the analysis of the semi-structured interviews, leading to the definition of four classes, or clusters: 1) Class 1, or Managers; 2) Class 2, or Game Designers; 3) Class 3, or Project Team Members; 4) Class 4, or Participants.
- The same procedure performed for the arbitrary division into sub-set was executed on the clusters defined by the algorithm, in order to identify meaningful discrepancies.

A summary of the results obtained thanks to both the qualitative analysis of the semi-structured interviews, and the quantitative analysis of the Q-sorts, is displayed in Table 6.7. A quick explanation of the symbols: "+" means that the representatives of a certain class generally assigned a positive impact of a specific element on the game's knowledge output ("++" represent a very strong agreement); symmetrically "-" stands for the element's negative impact, based on the opinion of the respondents (as for before, "–" suggests a strong judgment among the members of a class/cluster).
These results will be crucial, in the next chapter, for defining recommendation to the client (ProRail) with regards to the development of a KMF.

Game Element	**Game Requirement**	**Roles**			
		Class 1 (M)	Class 2 (D)	Class 3 (T)	Class 4 (P)
Actors/Roles	High variety of actors/roles involved in the game play	-	-	+	++
	Participants (operators) involved in the game design	+	-		
Technical Features	Number of real-life aspects taken into consideration during the game design	++	-	-	+
	Structured debriefing	+	+	-	-
	Strict rules (during the game play)	-	+	-	+
	Type of game (digital better than analog)	+	-	-	++
	Accurate input data	-	-	-	++
	Validation of simulator before starting of game session			+	+
	Number of game sessions (the higher the better)	+	-	++	-
Objective	Structured and concrete results	+	+		
	High complexity of game's scope	+	-	-	+
Context	Presence of a project manager dedicated to the game	+	+		
	Timing of the game (not too early, not too late, with regards to the desired time for implementing changes)		+		
Stakeholders	Unexpressed and/or conflicting stakeholders' interests	-	-		-

Game Element	Game Requirement	Roles			
		Class 1 (M)	Class 2 (D)	Class 3 (T)	Class 4 (P)
	Stakeholders involved in the game design process	-	+		-
KM Measure	Post-debriefing sessions for discussing lessons learned	-	+	-	+
	Possibility of consulting a repository of games (database including data, video recordings, images, etc.)	+	+	+	–
	Games' results organized in a structured database	+	-	+	-

Table 6.7: Summary of the obtained results: differences per class with regard to games' requirements (M: Managers; D: Game Designers; T: Project Team Members; P: Participants

As it is possible to note from Table 6.7, different groups of actors, or classes, give emphasis to different game elements.

Managers (Class 1 in the k-means clustering), displayed interest for elements such as: the number of game sessions; the role of games as tools for better understanding operators' needs; the value of games for the identification of procedures which are not standard, but are the result of experience and contextual factors.

Game Designers (Class 2), instead, believe that certain characteristics have a positive impact, such as: presence of a project manager; the adoption of strict rules during the game play; the role of the game as a meeting point for employees who would normally never interact with each other; the possibility of performing post-debriefing session in order to discuss the *lesson learned* (in addition to the debriefing).

Project Team Members (Class 3) showed a positive attitude towards elements such as: the validation of the simulator before starting the game sessions; the role of games in helping organizations designing and implementing new infrastructures.

Finally, Participants (Class 4) focused their attention on: the amount and variety of roles present during the game play; the accuracy of game's inputs data (e.g. data such as infrastructures, timetables).

Some elements are shared by more than one class. For instance the number of aspects related to a real-life problem taken into consideration by a game or simulation was regarded as very important by Class 1, Class 3, and Class 4; the complexity of a game, as directly correlated to the value and utility of its results by both Class 1 and 4; type of game, with digital simulations preferred to analog for testing purposes was considered relevant by Class 2, 3 and 4 (with the last one - Participant - generally considering digital simulations better, whatever the purpose). With regards to KMSs and KM practices, Class 1, 2, and partially 3 displayed interest in the development of a structure games database (a repository of data, video and audio recordings, forum for questions, etc.) for gathering and organizing games' results. Finally, both Class 3 and 4 expressed the willingness of performing post-debriefing session in order to discuss the *lesson learned*, in addition to the typical post-game session debriefing.

6.5.1 Influence on Knowledge Sharing Processes

The previous section showed how different categories of actors pay attention to different game elements. This, in turns, affect the actors' approach to knowledge sharing processes and

techniques. Some actors, for instance game designers, may be interested to some particular information which is only relevant during the designing of the game or simulation, and not later or before. The different perspective that each actor has towards different game elements therefore defines the way said actor is going to make use of KMSs or KM practices.

For instance, Class 1 (Managers), Class 3 (Project Team Members), and partially Class 2 (Game Designers), highly valued the possibility of consulting data from previously played games. This, in turns, could mean that they would benefit from the institution of a game repository or database that they could consult while preparing the game.
Also, managers (Class 1) and project team members (Class 3), expressed an interest for additional information on the presence of certain contextual factors: conflicts in stakeholders' interests, involvement of operators during the game design, time pressure, etc. This information could be relevant during a root-cause analysis for an unexpected problem occurred during a game, or even in the phases preceding a game, in order to avoid the manifestation of issues occurred in previous games by examining their characteristics. This kind of information could as well be stored in a games repository, for instance as part of projects based profile.
Game designers (Class 2), alternatively, displayed a high interest for structured debriefing and strict rules during the game play. The access to material concerning these game aspects should also be provided before the starting of the actual game sessions of newly developed game. Details such as the type and strictness of the game rules, or the employed debriefing approach during previously played games could help game designers in the phase of defining a new game, or improving an existing one.
Finally, representatives of Class 4 (Participants) expressed for the most part no interests in consulting any type of data from former games. This consequentially indicates their lack of concern for an eventual games repository or platform. Representatives of this class instead revealed that they would be positively affected by more personal and interactive activities. Therefore, they could benefit from KM practices such as simulation training days, discussion sessions, or community meetings, that could take place after the process of debriefing, or completely independently from a specific game.

The next chapter expands on how such differences in perspective among groups of stakeholders may affect the form in which KM measures are applied. As a result of the considerations expressed in this analysis some suggestions will be provided on the type of KMS and KM practices to apply. The measure are necessarily based on the ProRail case study, but they were generalized as much as possible in order to be applicable to other contexts and institutions.

7 DISCUSSION

This chapter builds on the formerly executed analysis, connecting the observed discrepancies among groups of actors, with respect to game elements, to KM measures.

7.1 ANALYSIS OF CURRENT SITUATION

On the basis of the finding presented in the previous section, it is possible to conclude that groups of actors who cover different roles have dissimilar perceptions on games, their requirements and their knowledge output. This brings them to consequentially have very distinct needs and expectations in terms of knowledge sharing and reuse. In the light of the above, it is then possible to investigate the current situation, with regards to KMSs and KM practices employed within ProRail, with the scope of ascertain whether these procedures reflect the actual needs of the various actors. The inquiry was implemented by means of the combination of two theories extrapolated from the examined literature:

- Nonaka's SECI model (also known as Knowledge Spiral Model): this theory, as presented is Section 2.8, allows the allocation of KM practices, tools and systems into four knowledge conversion processes (Socialization, Externalization, Combination, Internalization). These process represent a loop - or better, a spiral - by which undergoing to knowledge is amplified and transformed, spreading from an individual to an organizational level. Moreover, Nonaka's SECI model contains the definition of four different environments, called *'ba'*, which serve different knowledge purposes, from knowledge creation to knowledge sharing and reuse. The four *'ba'* are identified through the combination of two different criteria: first, the distinction in individual and collective interaction; second, the discrimination between virtual and face-to-face communication.

- Four categories of knowledge on the cognitive level [Blackler, 1995; Lam, 2000; Collins, 1993]: this theory brings together the ontological (individual/collective) and epistemological distinction (tacit/explicit), thus defining four typologies of knowledge: embrained, encoded, embedded, embodied (explanation in Section 2.2).

The combination of the above presented theories is possible thanks to the fact that they are both represented by a $2x2$ matrix, which allows for a juxtaposition of the four dimensions contained in each model. The resulting framework was applied to the case study at hand - represented by ProRail, with the aim of getting a deeper understanding of the current KM dynamics at play. Afterwards, all improvement points being considered, the model is proposed once again, this time displaying a possible proposed approach.

To be noted that, in the employed model, two additional categories of actors are considered, which were not contemplated in previous parts of this study: accident investigators and system optimizers. There are two reason for this change: first of all, it was not possible to encounter representatives of said categories to interview; second, even though they were not considered earlier, it might be relevant to consider if they could benefit of any aspect from an eventual KMF.

By looking at the application of the selected theories to the state of the art of KMS and KM procedures in ProRail, it is evident how some processes of knowledge creation and sharing are being completely omitted. At the same time, there seems to be a plurality of tools meant to perform the same function, but each one for different types of actors. Just for the Combination process (explicit to explicit knowledge), it is possible to identify 5 different KMSs:

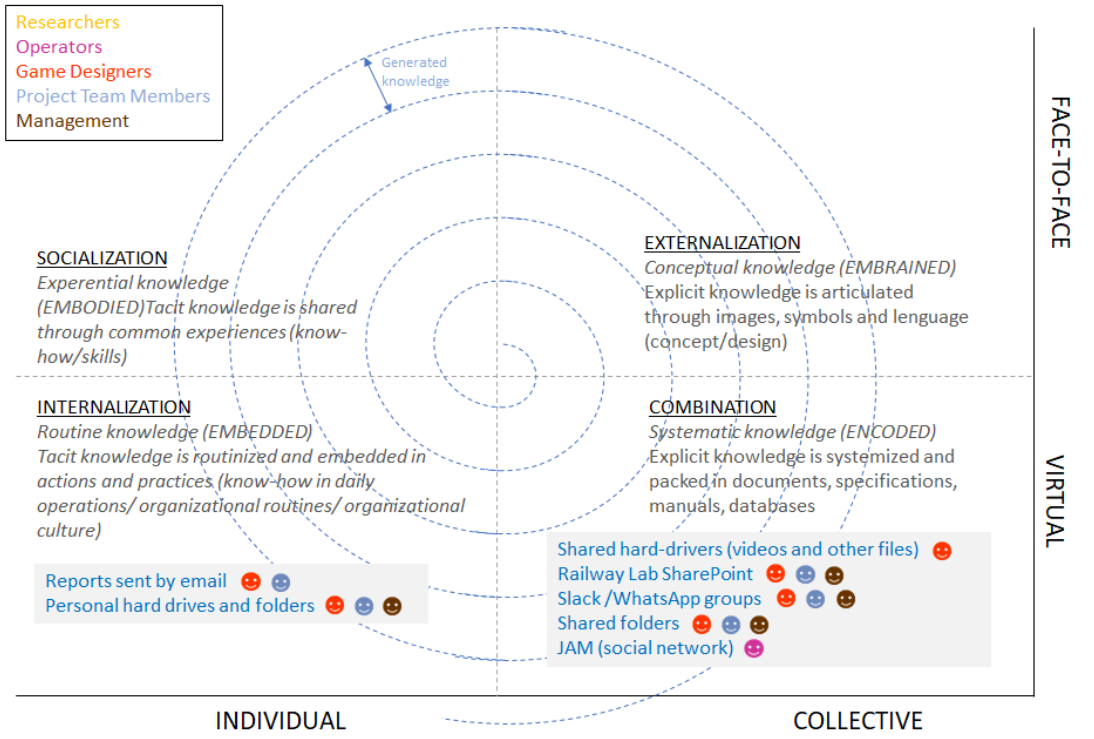


Figure 7.1: Applied framework: current situation

1. Shared hard-drives containing video recordings or other types of information on game sessions and game design → these tools are usually used by game designers, at times even just a small sub-set of all the designers working on a specific game.
2. RailwayLab SharePoint → a platform dedicated to employees of different departments (Innovation, Capacity Management, Learning and Education) in the whole railway branch (ProRail, NS). This application contains all kinds of documents on several projects. However, it has its drawbacks: 1) it is not possible to perform a search of projects or personnel based on keywords (which could help finding someone who is already working on the topic of interesting, avoiding this way an eventual duplication of efforts); 2) there is no available function for talking through a private chat, people necessarily have to communicate by email; 3) it just contains information regarding recent projects (from around 2016, year in which it was introduced).
3. Slack and WhatsApp groups → these social media applications are occasionally applied for specific projects, in particular when the employees involved need to share updates, pictures, and/or video recordings in a fast and easy manner. The problem of using these applications as KMS is that the storing of data results chaotic. Moreover, they are just accessible by the people who are working in that moment at that specific project: other employees might not even be aware of the existence of such groups, thus ignoring information that might be useful for their everyday activities.
4. Shared folders → as in the case of shared hard-drives, shared folders are often jointly used by just a handful of people. Sometimes they are even retained by a single person, who has to be contacted by email in order to get the necessary data.
5. JAM → this social network, similar in the outlook and structure to Facebook, is meant to be entirely dedicated to train traffic controllers, and it is maintained by ProRail's Learning and Education Department. The first issue with this KMS is that, how the analysis of semi-structured interviews and Q-sorts proved, operators are not generally interested in consulting any kind of database or repository of data. Instead, they might benefit from more people-focused KM procedures, such as training days with simulators, or joint post-debriefing discussions with game designers, project team members and/or

other roles. Moreover, the audience of this social network appears to be quite restricted, being limited to train traffic controllers from ProRail, and not to the rest of operational personnel.

Shared folders, hard-drives and reports sent by email can also be considered as part of the Internalization process, which involves the conversion of implicit knowledge from collective to individual and vice-versa. However, this KMSs are quite scattered, and applied in very different ways depending on the individual employee.
Two conclusions can then be drafted after evaluating Figure 7.1:

- Two out of four quadrants identified by the applied model are empty, which means that knowledge cannot perform an entire loop composed by the four conversion process, and it can therefore not be transformed and amplified throughout the organization. In particular, there are no KM procedures which involve a face-to-face interaction among employees, neither in a individual nor a collective form. This hinders the process of knowledge sharing among communities-of-practices: know-how is not distributed among different departments, and tacit skills which could be highly relevant for the organization remain restricted to the minds of individuals, or to limited groups of employees. Tools such as shared hard-drives or folders can in fact be helpful for sharing explicit knowledge, such as raw data and information, but they cannot build or distribute tacit knowledge. Any knowledge creation or knowledge sharing process which is focused on tacit knowledge, in fact, needs to take into consideration the high relevance of personal communication and interaction, which sometimes may be the only way of transmitting an individual's expertise.
- The presence of many different KMSs dedicated to diverse scope and accessible by just a restricted percentage of all actors might actually be more ambiguous than helpful for the organization as a whole. A part from the respective drawbacks of each KMS presented in the previous paragraph, the lack of a common, unified KM platform means that the resulting organizational knowledge will necessarily be less than the sum of all the individuals' knowledge.

7.2 PROPOSED CHANGES

As a result of the findings of the analysis of the semi-structured interviews and Q-sorts, it was possible to assert that different actors, who cover different roles within the processes involved in gaming, perceive games in diverse and sometimes contrasting ways. The same is applicable to their consideration of knowledge outcomes resulting from taking part in a game. It therefore seems logical that distinct approaches need to employed in the definition of KMSs and measures for the generation and sharing of knowledge, depending on scope and target group. In particular, it was evident from the previous section that there is a need for personal interaction and and interplay among the different actors, which is especially critical for the creation of tacit knowledge.

Despite the fact that the main target group of this research consists in game designers and project team members (supposedly the ones who would be more interested in a KMF), also other actors were taken into account in defining a new set of KMSs and KM procedures. Particular attention was given to people-focused measures, in addition to data-focused repositories and systems. Moreover, the literature review presented in Chapter 2 was taken into account in the definition of the KM measure: many notions on KM best practices were retrieved from Arora [2002]; Hoegl and Schulze [2005]; Ceptureanu and Ceptureanu [2010]. The resulting proposed model is presented in Figure 7.2.

- **Informal events and community meetings** ⇒ These two KM measures could serve the particular knowledge sharing process of *socialization*. They consist, in fact, in occurrences during which informal and open conversation is stimulated, facilitating the sharing of tacit knowledge [Leonard and Sensiper, 1998].

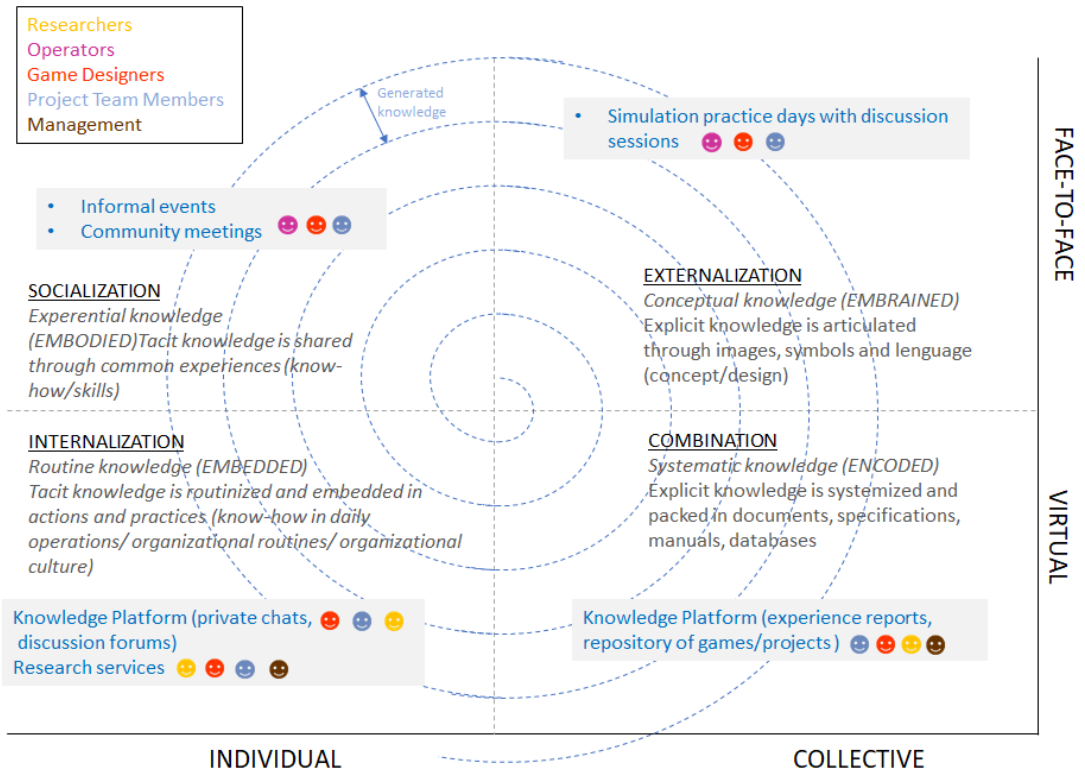


Figure 7.2: Applied framework: proposed approach

- **Simulation practice days** ⇒ One or more game sessions, which are only for training and exercising, and not expected to produce any concrete output or result. Such training sessions would be fundamental for the process of *externalization*. The types of actors included could be participants, game designers, and project team members. This KM practice could result particularly useful to the category of participants - i.e. operators (train drivers, train traffic controllers, etc.) - who, as it was possible to deduce from Section 6.5, are not interested in consulting a game repository. However, they generally expressed the desire of incrementing the occasions for training with a simulator, and possibly sharing their experience with other operators through presentations or discussions. These could be executed at the end of the simulation practice days.

- **Knowledge Platform** ⇒ . After the execution of the analysis of the obtained results from this particular case study, this KMS is considered the most effective tool for the process of *combination* and *externalization*. The development of such a platform would in fact result in the elimination of duplicated efforts, which happens nowadays within ProRail due to the contemporary existence of several different platforms or applications used for sharing purposes. The purpose of Knowledge Platform is twofold:

  - With regards to *combination*, the main employed tools would be the repository of projects related to games (or even any project in the organization), and the experience reports. The categorization of games based on their characteristics, scope, technical features, and contextual factors could be particularly appealing for game designers, project team members, and even managers, who are interested in acquiring valuable knowledge from previously executed projects.

  - Concerning *externalization*, instead, a more personal approach would be provided thanks to discussion forums and private chats. Through these instruments, experts would be able to easily and quickly get in contact, rapidly sharing helpful information

The Knowledge Platform has therefore a double connotation. On the one hand, it would serve as a data-oriented repository of games projects, with focus on *codification* [Roungas et al., 2017], in which each game would have its own profile characterized by a short description, keywords, employees involved, and other information. On the other hand, its social media design would ensure *personalization*, allowing users to personalize their profile, define their skills, and communicate privately through chats.

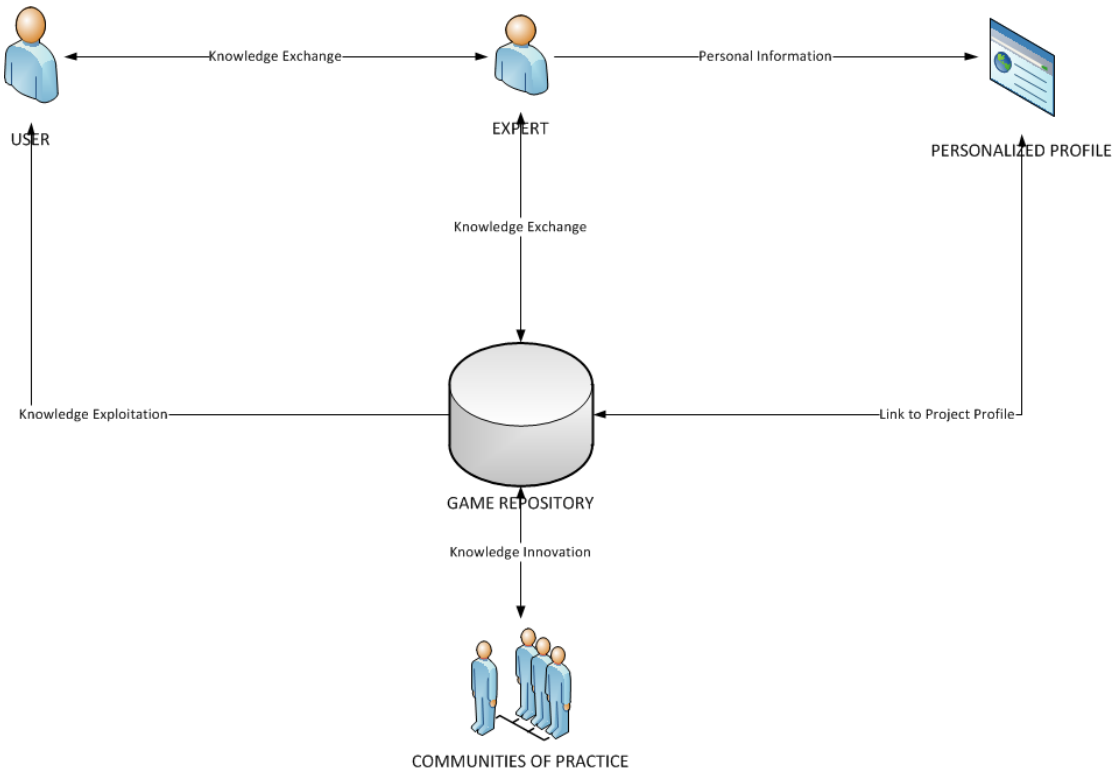


Figure 7.3: Structure of the Knowledge Platform

Figure 7.3 displays the functioning of the Knowledge Platform. Every user is able to introduce - on her own personalized profile - her skills, expertise, and projects in which she is taking part in, or on which she has working in the past. The projects present on a user's profile are then linked to the repository, were they are also provided with a profile giving a brief description of the project itself. Such profiles could contain the project's objectives, state of the art, difficulties encountered, a list of lessons learned, or suggestions for future projects, together with more quantitative/qualitative data, related for example to game sessions or debriefing (raw data, video/audio recordings). Such material would be provided by experts (i.e. project manager, project team members, or managers), who could constantly update the repository by uploading experience reports, notes, and other types of documents. At the same time, they could use the repository to get useful insights for their current projects. Additionally, the repository would be valuable for any kind of users within the company: they could get important information in an easy and fast way, saving time and effort. In case it was necessary, they could however also contact experts directly: this function would be provided by the social media features of the Knowledge Platform, such as discussion forums, private chats, possibility of scheduling meetings (both face-to-face, or, for instance, through Skype), conference tools. Finally, the Knowledge Platform would serve the scope of knowledge innovation, by the process of exchange and renewal that would be triggered within Communities of Practices: groups of experts who share common interests.

- **Research Services** ⇒ The company could also make increased use of external professionals, such as researchers, for gaining insights on organizational practices. Such KM

practice provides in fact with both promptly usable information (predominantly explicit knowledge directly applied for experimentation), and material such as patents or surveys [Leonard and Sensiper, 1998].

The combination of the tools and measures displayed in the proposed approach can be then combined into an integrated KMF. The development of such framework is not within the main scope of this thesis project; however, the author attempted to define its requirements and characteristics on the basis of the findings of the performed analysis combined with insights gained through the review of available literature. The major limitation is represented by the fact that it was not possible to test and evaluate the framework, mainly due to time constraints. More details on the KMF, its limitations and possible future work are introduced in the next section.

7.2.1 Suggestions for KMF

In this section, a proposition for ProRail will be displayed. In particular, the aim of this part of the report is to offer advises for the development of a KMF which could be applied, in the next future, to the ERTMS case study. As mentioned in Section 5.3, the ERTMS simulation is an ongoing project, that will last for at least other eight years: it is therefore fundamental to preserve data and information from every game process, in order to build on available knowledge. The improvement of the ERTMS simulation will in turn speed up and facilitate the introduction of the ERTMS safety system in the Dutch railway sector.

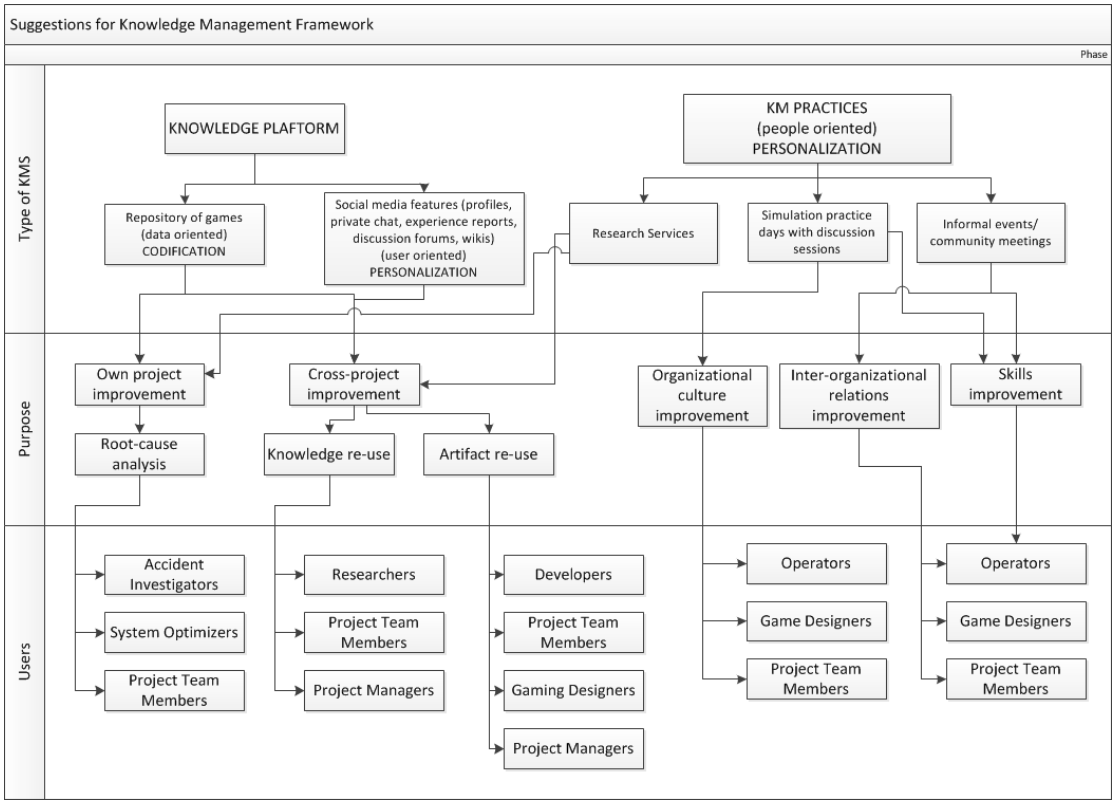


Figure 7.4: Suggestions for KMF

The KMF presented in this section is not only the result of the analysis of all the information gathered throughout this whole thesis project, but rather a consequence of the combined efforts of different researchers and ProRail employees [Roungas et al., 2017]. This KMF can be described as *hybrid* (see Section 2.10): it is partially *descriptive* , that is contains a characterization of the KMSs (presented in the previous section); and partially *prescriptive*, in the sense

that is indicates different ways of applying KM measures [Rubenstein-Montano et al., 2001]. As every KMF, it can be defined by three main elements (see Section 2.10):

- Type of KMS ⇒ The framework can be described as hybrid, with a double focus on codification and personalization. It in fact consists of two aspects: 1) a 'Knowledge Platform'; 2) people-oriented KM procedures. The Knowledge Platform will have a configuration similar to the one of social-media platforms. On the one hand, it will include a repository of games (and eventually even other types of projects), which will be possible to search through keywords: each game would then have its 'profile', with a brief explanation of its purpose, an indication of the employees involved, and other details. This aspect could be characterized a *codification* type of KMS. On the other hand, the *personalization* element would be taken care of by other features typical of social-medias (already presented in Section 2.5.1), such as: private chats (peer-to-peer communication), user-generated content, networking (building a virtual community), wikis (collectively creating and modifying files, i.e. Google Docs).

- Purpose ⇒ The proposed KMF incorporates three main general scopes [Arora, 2002]:

  1. Knowledge exploitation: improving knowledge sharing - in particular tacit - among different teams, units, and departments; enhancing the reuse and allocation of knowledge within the organization. This is done by reinforcing the organizational culture in a knowledge sharing perspective: creating spaces (virtual or physical) were employees can freely communicate and exchange ideas and know-how. Such objective can then be broken down into more specific goals: own- and cross-project improvement. In turns, the own-project improvement is mainly related to root-cause analysis: identifying what 'went wrong' during the execution of a project or process; while the cross-project improvement is focused on knowledge and artifact (design, process, code, or product) reuse.

  2. Knowledge innovation: comparing knowledge assets possessed by the organization with knowledge assets needed. This practices allows firms to continuously generate new innovations, which in turns foster the creation of new knowledge. The creation of new knowledge is triggered by the interaction of experts, who are able to share know-how, procedures, and skills, in a formal or informal manner. Knowledge innovation therefore entails the improvement of organizational culture, and the enhancement of inter-organizational relations (networks).

  3. Skills enhancement: knowledge repositories and communities of practices do not only serve the previously presented objectives; they also permit the constant enrichment of employees' skills and competences.To be in contact with people with a great expertise and experience would allow in fact other employees to acquire useful skills in a much shorter time, and with much fewer efforts than if they had to develop them by themselves. The sharing of experts' knowledge throughout the organization also avoids the problem of concentrating know-how in too few people, with the risk of the company suffering a loss of expertise, in the case they would leave.

- Intended user ⇒ the principal intended users of this KMF are game designers and project team members. This was at least the initial request of the client; however, during the course of the research, relevant aspects were revealed with regards to knowledge sharing needs of other categories of actors, such as participants (operators), and managers. Additionally, the proposed KMF takes into consideration the roles of system optimizers and accident investigators (for the specif scope of root-cause analysis).

This framework, partially based on the work of Bill Roungas and Julia Lo, together with other authors, was constructed with the objective in mind to be as generalizable as possible. It is in fact the author's hope that it could be applied to other context and organization, even for different types of games.

Limitations

The proposed KMF, as previously stated, was not verified and validated through surveys and other techniques, and it may therefore be subjected to faults and errors. Some obvious limitations are ethical in nature: there might in fact be some restraints in the sharing of videos and recordings due to privacy issues.
Moreover, the author did not perform any feasibility study, both for time constraints and being this point not the main objective of the research. Therefore, it is not possible, right now, to give an estimation of the necessary resources for the development of such a framework.
Another limit to be considered is the sample of both games and interviewees on which said framework was based on. The restricted availability of time and human resources only allowed the interviewing of a certain amount of employees, which could therefore result in slightly biased results. The games which constituted the units of analysis of the case study were moreover only related to testing; the research did not consider any decision-making or learning simulation. With regard to these aspects, suggestions for future improvement of the research are present in the next chapter.

8 CONCLUSIONS AND RECOMMENDATIONS

In the light of the accomplished qualitative and quantitative analysis, this conclusive chapter will firstly attempt to answer to the main research question and sub-questions, and subsequently extend on recommendations for the client of this research project, ProRail.

8.1 FINDINGS

This dissertation has aimed to integrate available literature on knowledge and on serious games, in an attempt of identifying the most relevant games' aspects for knowledge generation. Moreover, this final chapter attempts to build up on achieved results in order to provide the requirements for a KMF for serious games. These objectives are summarized in the research question:

What are the necessary requirements for games to foster the development ,as well as the reuse, of tacit knowledge?

Answering to the above inquiry has required several steps, as well as the application of a diversity of research approaches.

SQ1: *What are the games' element or processes which are central in the generation of tacit knowledge?*

The administration of the semi-structured interviews has led to the identification of model-like diagram composed by: eight game characteristics, that represent the independent variables; three main contextual factors, which operate as moderating variable; five categories of tacit knowledge that, as dependent variables, are negatively or positively influenced by the previous elements.
First, the eight identified game elements are:

1. structured and concrete results;
2. unexpressed stakeholders' interests and expectations;
3. structured debriefing;
4. presence of a project manager;
5. simulator validated before the game sessions (for digital games);
6. strict rules during the game play;
7. high variety of roles/actors involved in the game design;
8. high complexity of the game's scope.

Second, the three determined contextual factors are instead:

1. time pressure;
2. pressure from stakeholders;
3. guidance and involvement of the top management.

Third and last, the determined categories of tacit knowledge are:

1. knowledge about game processes;
2. knowledge about operational activities;
3. knowledge about technical aspects of simulations;
4. knowledge about inter-actor relations;
5. stronger 'organizational perspective'.

All of these game elements differently impact on the game's output, and on the generation and reuse of knowledge. The effect of each game requirement, contextual factor, as well as the meaning of the different types of tacit knowledge are described in details in Section 6.1.

In addition to these specific features, thanks to the employment of the Q-sort method, it has been revealed that technical aspects (such as strict rules, number of participants, number of game sessions, type and complexity of the game, etc.) are generally regarded as subordinate. Other elements, more social and relational in nature, were instead given crucial importance: collaboration among different parties and roles, relevance of facing conflicts in stakeholders' interests, strength of games and simulations as a meeting point.

SQ2: *What are the dissimilarities - with respect to different actors and/or roles - in the consideration of the most relevant aspects for knowledge generation and sharing?*

The cluster composition based for the most part on the role of the different respondents allowed the identification of discrepancies in the consideration of game characteristics, contextual factors and generated knowledge.

Class 1, namely of Managers, gave particular emphasis to features such as:

- the complexity of a game, as directly correlated to the value and utility of its results;
- the number of aspects related to a real-life problem taken into consideration by a game or simulation;
- the number of game sessions;
- games as a tool for better understanding operators' needs;
- the value of games for the identification of procedures which are not standard, but are the result of experience and contextual factors.
- the presence of a structured database (a repository of data, video and audio recordings, forums, etc.) for gathering and organizing games' results;

Class 2, namely of Game Designers, considered as fundamental aspects such as:

- presence of a project manager;
- adoption of strict rules during the game play;
- type of game, with digital simulations preferred to analog for testing purposes;
- the role of the game as a meeting point for employees who would normally never interact with each other;
- the possibility of performing post-debriefing session in order to discuss the *lesson learned* (in addition to the debriefing);
- the presence of a structure database (a repository of data, video and audio recordings, forum, etc.) for gathering and organizing games' results;

Class 3, namely Project Team Members, demonstrated particular interest for features such as:

- the validation of the simulator before starting the game sessions;
- the number of real-life aspects taken into account for the game design;
- type of game, with digital simulations preferred to analog for testing purposes;

- the role of games in helping organizations designing and implementing new infrastructures;
- the presence of a structure database (a repository of data, video and audio recordings, forum, etc.) for gathering and organizing games' results;
- the possibility of consulting video or audio recordings from previously played game sessions or debriefings;

Finally, Class 4, namely Participants focused their attention on:

- the amount and variety of roles present during the game play;
- the accuracy of game's inputs data (e.g. data such as infrastructures, timetables);
- the complexity of a game, as directly correlated to the value and utility of its results;
- the number of real-life aspects taken into account for the game design;
- type of game, with digital simulations generally preferred to analog games;
- the possibility of performing post-debriefing session in order to discuss the *lesson learned* (in addition to the debriefing);

SQ3: *How do such differences, if present, affect the needs of the different actors in terms of knowledge sharing and acquisition during the different game processes?*

Different groups of the considered actors have a dissimilar and sometimes divergent outlook on games' elements, on their relevance and scope. As explained in Section 6.5.1, this in turn provokes a diversity of knowledge sharing and knowledge acquisition needs. Most of the identified classes displayed interest in games' aspects which are fundamental in the phases preceding the game play itself. This, of course, is based on the assumption that actors are responsive to the presence of some sort of KMS which gather data about games. Being this assumption true, for at least three classes out of four (Class 1 (Managers), Class 3 (Project Team Members), and partially Class 2 (Game Designers)), it is then possible to better understand what elements would be considered more relevant, and by which group or class.
Managers (Class 1) and project team members (Class 3), could make use of the Knowledge Platform for acquiring additional information on the presence of certain contextual factors - such as conflicts in stakeholders' interests, involvement of operators during the game design, time pressure, etc. - that would be stored in the projects' profiles within the repository of games. This consultation could help preventing the manifestation of issues detected in previous games/projects.
Game designers (Class 2), on the other hand, could retrieve valuable insights on debriefing techniques and rules applied during the game play. These kind of information could also be included in the repository section of the Knowledge Platform, with the purpose of supporting game designers in developing a new game, or correct and enhance an existing one.
Finally, representatives of Class 4 (Participants) expressed for the most part no enthusiasm for an eventual games repository, while at the same time made explicit their interest in face-to-face, collective and interactive procedures. They could therefore gain greater advantage from the KM practices described in chapter 7: simulation training days, discussion sessions, or community meetings, that could take place during the process of debriefing, or completely independently from a specific game.

SQ4: *What measures can be proposed for the improvements of knowledge generation, sharing and reuse process for serious games and simulation?*

A review of the existing literature, combined with the insights gained through the analysis of the gathered data, led to the definition of a set of suggestions, displayed in the form of a proposed KMF. The framework, described in details in Section 7.2.1, aims at achieve

three main objectives: 1) knowledge exploitation; 2) knowledge innovation; 3) skills enhancement. This can be accomplished by combining a KMS with more people-oriented KM practices. The measures suggested in the previous chapter to ProRail resulted as such:

- a 'Knowledge Platform', with a double characterization:
  - codification ⇒ games database, where projects are defined by a 'profile' containing all kinds of information related to the game itself (technical features, contextual factors, employees involved, video and audio recordings of game sessions and debriefing, raw data output, etc.)
  - personalization ⇒ personalized user profiles, displaying personal information (current projects, skills, expertise, documents with notes, lessons learned, etc.). Users would also be able to communicate with each other in a fast and simple way thanks to the social media features of the platform: discussion forums, private chats, possibility of scheduling meetings or arranging virtual conferences.
- a set of KM practices, which would foster the exchange of knowledge within and among communities of experts, promoting in turn the generation of new knowledge, as a result of an improved organizational culture and stronger network relations:
  - simulation practice days, combined with discussion sessions;
  - informal events and community meetings;
  - research services.

The second block of the KMF, composed by KM practices rather than KMS, was introduced as a consequence of realizing that not all the actor groups (i.e. participants) are interested in looking for information by consulting a database or a platform. This might not be a crucial issue, since the suggestions made for the KMF were primarily intended for game designers, project team members, and managers. However, during the course of the research, it clearly emerged that participants - regardless of the case study they participated in - strongly believe that games are an incredible occasion for both acquiring new knowledge and sharing existing one. Moreover, the transfer of knowledge does not only concern technical aspects, but is rather broader in nature and content. Participants (usually covering operational roles in the considered case studies) argued in fact to have gained, through games, a better and deeper understanding of other operators' tasks, needs, and expectations. This, in turn, helped them developing a wider mindset, thanks to which they are able to conceive themselves as elements of a more complex, organizational mechanism.

8.2 RECOMMENDATIONS

This section is intended to provide recommendations to the client of this research project, ProRail, with regards to the management of knowledge deriving from serious games and simulation, as well as for the management of the games themselves.]]

The most general advice to be provided is primarily designed for game designers and project managers. While preparing a game, it might be relevant in fact to look at the aspects identified as most relevant by this research, and act accordingly. Aspects such as: evaluating stekeholders' interests in an early stage, and even incorporating them in the game design; involving operational personnel in the design stage; preparing a structured debrief; or establishing strict criteria for the expected results, all of these elements are worth being taken into consideration when arranging and organizing a new game.

Another important suggestion is to establish a project manager figure exclusively focused on game processes. It was in fact observed in many interviews a contrast between a respondent's job function, and the activities that he or she actually had to perform while taking part

in the game, considered as a project. The presence of a project manager could relieve other actors - such as game designers and project team members - of extra weight caused by organizational or practical issues, allowing them to perform their actual job functions at their best. In addition to this, each game would receive a greater, specific attention in terms of planning, scheduling, finding available participants, setting up gaming spaces, and other organizational aspects.

Another aspect to take into consideration is the role of technology and IT in tacit knowledge sharing. IT can without doubt enable individuals to share their tacit skills and know-how (at least with a low to medium degree of tacitness) by supporting various processes of tacit-to-explicit conversion. Nevertheless, it may not be as rich as face-to-face interactions. Some authors connected social interactions in social media with tacit knowledge sharing. For example, Marwick [2001] argues that online discussion forums, chat rooms and other real-time interactions can simplify and promote the effective transfer of tacit knowledge among employees. Lai and Chu [2000] has also confirmed possibility of tacit knowledge transferring in internet discussion and chat sessions. Additionally, Wahlroos [2010] observed that the emerging social media represent a significant potential in improving tacit knowledge sharing through the support of live conversations, networking and collaboration among individuals. These researches show a very important point: technology can be a mean of tacit knowledge transferring. However, one significant recommendation, deriving from both the qualitative and quantitative analysis performed in this research, is not to overlook the fundamental role played by face-to-face interaction, both between single individuals and among groups. It is in light of this consideration that the proposed changes presented in the previous chapter always include more people-oriented KM practices, rather than KMS.

8.3 LIMITATIONS AND FUTURE WORK

This research project had the primary objective of understanding which games' elements and characteristics are more strongly influential in the generation of knowledge, and in particular tacit skills and know-how. The broader objective of the client (i.e. ProRail), was however the definition of a KMF that could be applied to serious games, and principally to the ERTMS simulation. The author therefore tried to partially achieve also this second objective, by using the results obtained by attempting to answer to the research question for delineating some suggestions, in terms of a proposed KMF. The project was however limited, both due time and resource constraints.

Many are the actions that can be implemented on the achieved results, in order to gain an even deeper understanding of the dissimilarities in the perception of games for different stakeholders, and propose an effective KMF for knowledge sharing and reuse. First, a study with the same research approach (semi-structured interviews and Q-sorting) could be performed on a wider sample, taking into consideration not only games with a testing purpose, but also learning and decision making.
Second, qualitative analysis tools could be applied for the analysis of the transcripts of the semi-structured interviews (e.g. Atlas.ti). This course of action was attempted by the author in a late stage of the research, when there was not enough time to correctly employ these instruments.
Third, with regards to the analysis phase, other algorithms could be employed for the quantitative analysis of the data set resulting from the implementation of the Q-sorts. Due to time constraints it was in fact only possible to use PCA and k-means clustering. However, there are other methods that could reveal interesting information, such as the Gaussian Mixture Model, or the algorithm for Mixture of Factor Analyzers. The Gaussian Model is similar in scope to the k-means, but, in contrast to it, it does not associates each observation to a class in an unequivocal way; instead, it indicates, for all of the respondents, the percentage in which they belong to one cluster or the other [Bouveyron and Brunet-Saumard, 2014]. This approach

might give additional information on the differences existing among groups of stakeholders. The Mixture of Factor Analyzers algorithm can actually be considered as a more complex version of the Gaussian Model: it aims at representing each class in a lower-dimensional space, by adapting the model complexity to the complexity of the data. It is particularly suitable for those cases in which the number of variables much exceeds the number of available observations [McLachlan et al., 2007].

Fourth, further analysis can be carried out on the model resulting from the analysis of the semi-structured interviews. In particular, it might be interesting to test and validate whether the depicted relations among game features, contextual factors and generated knowledge are accurate also for other case studies.

Fifth and last, this thesis project aimed since its beginning at posing the basis for the definition of an KMF effective for the sharing and reuse of both the explicit knowledge and tacit skills and expertise. It is the author's hope that the suggestions obtained at the end of this research may useful for further studies expanding on a better definition, as well evaluation and validation, of a generic KMF which could be applied not only in ProRail, but also in other organizations.

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A | INTERVIEW PROTOCOL

A.1 QUESTIONS

1. What were the objectives of the game?
   a) What were the client's (in this case ProRail's) needs?
   b) What was expected from the game?
   c) Did final results matched expectations? And if not, why?
2. Were there any contextual factors that influenced the game design or game play? For example other projects being executed simultaneously, media, pressure from politics, time restrictions, or others.
3. Who were the participants in the game? How were they chosen?
4. Who were the stakeholders involved?
5. What were the rules of the game? In a scale from 1 (very loose) to 5 (very strict) to which extend where they strict or loose?
6. Was the game analog or digital? Multi-player or single-player? If multi-player, how many participants in total? And per game run/game session?
7. Was there a reward for all different participants?
8. Were the participants or the stakeholders motivated during the game play? How?
9. Was information available to all participants about the potential actions and rewards of the other participants? Did all participants had complete knowledge about all the previous moves?
10. What was the scenario(s)? Was the game repeated, with the same or similar scenario? And was there a repetitive element inside the game?
11. How many game session, or game runs, were executed?
12. What was your role in the game (game designer, stakeholder,etc.)? And your tasks during the game play? Were they related to your job function?
13. What were the inputs you were confronted with in the initial situation? What type of data did you receive?
14. What were the deliverables and the outputs, in form of data, of the process you were involved in?
15. Did you use any tool, technique or method for storing or sharing such outputs/data (emails, face-to-face interaction, database, wikis, applications)?
16. What are the challenges that emerged during the design, the game sessions and the debriefing?
17. Did everything go as expected? What were the differences between what you wanted to do, or to obtain from the game, and what actually happened?
18. If you could participate in another game, or repeat the one you were involved into, would you do something different, use a different approach?

19. Do you think that which participating in the game design, session or debriefing made the organization realize problems related to operational situations? Could you name an example?
20. Do you think participating in the game design, session or debriefing helped you in your everyday working activities? Or if it didn't, why? Could you give an example?
21. Do you think you gained any particular insight or knowledge from the game? Why is such knowledge valuable for you?
22. Do you think games are useful for your role in particular or for the organization in general? Why?
23. Is there something we did not discuss yet but that you think is important for me to know regarding this game?
24. Do you have names of other participants or stakeholders that were involved in the game play or game design who I could interview?

A.1.1 Questions Objectives

- Question 1: understanding game's objectives.
- Questions 2: getting information on the context (hierarchical pressure, expectations, etc.)
- Question 3-11: understanding game characteristics (actors, participants, rules, goals, etc.).
- Question 12: understanding role of each interviewee in the game (which process/stage of the game they took part in).
- Questions 13-14: Understanding for each role (process) inputs and outputs (type of data/information)
- Question 15: understanding how inputs and outputs are managed (shared, stored, reused, etc.; and how: emails, face-to-face, databases, shared repositories).
- Question 16-23: evaluating the possible generation of tacit skills thanks to the participation in the game as well as game's impact on participants' operational activities.
- Question 24: Suggestions of other possible interviewees.

A.1.2 Results

- Generated knowledge: types of data/information (explicit knowledge) - skills (tacit knowledge);
- Game's elements/processes which foster knowledge generation;
- Knowledge exchange needs for each actor taking part in the game;

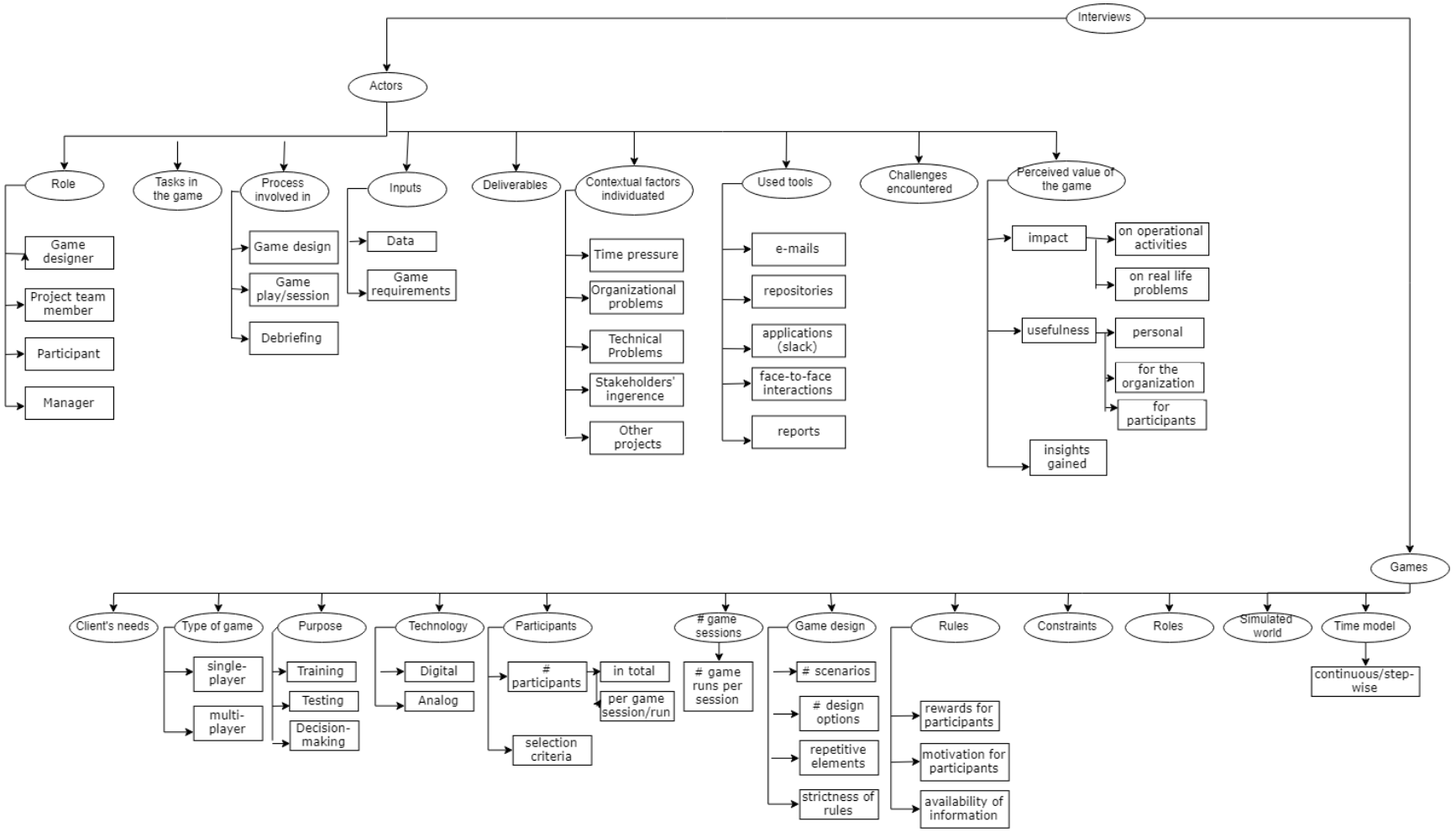


Figure A.1: Coding Scheme for Semi-Structured Interviews

B | STATEMENTS FOR Q SORTING

1. Insights from game players or participants should be incorporated at an early stage in the game design process.
2. It is important to have a structured debriefing in order to have valuable and useful results.
3. I would like to have a way to consult results as well as access documentation from previously played games.
4. The needs of each stakeholder involved in the game should be analyzed before the beginning of the game design process.
5. Game designers are mainly concerned in designing a game which can obtain measurable quantitative results.
6. Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.
7. Games represent a unique occasion for participants (e.g. train drivers, train traffic controllers) to come in contact with the designers of the infrastructures.
8. I believe that, in games, strict rules and high validity of results are more useful than loose rules and more space for personal interaction (open discussion, face-to-face interaction).
9. In order to be helpful and have valuable results games should be characterized by a balance between number of possible scenarios and accuracy of data.
10. Participating in the game improves participants' ability to cope with unexpected changes in their day-to-day working activities.
11. Games allow to test situations which would not be possible to test in real life.
12. Games allow for a better understanding among participants of each other roles and tasks.
13. Games allow to better understand the reasons of certain actions performed by participants in real life.
14. Games serve as an occasion for participants to evaluate each others' work.
15. The organization as a whole gains through games a better understanding of operations and their functioning.
16. Games bring together actors that would not interact so closely in real life (e.g. representatives of municipalities or ministries, members of project team, train traffic controllers, game designer, etc.)
17. Games can help organizations implementing new infrastructure designs.
18. Games are useful for the organization for understanding participants' needs (e.g. for the railway sector: operators, train traffic controller, train drivers).
19. Games allow the identification of procedures which are not standard (documented/ described), but are the result of experience and contextual factors.
20. Games' biggest value is in explaining experts' role and tasks to the not experts.
21. Games should just be used for learning purposes or for explaining complex design to non-experts, but not for decision making.

22. The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.
23. The complexity of a game is directly correlated to the value and utility of its results.
24. Games generate a positive environment for people to work in together, especially if they come from different organizations or context.
25. Games have value as a learning tool just for people with a low expertise (beginners or other stakeholders who are not involved in the project team or design process).
26. Games related to a particular field (e.g. logistics) are not useful for people with high expertise in that same field, unless they represent a level of complexity which could just be digitally tested.
27. Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).
28. I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.
29. The results of a game are valuable as long as the game takes into consideration as many aspects related to the problem as possible (e.g. in the design of a new infrastructure such aspects would be: logistics, maintenance, reliability, etc.).
30. A higher number of participants ensure a better validity of results.
31. I think a game is more effective if there is a variety in participants' roles and expertise.
32. I believe that the more times a game session is repeated, the accuracy and validity of the results increase.
33. I think that games' results (both qualitative and quantitative) would be more useful if organized in a structured database (e.g. combination of repositories of data, videos, forum for questions, etc.)
34. In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game.
35. I think it would be useful for game designers, project teams, and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)
36. Analog games should be preferred for learning purposes, while digital games for testing purposes.
37. Digital games and simulations are better than analog games for testing purposes.
38. The process itself of designing and playing a game - especially for more complex, digital simulations – helps the organization (project team members, management, game designers) advancing its organizational and technical skills.
39. Games are drivers of technological innovation for the organization.
40. Games are drivers of technical advancements (e.g. developing a software for the game play)

C | Q-SORT PROTOCOL

1. The respondents are asked to take the deck of cards [Q-set] and the score sheet and sit at a table. All 40 cards in the deck contain a statement about the relation between game characteristics and generation of knowledge, in particular tacit knowledge. The interviewer will ask the respondents to rank-order these statements from her own point of view. The question for the respondent is: "To what extent do you agree with the following statements". The numbers on the cards (from 1 to 40) have been assigned to the cards randomly, and are only relevant for the administration of your response.
2. The objective of the study is to understand those games' elements or characteristics which are involved in the generation or reuse of knowledge, both tacit and explicit, throughout the processes of game design, game play, and debriefing.
3. The respondents are asked to read the 40 statements carefully and split them up into three piles: a pile for statements they tend to disagree with, a pile for cards they tend to agree with, and a pile for cards they neither agree or disagree with, or that are not relevant or applicable to them. The respondents are asked to use the three boxes "AGREE", "NEUTRAL OR NOT RELEVANT" and "DISAGREE" at the bottom left of the score sheet. They are moreover assured that there are no right or wrong answers, since just the interviewer is interested in their point of view. When the respondents have finished laying down the cards in the three boxes on the score sheet, the interviewer will count the number of cards in each pile, and write down this number in the corresponding box, being carefully to check whether the numbers you entered in the three boxes add up to 40.
4. The respondents are asked to take the cards from the "AGREE" pile and read them again. Then select the two statements they most agree with and place them in the two last boxes on the right of the score sheet, below the "11" (it does no matter which one goes on top or below). Next, from the remaining cards in the deck, they select the three statements they most agree with and place them in the three boxes below the "10". Respondents should follow this procedure for all cards from the "AGREE" pile.
5. Now the respondents have to follow the same procedure, but with the cards from the "DISAGREE" pile. Just like before, they are asked to read them again, select the two statements they most disagree, and place them in the two last boxes on the left of the score sheet, below the "1". Then they follow this procedure for all cards from the "DISAGREE" pile.
6. Finally, respondents take the remaining cards, read them again, and arrange them in the remaining open boxes of the score sheet.
7. After all the cards have been placed on the score sheet, respondents are asked to go over the chosen distribution once more and shift cards if they want to.
8. Respondents are then asked to explain why they "agree most" with the two cards they placed under the "11". Answers are recorder and transcribed, or directly written on a paper sheet.
9. The same procedure happens for the two "disagree most" cards.
10. When finished, the respondents or the interviewer write down the number of the cards in the boxes they have been placed on.

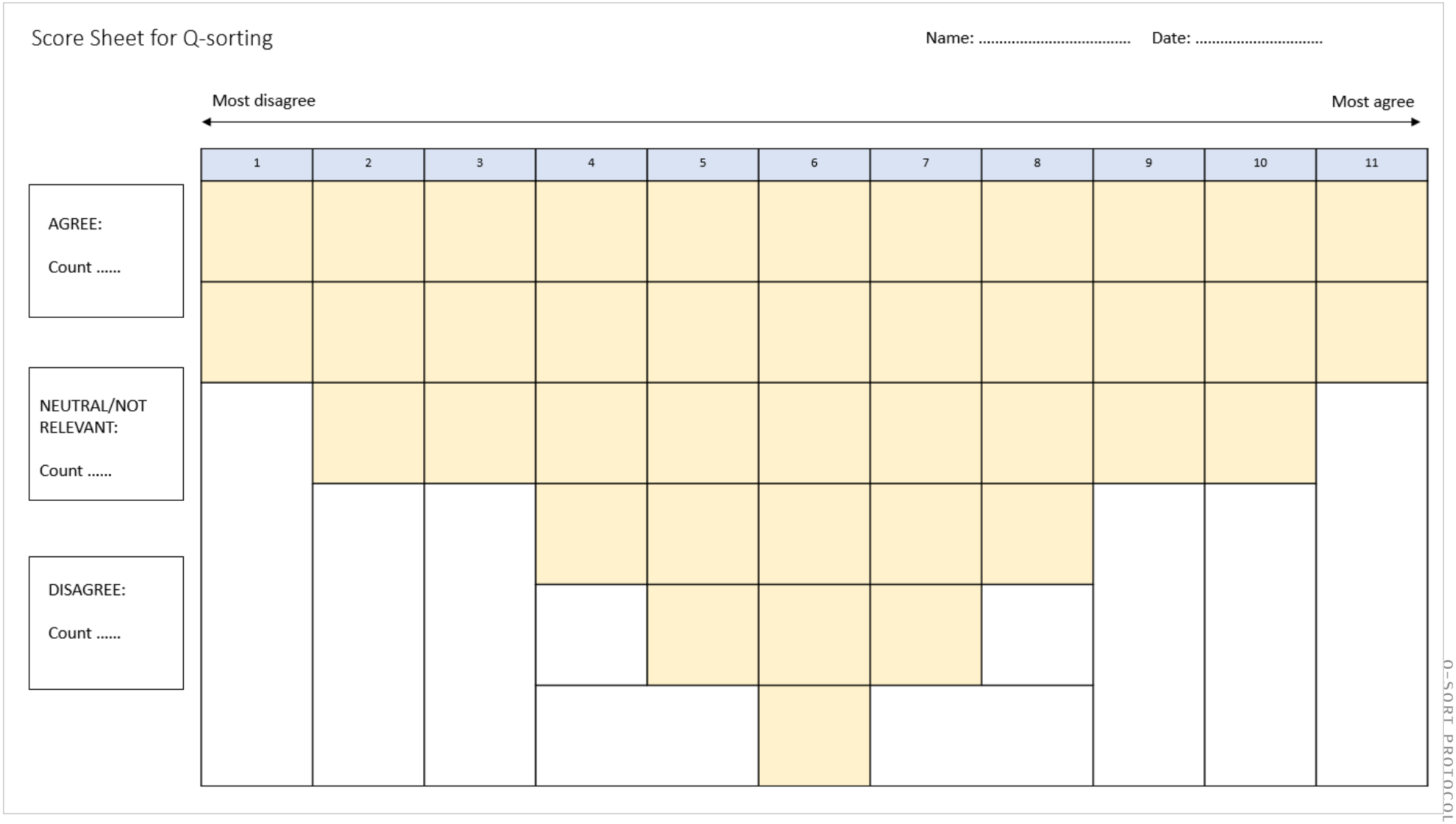


Figure C.1: Score Sheet for Q-sorting

D RESULTS OF SEMI-STRUCTURED INTERVIEWS

D.1 OBSERVED CONTEXTUAL FACTORS

This section presents the results of the qualitative analysis of the semi-structured interviews, with respect to the identified contextual factors.

Respondent	CF1	CF2	CF3	CF4
1Om_PR	X	X		
2Kd_NS				
3Kd_NS			X	
4Ot_PR				
5Kd_NS	X			
6Kp_PR				
7Om_PR	X	X		
8Kd_PR	X		X	
9Od_TU				X
10O'p_NS		X		
11Kp_NS	X			
12Et_PR				
13Et_PR		X	X	
14Kp_NS	X	X		
15Et_PR	X(+)	X	X	
16Od_TU	X	X		
17Ot_PR	X			
18Kt_PR	X	X		
19Od_TU	X	X	X	
Total	11	8	5	1

Table D.1: Identified Contextual Factors

D.2 OBSERVED GAMES' CHARACTERISTICS

This section shows the results of the qualitative analysis of the semi-structured interviews, with respect to the identified game characteristics.

Respondent	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
1Om_PR	X	X					X					
2Kd_NS				X								
3Kd_NS	X							X				X
4Ot_PR												
5Kd_NS				X				X				
6Kp_PR									X			
7Om_PR	X		X	X								
8Kd_PR		X	X	X								
9Od_TU						X				X		

Respondent	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
10O'p_NS	X	X										
11Kp_NS												
12Et_PR					X							
13Et_PR					X							
14Kp_NS			X		X							
15Et_PR					X							
16Od_TU		X	X			X						
17Ot_PR											X	
18Kt_PR												
19Od_TU	X						X (-)					
Total	4	4	4	4	4	2	2	2	1	1	1	1

Table D.2: Identified Game Characteristics

D.3 OBSERVED TYPES OF GENERATED KNOWLEDGE

Finally, this section contains the recognized categories of knowledge resulted from the qualitative analysis of the semi-structured interviews.

Respondent	K1	K2	K3	K4	K5
1Om_PR	X			X	X
2Kd_NS			X		X
3Kd_NS		X			
4Ot_PR					
5Kd_NS	X	X	X		X
6Kp_PR		X	X		X
7Om_PR		X			X
8Kd_PR	X	X			
9Od_TU		X		X	X
10O'p_NS				X	
11Kp_NS					X
12Et_PR		X	X		
13Et_PR			X		
14Kp_NS	X	X			X
15Et_PR	X		X	X	X
16Od_TU		X			
17Ot_PR	X	X			X
18Kt_PR	X		X		
19Od_TU					X
Total	7	10	7	4	11

Table D.3: Identified types of generated knowledge

E RESULTS OF Q-SORT RESPONSES

The graphs presented in this Annex have been achieved by executing the following procedure:

1. Q-sort responses are divided in groups:
   - in the case of Figure E.1 the respondents have been gathered on the basis of their role (game designers, manager, participant, project team member);
   - with regards to E.2, instead, interviewees have been arranged on the basis of the case study they took part in (infrastructural change (OV-SAAL), frequency increase (Ketensimulatie), safety enhancement (ERTMS):
   - finally, in the last graph, respondents have been grouped by the organization they belong to (ProRail, NS).The TU Delft group was not included in the graph, being represented by only one interviewee (skewed results).
2. For each group, the average response value is calculated for every single statement (e.g. the group of 'designers' will be represented by a 40-dimensional vector, called *centroid*).
3. The average response value per statement is calculated also with regards to the total sample (once again a 40-dimensional vector).
4. For each case (division by role, case study, or organization), the average of the total sample is subtracted from the centroid of each group. For instance, in the division by role, the result of this operation would be four new 40-dimensional vectors, which are ultimately represented in the graph.
5. The vectors obtained represent, for each group, the distance of the centroid of that group from the average of the total sample.

The advantage of this visualization is represented by the possibility of instantly recognizing strong similarities or dissimilarities among groups.

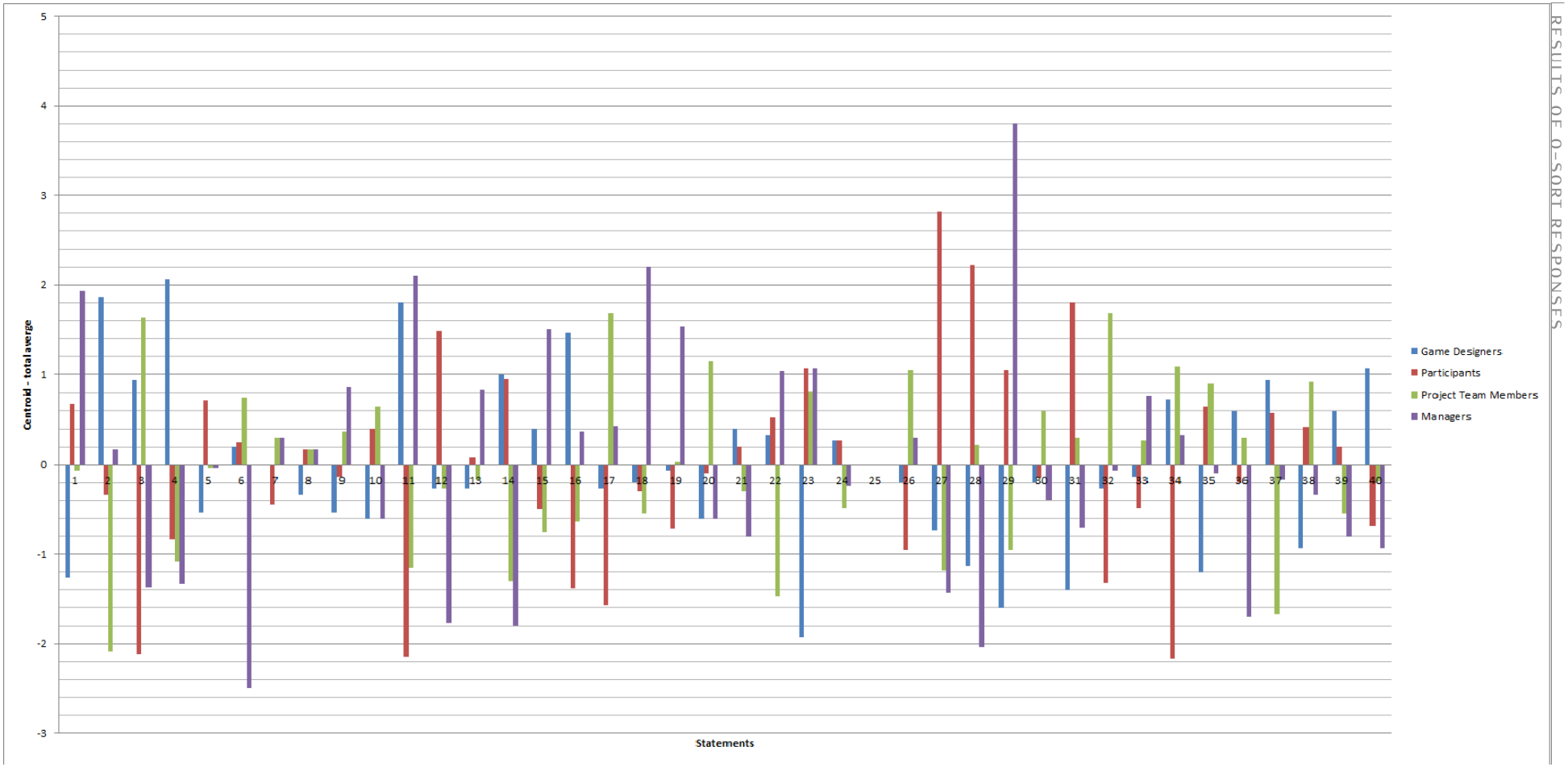


Figure E.1: Difference between centroids per group and average of the total sample

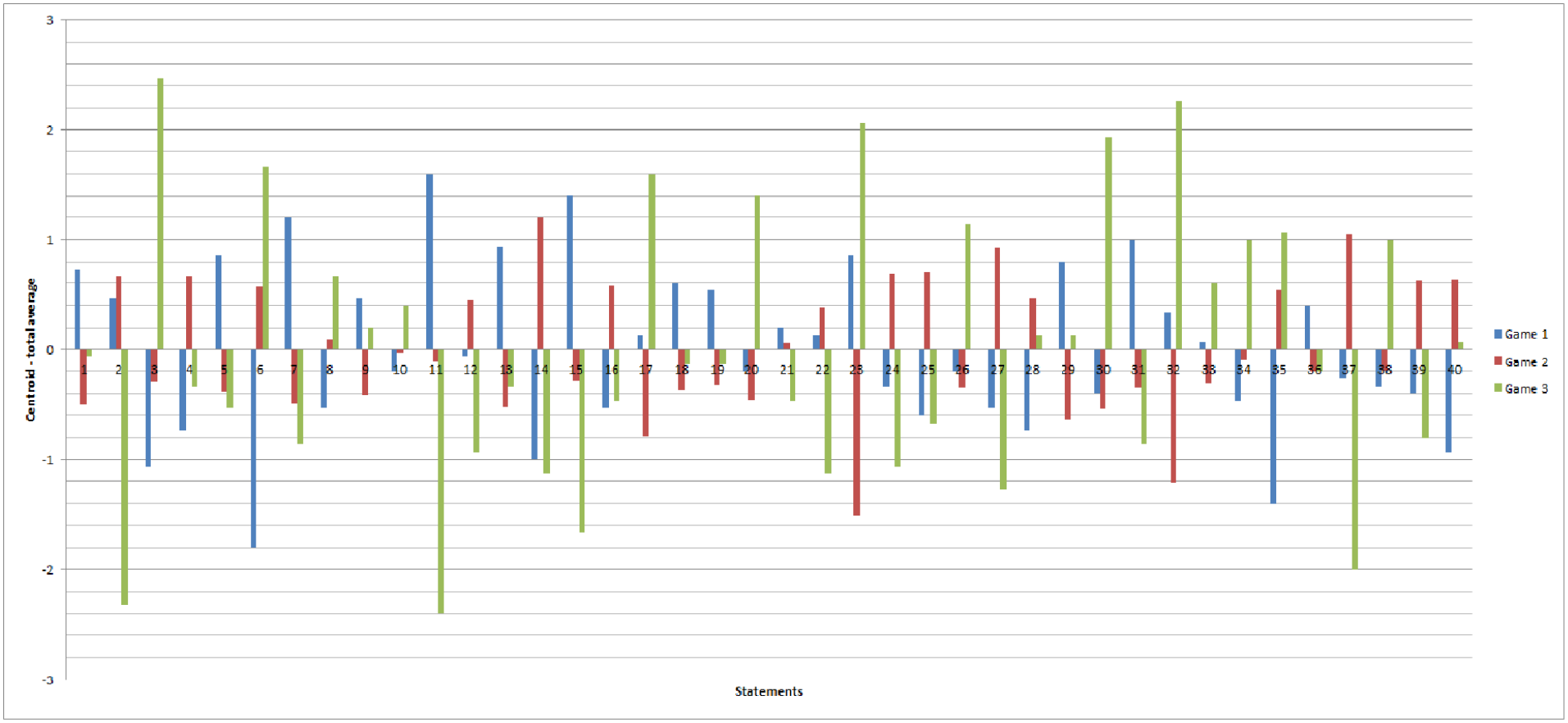


Figure E.2: Difference between centroids per group and average of the total sample (Game 1 = Infrastructural Change (OV-SAAL), Game 2 = Frequency Increase (Ketensimulatie), Game 3 = Safety Enhancement (ERTMS))

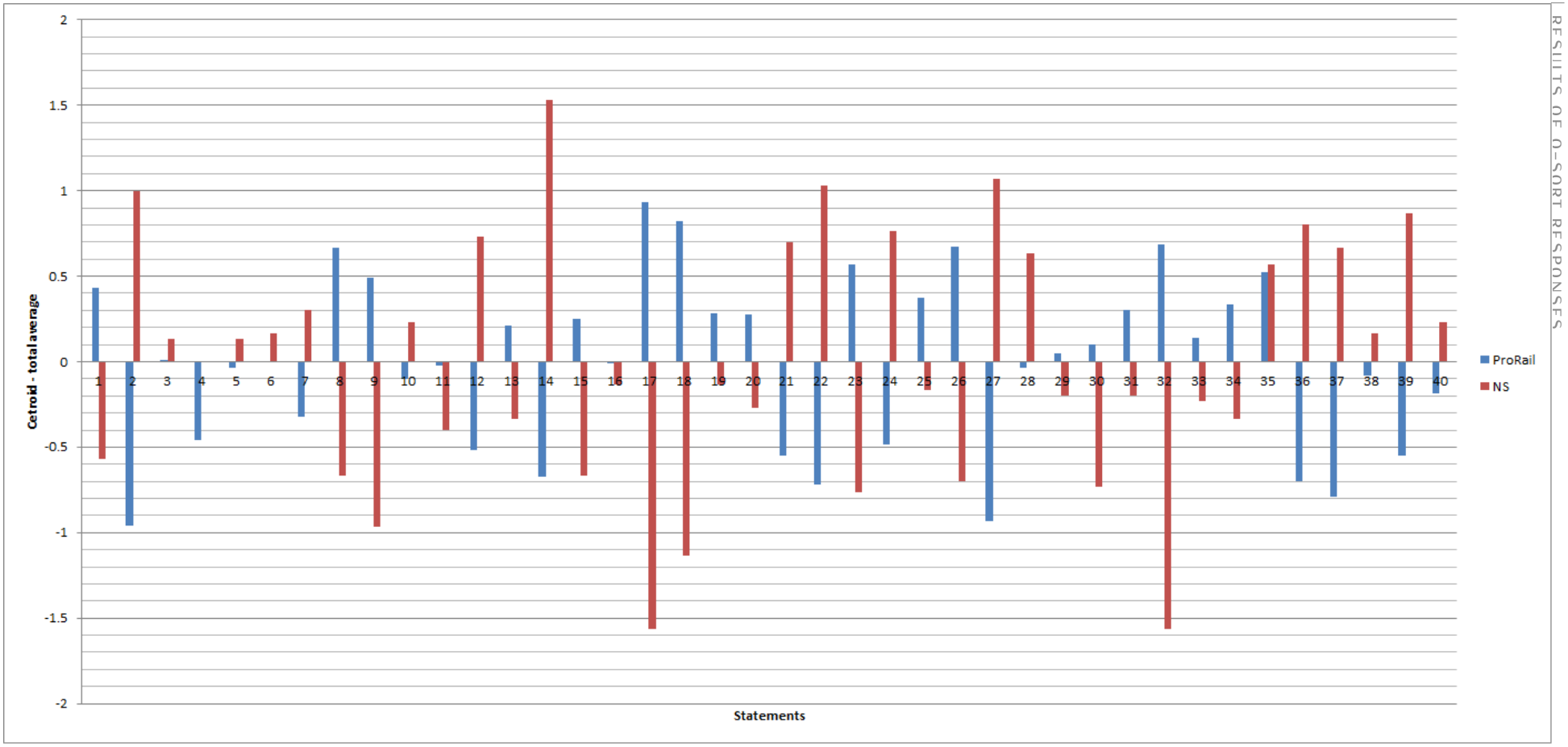


Figure E.3: Difference between centroids per group and average of the total sample (division by organization)

E.1 DIVISION PER ROLE

The graph in figure E.1 shows a tendency to disagreement among certain roles. In particular, it appears that participants and managers are more likely to have discordant opinions, as well as game designers and managers. Table E.1, displays the encountered differences, considering all the different groups at the same time.

N.	Statement	D	P	T	M
1.	Insights from game players or participants should be incorporated at an early stage in the game design process.	DISAGREE	AGREE	SLIGHLTY DISAGREE	AGREE
2.	It is important to have a structured debriefing in order to have valuable and useful results.	STRONGLY AGREE	SLIGHLTY DISAGREE	STRONGLY DISAGREE	SLIGHTLY AGREE
3.	I would like to have a way to consult results or access documentation from previously played games.	AGREE	DISAGREE	AGREE	DISAGREE
4.	The needs of each stakeholder involved in the game should be analyzed before the beginning of the game design process.				
	AGREE	DISAGREE	DISAGREE	DIASAGREE	
6.	Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.	AGREE	AGREE	AGREE	STRONGLY DISAGREE
11.	Games allow to test situations which would not be possible to test in real life.	AGREE	DISAGREE	DISAGREE	AGREE
12.	Games allow for a better understanding among participants of each other roles and tasks	DISAGREE	AGREE	SLIGHTLY DISAGREE	DISAGREE
14.	Games serve as an occasion for participants to evaluate each others' work.	AGREE	AGREE	DISAGREE	DISAGREE
16.	Games bring together actors that would not interact so closely in real life (e.g. representatives of municipalities or ministries, members of project team, train traffic controllers, game designer, etc.)	AGREE	DISAGREE	DISAGREE	AGREE
17.	Games help organizations implementing new infrastructure designs.	DISAGREE	DISAGREE	AGREE	AGREE
18.	Games are useful for the organization for understanding operators' needs.	SLIGHTLY DISAGREE	DISAGREE	DISAGREE	STRONGLY AGREE
19.	Games allow the identification of procedures which are not standard, but are the result of experience and contextual factors.	SLIGHTLY DISAGREE	DISAGREE	DISAGREE	AGREE
20.	Games' biggest value is in explaining experts' role and tasks to the not experts.	DISAGREE	DISAGREE	DISAGREE	DISAGREE
22.	The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.	AGREE	AGREE	AGREE	AGREE

N.	Statement	D	P	T	M
23.	The complexity of a game is directly correlated to the value and utility of its results.	DISAGREE	AGREE	AGREE	AGREE
27.	Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).	DISAGREE	STRONGLY AGREE	DISAGREE	DISAGREE
28.	I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.	DISAGREE	STRONGLY AGREE	SLIGHLTY AGREE	STRONGLY DISAGREE
29.	The results of a game are valuable as long as the game takes into consideration as many aspects related to the problem as possible (e.g. in the design of a new infrastructure such aspects would be: logistics, maintenance, reliability, etc.).	DISAGREE	AGREE	DISAGREE	STRONGLY AGREE
31.	I think a game is more effective if there is a variety in participants' roles and expertise.	DISAGREE	STROGNLY AGREE	AGREE	DISAGREE
32.	I believe the more times a game session is repeated, the accuracy and validity of the results increase.	SLIGHLTY DISAGREE	DISAGREE	AGREE	SLIGHTLY DISAGREE
34.	In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game.	AGREE	STRONGLY DISAGREE	AGREE	AGREE
37.	Digital games and simulations are better than analog games with respect to testing.	AGREE	AGREE	DISAGREE	SLIGHTLY DISAGREE
38.	The process itself of designing and playing a game - especially for more complex, digital simulations – helps the organization (project team members, management, game designers) advancing its organizational and technical skills.	DISAGREE	AGREE	AGREE	DISAGREE
40.	Games are drivers for technical advancements (e.g. developing a software for the game play).	AGREE	AGREE	SLIGHLTY DISAGREE	AGREE

Table E.1: Q-sort responses: compared opinions of different groups of actors (D = game designers, P = participants, T = project team members, M = managers)

E.2 DIVISION PER CASE STUDY/GAME

This section gives a presentation of the biggest points of disagreement, with regards to the Q-sort responses grouped per case study (game). Table E.2, based on the graph in Figure E.2, displays the statements that registered the highest discrepancies among groups of respondents. By examining the statements, it is possible to cluster them into three main categories, or subjects: game's technical aspects, role of games within the organization, and KMS and KM

practices related to games.

N.	Statement	Game 1	Game 2	Game 3
2.	It is important to have a structured debriefing in order to have valuable and useful results.	AGREE	AGREE	STRONGLY DISAGREE
3.	I would like to have a way to consult results or access documentation from previously played games.	DISAGREE	DISAGREE	STRONGLY AGREE
6.	Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.	DISAGREE	AGREE	AGREE
7.	Games represent a unique occasion for operators (e.g. train drivers, train traffic controllers) to come in contact with the designers of the infrastructures.	AGREE	DISAGREE	DISAGREE
11.	Games allow to test situations which would not be possible to test in real life.	AGREE	SLIGHLTY DISAGREE	STRONGLY DISAGREE
14.	Games serve as an occasion for participants to evaluate each others' work.	DISAGREE	AGREE	DISAGREE
15.	The organization as a whole gains through games a better understanding of operations and their functioning.	AGREE	DISAGREE	DISAGREE
17.	Games help organizations implementing new infrastructure designs.	SLIGHTLY AGREE	DISAGREE	AGREE
22.	The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.	SLIGHLTY AGREE	AGREE	DISAGREE
23.	The complexity of a game is directly correlated to the value and utility of its results.	AGREE	DISAGREEE	STRONGLY AGREE
27.	Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).	DISAGREE	AGREE	DISAGREE
30.	A higher number of participants ensure a better validity of results.	DISAGREE	DISAGREE	AGREE
32.	I believe the more times a game session is repeated, the accuracy and validity of the results increase.	AGREE	DISAGREE	STRONGLY AGREE
35.	I think it would be useful for both game designers, project teams and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)	DISAGREE	AGREE	AGREE
37.	Digital games and simulations are better than analog games with respect to testing.	DISAGREE	AGREE	STRONGLY DISAGREE
39.	Games are drivers of technological innovation for the organization.	DISAGREE	AGREE	DISAGREE
40.	Games are drivers for technical advancements (e.g. developing a software for the game play)	DISAGREE	AGREE	SLIGHTLY AGREE

Table E.2: Q-sort responses: compared opinions of respondents taking part in different case studies (Game 1 = Infrastructural Change (OV-SAAL); Game 2 = Frequency Increase (Ketensimulatie), Game 3 = Safety Enhancement (ERTMS))

E.3 DIVISION PER ORGANIZATION

In this specific case, just two out of three organizations were considered. In fact, even though the respondents belong to three different institutions (ProRail, NS, TU Delft), TU Delft was left out in the graph displayed in Figure E.3 because just represented by one interviewee. This would have therefore resulted in a very skewed chart. Nevertheless, it is outstanding the contrast between the ProRail and NS. Interviewees from the two different organizations showed contrasting opinion in all of the statements, except for one, statement 35, on which they both agree: *"I think it would be useful for both game designers, project teams and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)"*.

The table below displays the statements for which the most disagreement between the two companies was registered.

N.	Statement	ProRail	NS
2.	It is important to have a structured debriefing in order to have valuable and useful results.	DISAGREE	AGREE
8.	I believe that, in games, strict rules and high validity of results are more useful than loose rules and more space for personal interaction (open discussion, face-to-face interaction).	AGREE	DISAGREE
9.	In order to be helpful and have valuable results games should be characterized by a balance between number of possible scenarios and accuracy of data.	AGREE	DISAGREE
12.	Games allow for a better understanding among participants of each other roles and tasks.	DISAGREE	AGREE
14.	Games serve as an occasion for participants to evaluate each others' work.	STRONGLY DISAGREE	AGREE
17.	Games help organizations implementing new infrastructure designs.	AGREE	STRONGLY DISAGREE
18.	Games are useful for the organization for understanding operators' needs.	AGREE	DISAGREE
21.	Games should just be used for learning purposes or for explaining complex design to non-experts, but not for decision making.	DISAGREE	AGREE
22.	The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.	DISAGREE	AGREE
23.	The complexity of a game is directly correlated to the value and utility of its results.	AGREE	DISAGREE
24.	Games generate a positive environment for people to work in together, especially if they come from different organizations or context.	DISAGREE	AGREE
27.	Digital games (e.g. computer simulations) are more beneficial than analog games (e.g. board games).	DISAGREE	AGREE
32.	I believe that the more times a game session is repeated, the accuracy and validity of the results increase.	AGREE	STRONGLY DISAGREE
36.	Analog games are better used for learning purposes than testing.	DISAGREE	AGREE
37.	Digital games and simulations are better than analog games, with respect to testing.	DISAGREE	AGREE
39.	Games are drivers of technological innovation for the organization.	DISAGREE	AGREE

Table E.3: Q-sort responses: compared opinions of respondent belonging to different organizations

F RESULTS OF PRINCIPAL COMPONENT ANALYSIS

F.1 PRINCIPAL COMPONENTS ANALYSIS

In this research, the added value of performing PCA is to reduce the number of dimensions of the observation, which, in this case, equals to 40, that is the number of statements (variables). It would be in fact impossible to have any kind of visualization of the results in a 40-dimensional manner: PCA therefore helps in transforming the data in a way that both observations and variables can be displayed in a two-dimensional graph. The two dimensions are determined by the two factors which, combined, are accountable for most of the variance in the sample. Such transformation does not just contribute to the data visualization, but also to the interpretation of the results. On the one hand, by locating observations in a two-dimensional space it should be possible to identify clusters - or groups - of people who tend to think the same way in respect to the considered factors (which are responsible for most part of the variability in the responses, and should therefore explain eventual differences between q-sorts). On the other hand, the positioning of variables in the graph permits to understand which variables are positively or negatively correlated, or not correlated at all.

PCA operates by the following steps:

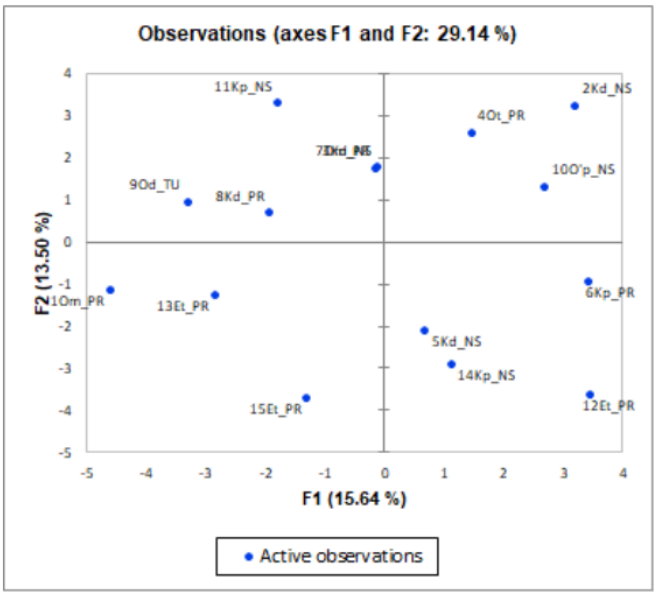
1. Feature scaling (or mean normalization): the first step is to calculate for each feature $x_j^{(i)}$ (variable) its average μ_j. Then, each feature $x_j^{(i)}$ is replaced by the difference $x_j^{(i)}$ - μ_j. This happens in order for variables to have comparable scales.
2. Covariance matrix: the second step is the calculation of the covariance matrix, which enables the identification of the eigenvectors.
3. The eigenvectors indicate the direction of the new axes (principal components), which will represent the lower-dimensional space. Each eigenvector will correspond to an eigenvalue, whose magnitude indicates how much of the data's variability is explained by its eigenvector.
4. Re-orient data: the original data set is now multiplied by the eigenvectors, which define the direction of the principal components (new axes).
5. Plot re-oriented data: after being re-oriented, the data can be plot on the new axes.
6. Bi-plot: in the final step of PCA, the obtained axes are standardized on the same scale, and arrows are added in order to represent the original variables. In conclusion, to summarize, the elements of the new bi-dimensional graph are:
   - Axes, which represent the principal components.
   - Points, which stand for the observations re-oriented in a lower-dimensional space.
   - Arrows, that describe the initial variables. The closer they are the more correlated.

The tools selected for the PCA were the Excel add-in tool XLSTAT and R Studio.

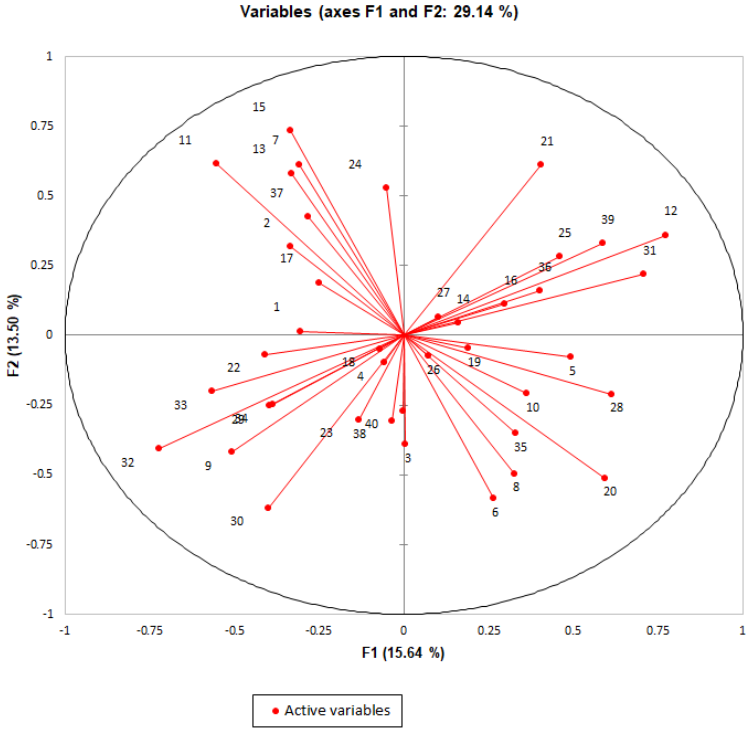
F.2 PRINCIPAL COMPONENTS

F1 and F2 are the factors which, combined, explain the highest percentage of the variance in the sample (29.14%); for this reason, they are also called principal components. The amount of explained variance is however not very high, which means that the factors chosen for this

two-dimensional representation of the observations are just accountable for a small percentage of the variation of responses. As it can be observed in the Figure F.1a, the respondents are really scattered in the graph, and it is almost impossible to define groups or clusters of people who thought the same way, at least with respect to factor 1 and 2. The only remarkable results in that observation 7 and 3 are overlapping, which means they responded in a very similar way with respect to the chosen factors. However, as it is possible to see in further sections, they are just similar with regards to these specific factors.



(a) PCA, First Iteration: Observations



(b) PCA, First Iteration: Variables

Figure F.1: Results of the first PCA iteration

By looking at Figure F.1b, it is possible to determine whether variables are correlated to each other or not. The correlation between statements can be assessed through these simple rules:

- If variables are far away from the center:
  - if they are close to each other, then they are positively correlated (r close to 1);
  - if they are orthogonal, then they are not correlated (r close to 0);
  - if they are on opposite sides of the circle, then they are negatively correlated (r close to -1).
- If variables are close to the center, it means that they are better explained by other axes (factors), so any interpretation might be hazardous.

A way to prove the truthfulness of these principles is to go and check the variables correlation matrix. By doing so, it is possible to ascertain the relation between different statements. In this case, the following variables showed to have a relevant positive or negative correlation (r):

- Statement 11 and 15 $\implies r = 0.79$
  "11. Games allow to test situations which would not be possible to test in real life".
  "15. The organization as a whole gains through games a better understanding of operations and their functioning."
- Statement 15 and 13 $\implies r = 0.66$
  "15. The organization as a whole gains through games a better understanding of operations and their functioning."
  "13. Games allow to better understand the reasons of certain actions performed by participants in real life."
- Statement 30 and 32 $\implies r = 0.61$
  "30. A higher number of participants ensure a better validity of results."
  "32. I believe the more times a game session is repeated, the accuracy and validity of the results increase."
- Statement 12 and 32 $\implies r = -0.65$
  "12. Games allow for a better understanding among participants of each other roles and tasks."
  "32. I believe the more times a game session is repeated, the accuracy and validity of the results increase."
- Statement 20 and 11 $\implies r = -0.61$
  "20. Games' biggest value is in explaining experts' role and tasks to the not experts."
  "11. Games allow to test situations which would not be possible to test in real life."
- Statement 20 and 15 $\implies r = -0.47$
  "20. Games' biggest value is in explaining experts' role and tasks to the not experts."
  "15. The organization as a whole gains through games a better understanding of operations and their functioning."

Even though the correlation values among statement are not outstanding, Figure F.1b shows, for each quadrant, a certain concentration of statements. By scrutinizing the values of r as well as the content of the statements contained in each quadrant, it may be possible to identify hidden correlations among groups of statements.

Statements	7	11	13	15	17
7. Games represent a unique occasion for operators (e.g. train drivers, train traffic controllers) to come in contact with the designers of the infrastructures.	1	0.501	0.483	0.399	0.267
11. Games allow to test situations which would not be possible to test in real life.		1	0.476	0.790	0.368
13. Games allow to better understand the reasons of certain actions performed by participants in real life.			1	0.665	0.133
15. The organization as a whole gains through games a better understanding of operations and their functioning.				1	0.479
17. Games help organizations implementing new infrastructure designs.					1

Table F.1: Correlation Values Statements top-left Quadrant

The statements contained in Table F.1 seem to all refer to the role of games within an organization.

Statements	9	22	30	32	33
9. In order to be helpful and have valuable results games should be characterized by a balance between number of possible scenarios and accuracy of data.	1	0.124	0.528	0.676	0.117
22. The validity of a game's results and its usefulness are highly dependent on the people involved, and on their level of expertise.		1	0.100	0.088	0.078
30. A higher number of participants ensures a better validity of results.			1	0.615	0.201
32. I believe the more times a game session is repeated, the accuracy and validity of the results increase,				1	0.418
33. I think that games' results (both qualitative and quantitative) would be more useful if organized in a structured database (e.g. combination of repositories of data, videos, forum for questions, etc.)					1

Table F.2: Correlation Values Statements bottom-left Quadrant

Table F.2 incorporates, instead, what seem to be the game requirements which would ensure a high validity of results, such as: expertise of people involved, accuracy of data, number of scenarios, players, and game sessions, or even the organization of games' results into a structured database. It is particularly interesting to note how a statement concerning the gathering of games' information and result into a repository (st. 33) is found in this quadrant, positively correlated to all other statements related to effectiveness and legitimacy of games' results.

Statements	6	8	20	28	35
6. Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.	1	0.572	0.438	0.238	0.225
8. I believe that, in games, strict rules and high validity of results are more useful than loose rules and more space for personal interaction (open discussion, face-to-face interaction).		1	0.583	0.375	0.247
20. Games' biggest value is in explaining experts' role and tasks to the not experts.			1	0.327	0.196
28. I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.				1	0.475
35. I think it would be useful for both game designers, project teams and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing).					1

Table F.3: Correlation Values Statements bottom-right Quadrant

Statements contained in Table F.3 do not seem to target a specific game element or a more general subject. They in fact refer to a variety of features (games' role, rules, inputs, and knowledge management practices).

Statements	12	21	31	39
12. Games allow for a better understanding among participants of each other roles and tasks.	1	0.474	0.707	0.611
21. Games should just be used for learning purposes or for explaining complex design to non-experts, but not for decision making.		1	0.369	0.234
31. I think a game is more effective if there is a variety in participants' roles and expertise.			1	0.164
39. Games are drivers of technological innovation for the organization.				1

Table F.4: Correlation Values Statements top-right Quadrant

Table F.4 displays a high value of correlation especially between statement 12 and 31. This connection links the relevance of the presence of a variety of roles in game processes to the effectiveness and value of the game itself, as well as to the possibility, for the actors, to get a better understanding of each other's needs, duties, and efforts.

F.2.1 Limitations

As it possible to acknowledge from the examples just presented, the values of r are not very high: just two combinations of variables in fact exceed a r of 0.7). This is even more problematic considering the fact that the amount of statements -thus variables - at end is 40, a quite elevated quantity, considered the fact that, from this analysis, just a few result to be somehow correlated.

This is most likely due to two reasons: the dimension of the sample, and the variety of aspects taken into consideration by the statements. Regarding the first explanation, the number of respondents: this element was unfortunately just partially in control of the author. Out of all the possible interviewees contacted, in fact, just about a half resulted to be available. With respect to the second facet, these 40 variables are related to many different aspects of gaming

(actors, processes, rules, typology, scope, etc.), so there is not just a high number of dimension, but even a great variety among them. At the end of the Q-sorting, in fact, each observation is codified as a 40-dimensional vector; what PCA tries to achieve is to transform both variables and observations in a way that their number of dimension is lower, and therefore easier to analyze and make sense of. In this process, some factors are identified which should allow to reduce the dimensions while loosing the lowest possible meaning. These factors are called Eigenvalues, and each of them is accountable for a certain percentage of the variance in the sample. Usually, the first two of these factors are chosen in order to represent results in a bi-dimensional manner. If the explained variance of the two main factors - combined - is quite high (¿50%), it means that such factors well represent the totality of variables, and can be used to cluster observations on the basis of where they are located on the plan. If instead, like in this case, the explained variance is low (between 20 and 30%), it suggests that it might be very difficult for the two factors to properly represent the sample. This becomes even cleared when looking at the disposition of both variables and observations in the output bi-dimensional graphs (F.1.

F.2.2 PCA: Descriptive Statistics

This section displays important information with regards to the results of the application of PCA algorithm.

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
1	15	-2.000	5.000	1.067	1.710
2	15	-4.000	5.000	2.333	2.350
3	15	-5.000	5.000	-0.133	2.326
4	15	-2.000	5.000	1.333	2.440
5	15	-5.000	1.000	-2.467	1.552
6	15	-2.000	5.000	2.000	1.890
7	15	-4.000	4.000	0.200	2.145
8	15	-5.000	2.000	-2.667	1.718
9	15	-3.000	2.000	0.133	1.552
10	15	-2.000	5.000	0.600	2.131
11	15	-4.000	5.000	2.400	3.112
12	15	0.000	5.000	3.267	1.624
13	15	0.000	5.000	2.667	1.447
14	15	-5.000	4.000	-1.200	2.808
15	15	-4.000	5.000	2.000	2.673
16	15	-2.000	5.000	1.133	2.031
17	15	-4.000	5.000	0.067	2.344
18	15	-2.000	4.000	1.800	2.111
19	15	-1.000	4.000	1.467	1.685
20	15	-4.000	2.000	-1.400	1.639
21	15	-5.000	-1.000	-3.200	1.373
22	15	-2.000	4.000	0.467	1.885
23	15	-5.000	3.000	-2.067	2.492
24	15	-1.000	4.000	1.733	1.624
25	15	-5.000	2.000	-2.000	2.360
26	15	-5.000	1.000	-2.800	1.521
27	15	-5.000	2.000	-3.067	2.219
28	15	-4.000	4.000	0.533	2.696
29	15	-5.000	5.000	-0.800	2.624
30	15	-4.000	5.000	-0.600	2.720
31	15	-4.000	4.000	0.200	2.624
32	15	-5.000	4.000	0.067	2.374
33	15	-2.000	3.000	-0.267	1.387

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
34	15	-5.000	2.000	-0.333	2.024
35	15	-5.000	5.000	2.600	2.354
36	15	-5.000	0.000	-2.800	1.612
37	15	-5.000	1.000	-2.333	1.988
38	15	-1.000	5.000	1.333	1.589
39	15	-2.000	4.000	-0.200	1.424
40	15	-4.000	1.000	-1.067	1.870

Table F.5: PCA: Summary Statistics

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
1	**1**	-0.166	-0.429	-0.143	-0.122	0.000	0.016	0.089	0.212	-0.463	0.035	-0.084	0.183	-0.369	0.359	-0.332	0.159	0.281	-0.160	-0.143	-0.329	-0.010	0.420	-0.147	-0.071	0.049	0.095	-0.039	0.602	-0.083	0.060	0.016	0.430	-0.447	-0.064	-0.342	0.175	0.123	-0.141	-0.267
2	-0.166	**1**	-0.187	-0.021	-0.228	-0.048	0.057	-0.065	0.026	-0.328	0.518	-0.231	0.287	0.390	0.296	-0.100	-0.510	0.101	0.229	-0.352	0.000	0.382	-0.033	0.137	-0.090	-0.659	-0.009	-0.278	-0.151	0.067	-0.533	-0.017	0.139	0.040	-0.349	0.226	0.331	-0.242	0.192	-0.125
3	-0.429	-0.187	**1**	0.424	0.021	0.260	0.077	-0.185	-0.272	-0.040	-0.199	-0.311	-0.332	0.094	-0.506	0.291	0.041	-0.151	-0.001	0.229	0.103	0.129	-0.174	-0.256	-0.364	0.493	-0.542	-0.193	-0.136	0.178	-0.311	0.183	0.010	0.627	0.277	0.255	-0.304	-0.006	-0.052	0.425
4	-0.143	-0.021	0.424	**1**	0.044	0.186	-0.191	-0.097	-0.201	-0.357	-0.019	-0.096	-0.310	0.042	-0.142	0.538	0.083	0.069	-0.458	-0.197	0.000	0.119	-0.325	-0.228	-0.298	0.308	-0.220	-0.116	0.000	0.140	-0.100	0.008	-0.014	0.068	-0.249	-0.018	0.216	-0.362	0.062	0.585
5	-0.122	-0.228	0.021	0.044	**1**	-0.292	-0.013	-0.045	-0.209	0.112	-0.328	0.450	-0.042	0.059	-0.275	-0.024	-0.325	0.013	-0.020	0.258	0.121	-0.018	0.139	-0.195	-0.273	0.042	-0.051	0.576	-0.011	-0.003	0.656	-0.301	-0.261	-0.167	0.199	0.268	-0.471	-0.077	0.116	-0.110
6	0.000	-0.048	0.260	0.186	-0.292	**1**	-0.634	0.572	0.000	-0.053	-0.486	0.000	-0.522	0.175	-0.410	-0.019	-0.210	-0.036	-0.045	0.438	-0.275	-0.180	0.121	-0.349	0.112	-0.050	0.034	0.238	-0.187	0.181	-0.202	0.016	0.109	-0.131	0.225	0.141	-0.076	0.143	0.186	0.283
7	0.016	0.057	0.077	-0.191	-0.013	-0.634	**1**	-0.717	-0.137	-0.122	0.501	0.045	0.483	-0.135	0.399	-0.203	0.267	-0.180	0.012	-0.362	0.500	0.187	-0.198	0.262	-0.254	0.228	-0.057	-0.403	-0.058	-0.321	0.005	0.095	-0.053	0.263	-0.096	0.153	0.184	-0.126	-0.220	-0.228
8	0.089	-0.065	-0.185	-0.097	-0.045	0.572	-0.717	**1**	0.143	0.039	-0.267	-0.034	-0.239	-0.015	-0.124	0.068	-0.130	0.453	0.485	0.583	-0.303	-0.360	0.306	-0.580	0.264	0.027	-0.162	0.375	-0.158	0.015	0.095	-0.076	0.040	-0.253	0.247	-0.180	-0.404	-0.279	-0.029	-0.037
9	0.212	0.026	-0.272	-0.201	-0.209	0.000	-0.137	0.143	**1**	0.255	-0.012	-0.440	-0.106	-0.190	-0.155	-0.323	0.017	0.074	0.002	-0.034	-0.690	0.124	0.095	-0.127	-0.019	-0.284	0.252	-0.325	0.309	0.528	-0.253	0.676	0.117	0.197	-0.258	-0.297	0.177	0.357	-0.569	0.028
10	-0.463	-0.328	-0.040	-0.357	0.112	-0.053	-0.122	0.039	0.255	**1**	-0.319	0.136	-0.347	0.165	-0.489	-0.102	-0.009	-0.511	0.155	0.278	0.093	0.014	-0.207	0.153	0.327	-0.084	0.311	0.127	-0.176	-0.044	0.309	0.048	-0.377	0.066	0.165	0.254	-0.185	0.359	-0.122	0.262
11	0.035	0.518	-0.199	-0.019	-0.328	-0.486	0.501	-0.267	-0.012	-0.319	**1**	-0.362	0.476	-0.023	0.790	-0.066	0.368	-0.052	0.084	-0.611	0.104	0.088	-0.236	0.249	-0.097	0.042	-0.368	-0.359	-0.290	-0.332	-0.308	0.189	0.407	0.215	-0.308	-0.017	0.150	-0.462	-0.158	-0.007
12	-0.084	-0.231	-0.311	-0.096	0.450	0.000	0.045	-0.034	-0.440	0.136	-0.362	**1**	-0.081	-0.113	0.016	0.162	-0.136	-0.087	-0.101	0.311	0.474	-0.440	-0.136	0.245	0.354	-0.139	0.461	0.536	-0.248	-0.317	0.707	-0.653	-0.505	-0.514	-0.007	0.278	0.096	0.074	0.611	-0.323
13	0.183	0.287	-0.332	-0.310	-0.042	-0.522	0.483	-0.239	-0.106	-0.347	0.476	-0.081	**1**	0.088	0.665	-0.300	0.133	0.351	0.098	-0.391	0.359	0.009	0.449	0.020	-0.063	-0.065	-0.119	-0.281	0.019	-0.181	0.056	0.111	-0.047	-0.236	-0.293	-0.092	0.008	-0.321	-0.243	-0.563
14	-0.369	0.390	0.094	0.042	0.059	0.175	-0.135	-0.015	-0.190	0.165	-0.023	-0.113	0.088	**1**	-0.266	-0.246	-0.562	-0.260	-0.024	-0.314	0.156	0.545	-0.084	0.003	0.032	-0.207	0.009	0.034	-0.295	-0.251	-0.004	-0.223	-0.271	-0.113	0.300	0.372	0.013	-0.192	0.025	0.433
15	0.359	0.296	-0.506	-0.142	-0.275	-0.410	0.399	-0.124	-0.155	-0.489	0.790	0.016	0.665	-0.266	**1**	-0.066	0.479	0.190	-0.016	-0.457	0.195	-0.298	0.064	0.247	0.113	0.018	-0.169	-0.139	-0.173	-0.393	0.000	-0.011	0.328	-0.238	-0.397	-0.166	0.175	-0.387	0.038	-0.400
16	-0.332	-0.100	0.291	0.538	-0.024	-0.019	-0.203	0.068	-0.323	-0.102	-0.066	0.162	-0.300	-0.246	-0.066	**1**	0.148	0.340	0.106	0.189	0.164	-0.335	-0.520	0.077	0.373	0.268	-0.267	-0.157	-0.113	-0.062	0.021	-0.387	-0.367	0.203	-0.182	-0.140	0.189	-0.236	0.479	0.153
17	0.159	-0.510	0.041	0.083	-0.325	-0.210	0.267	-0.130	0.017	-0.009	0.368	-0.136	0.133	-0.562	0.479	0.148	**1**	-0.113	-0.244	-0.141	0.049	-0.509	-0.121	0.118	0.090	0.617	-0.287	-0.153	-0.142	-0.172	0.079	0.358	0.291	0.156	-0.176	-0.287	-0.102	-0.064	-0.274	0.066
18	0.281	0.101	-0.151	0.069	0.013	-0.036	-0.180	0.453	0.074	-0.511	-0.052	-0.087	0.351	-0.260	0.190	0.340	-0.113	**1**	0.430	0.244	-0.089	-0.208	0.364	-0.475	0.086	0.058	-0.232	-0.193	0.291	0.152	-0.031	-0.083	-0.190	-0.134	-0.161	-0.470	0.000	-0.405	-0.062	-0.492
19	-0.160	0.229	-0.001	-0.458	-0.020	-0.045	0.012	0.485	0.002	0.155	0.084	-0.101	0.098	-0.024	-0.016	0.106	-0.244	0.430	**1**	0.538	0.198	-0.073	0.127	-0.369	0.216	-0.011	-0.335	-0.122	-0.152	-0.215	-0.055	-0.169	-0.187	0.133	0.176	0.121	-0.334	-0.329	-0.018	-0.330
20	-0.143	-0.352	0.229	-0.197	0.258	0.438	-0.362	0.583	-0.034	0.278	-0.611	0.311	-0.391	-0.314	-0.457	0.189	-0.141	0.244	0.538	**1**	0.057	-0.490	0.255	-0.499	0.166	0.092	-0.106	0.327	-0.113	0.135	0.252	-0.121	-0.239	-0.043	0.196	0.222	-0.504	0.110	0.177	-0.242
21	-0.329	0.000	0.103	0.000	0.121	-0.275	0.500	-0.303	-0.690	0.093	0.104	0.474	0.359	0.156	0.195	0.164	0.049	-0.089	0.198	0.057	**1**	-0.044	-0.088	0.038	0.088	0.191	-0.028	-0.066	-0.325	-0.570	0.369	-0.434	-0.480	-0.257	-0.093	0.471	0.000	-0.393	0.234	-0.145
22	-0.010	0.382	0.129	0.119	-0.018	-0.180	0.187	-0.360	0.124	0.014	0.088	-0.440	0.009	0.545	-0.298	-0.335	-0.509	-0.208	-0.073	-0.490	-0.044	**1**	-0.039	-0.003	-0.498	-0.209	0.162	-0.306	0.413	0.100	-0.381	0.088	0.078	0.156	0.158	0.038	0.254	-0.032	-0.335	0.354
23	0.420	-0.033	-0.174	-0.325	0.139	0.121	-0.198	0.306	0.095	-0.207	-0.236	-0.136	0.449	-0.084	0.064	-0.520	-0.121	0.364	0.127	0.255	-0.088	-0.039	**1**	-0.499	-0.328	-0.166	-0.014	0.176	0.385	0.320	0.024	0.278	0.263	-0.415	-0.041	-0.085	-0.437	0.060	-0.306	-0.522
24	-0.147	0.137	-0.256	-0.228	-0.195	-0.349	0.262	-0.580	-0.127	0.153	0.249	0.245	0.020	0.003	0.247	0.077	0.118	-0.475	-0.369	-0.499	0.038	-0.003	-0.499	**1**	0.354	-0.324	0.411	-0.014	-0.070	-0.120	-0.087	-0.236	-0.002	0.145	-0.067	-0.087	0.479	0.452	0.438	-0.077
25	-0.071	-0.090	-0.364	-0.298	-0.273	0.112	-0.254	0.264	-0.019	0.327	-0.097	0.354	-0.063	0.032	0.113	0.373	0.090	0.086	0.216	0.166	0.088	-0.498	-0.328	0.354	**1**	-0.119	0.164	-0.045	-0.288	-0.412	0.300	-0.459	-0.480	-0.254	-0.064	0.000	0.274	0.152	0.489	-0.081
26	0.049	-0.659	0.493	0.308	0.042	-0.050	0.228	0.027	-0.284	-0.084	0.042	-0.139	-0.065	-0.207	0.018	0.268	0.617	0.058	-0.011	0.092	0.191	-0.209	-0.166	-0.324	-0.119	**1**	-0.588	-0.028	-0.136	-0.366	0.240	0.036	0.027	0.255	0.383	-0.163	-0.378	-0.384	-0.310	0.332
27	0.095	-0.009	-0.542	-0.220	-0.051	0.034	-0.057	-0.162	0.252	0.311	-0.368	0.461	-0.119	0.009	-0.169	-0.267	-0.287	-0.232	-0.335	-0.106	-0.028	0.162	-0.014	0.411	0.164	-0.588	**1**	0.150	0.309	0.218	0.125	-0.108	-0.261	-0.387	-0.142	-0.136	0.545	0.493	0.108	-0.191
28	-0.039	-0.278	-0.193	-0.116	0.576	0.238	-0.403	0.375	-0.325	0.127	-0.359	0.536	-0.281	0.034	-0.139	-0.157	-0.153	-0.193	-0.122	0.327	-0.066	-0.306	0.176	-0.014	-0.045	-0.028	0.150	**1**	-0.238	-0.070	0.509	-0.363	0.117	-0.332	0.475	0.056	-0.524	0.022	0.290	-0.077
29	0.602	-0.151	-0.136	0.000	-0.011	-0.187	-0.058	-0.158	0.309	-0.176	-0.290	-0.248	0.019	-0.295	-0.173	-0.113	-0.142	0.291	-0.152	-0.113	-0.325	0.413	0.385	-0.070	-0.288	-0.136	0.309	-0.238	**1**	0.418	-0.193	0.124	0.173	-0.121	-0.090	-0.483	0.260	0.360	-0.237	-0.201
30	-0.083	0.067	0.178	0.140	-0.003	0.181	-0.321	0.015	0.528	-0.044	-0.332	-0.317	-0.181	-0.251	-0.393	-0.062	-0.172	0.152	-0.215	0.135	-0.570	0.100	0.320	-0.120	-0.412	-0.366	0.218	-0.070	0.418	**1**	-0.482	0.615	0.201	0.324	-0.241	-0.313	0.000	0.446	-0.254	-0.135
31	0.060	-0.533	-0.311	-0.100	0.656	-0.202	0.005	0.095	-0.253	0.309	-0.308	0.707	0.056	-0.004	0.000	0.021	0.079	-0.031	-0.055	0.252	0.369	-0.381	0.024	-0.087	0.300	0.240	0.125	0.509	-0.193	-0.482	**1**	-0.472	-0.495	-0.565	0.118	0.226	-0.260	-0.120	0.164	-0.084
32	0.016	-0.017	0.183	0.008	-0.301	0.016	0.095	-0.076	0.676	0.048	0.189	-0.653	0.111	-0.223	-0.011	-0.387	0.358	-0.083	-0.169	-0.121	-0.434	0.088	0.278	-0.236	-0.459	0.036	-0.108	-0.363	0.124	0.615	-0.472	**1**	0.418	0.421	-0.276	-0.190	-0.131	0.183	-0.756	0.082
33	0.430	0.139	0.010	-0.014	-0.261	0.109	-0.053	0.040	0.117	-0.377	0.407	-0.505	-0.047	-0.271	0.328	-0.367	0.291	-0.190	-0.187	-0.239	-0.480	0.078	0.263	-0.002	-0.480	0.027	-0.261	0.117	0.173	0.201	-0.495	0.418	**1**	0.170	0.052	-0.198	-0.216	0.076	-0.210	0.048
34	-0.447	0.040	0.627	0.068	-0.167	-0.131	0.263	-0.253	0.197	0.066	0.215	-0.514	-0.236	-0.113	-0.238	0.203	0.156	-0.134	0.133	-0.043	-0.257	0.156	-0.415	0.145	-0.254	0.255	-0.387	-0.332	-0.121	0.324	-0.565	0.421	0.170	**1**	0.225	-0.153	-0.118	0.104	-0.248	0.220
35	-0.064	-0.349	0.277	-0.249	0.199	0.225	-0.096	0.247	-0.258	0.165	-0.308	-0.007	-0.293	0.300	-0.397	-0.182	-0.176	-0.161	0.176	0.196	-0.093	0.158	-0.041	-0.067	-0.064	0.383	-0.142	0.475	-0.090	-0.241	0.118	-0.276	0.052	0.225	**1**	-0.128	-0.473	0.000	-0.068	0.188
36	-0.342	0.226	0.255	-0.018	0.268	0.141	0.153	-0.180	-0.297	0.254	-0.017	0.278	-0.092	0.372	-0.166	-0.140	-0.287	-0.470	0.121	0.222	0.471	0.038	-0.085	-0.087	0.000	-0.163	-0.136	0.056	-0.483	-0.313	0.226	-0.190	-0.198	-0.153	-0.128	**1**	-0.156	0.000	0.330	0.194
37	0.175	0.331	-0.304	0.216	-0.471	-0.076	0.184	-0.404	0.177	-0.185	0.150	0.096	0.008	0.013	0.175	0.189	-0.102	0.000	-0.334	-0.504	0.000	0.254	-0.437	0.479	0.274	-0.378	0.545	-0.524	0.260	0.000	-0.260	-0.131	-0.216	-0.118	-0.473	-0.156	**1**	0.173	0.227	0.051
38	0.123	-0.242	-0.006	-0.362	-0.077	0.143	-0.126	-0.279	0.357	0.359	-0.462	0.074	-0.321	-0.192	-0.387	-0.236	-0.064	-0.405	-0.329	0.110	-0.393	-0.032	0.060	0.452	0.152	-0.384	0.493	0.022	0.360	0.446	-0.120	0.183	0.076	0.104	0.000	0.000	0.173	**1**	0.158	-0.112
39	-0.141	0.192	-0.052	0.062	0.116	0.186	-0.220	-0.029	-0.569	-0.122	-0.158	0.611	-0.243	0.025	0.038	0.479	-0.274	-0.062	-0.018	0.177	0.234	-0.335	-0.306	0.438	0.489	-0.310	0.108	0.290	-0.237	-0.254	0.164	-0.756	-0.210	-0.248	-0.068	0.330	0.227	0.158	**1**	-0.139
40	-0.267	-0.125	0.425	0.585	-0.110	0.283	-0.228	-0.037	0.028	0.262	-0.007	-0.323	-0.563	0.433	-0.400	0.153	0.066	-0.492	-0.330	-0.242	-0.145	0.354	-0.522	-0.077	-0.081	0.332	-0.191	-0.077	-0.201	-0.135	-0.084	0.082	0.048	0.220	0.188	0.194	0.051	-0.112	-0.139	**1**

Figure F.2: PCA: Correlation Matrix

F.3 UTILIZATION OF OTHER FACTORS

In order to have more reliable conclusions on the obtained results, the PCA algorithm is reiterated, by using different combinations of factors. This may reveal correlations among variables which were not exposed by the two principal components (F1 and F2). This procedure, however, entails performing a dimensionality reduction based on factors which account for an even lower percentage of variability of the sample than in the case of F1 and F2. The following sections present some on the results obtained by applying different combinations of factors. The attempt of identifying underlying correlations among variables, as well as among observations (respondents), did not lead however to any conclusive results. Therefore, it appears precarious, if not impossible, to group variables, or observations, on the basis of two factors. Section F.4 offers a few explanation for this outcome, as well as suggestions for future research that might eventually apply PCA.

F.4 SUGGESTIONS FOR FUTURE RESEARCH

In these section some of the reasons which might explain the lack of conclusive results from the PCA are presented, together with suggestion for better implementing PCA in the future on similar case studies.

The lack of a clear definition of groups, both for variables and respondents, might be due to the elevated ration of statements (variables) on number of observations (interviewees). The solution for this issue might be twofold:

- Lower the number of statement $\Rightarrow$ The execution of this research showed, in its later stages, that the amount of statements developed for the Q-sort technique might have been unnecessarily high, despite the literature suggested a number between 40 and 80. Statements that are in fact often focused on the same subjects or game elements could be merged in order to better aim at a specific connection between game element and knowledge output. This might ease the attempt of unraveling hidden correlations, as well as clustering observations.
- Increase the number of interviewees $\Rightarrow$ Obviously, expanding the set of respondents would make statistical measurements more precise and accurate. Moreover, it would possibly help to include several games with different scopes (not just testing, but also decision making and learning).

By adopting the presented adjustments, it could be possible to reiterate the study and hopefully achieved better structured and clearer results.

G RESULTS OF K-MEANS CLUSTERING

G.1 DIFFERENCE BETWEEN CLUSTER CENTROIDS AND TOTAL AVERAGE OF THE SAMPLE

Figure G.1 displays the value of the differences - for each statement - between the centroids of the different clusters and the total average of the sample. The followed procedure is the same as for Annex F:

1. Q-sort responses are divided in groups on the basis of the clusters obtained after applying the k-means algorithm.
2. For each group, the average response value is calculated for every single statement. Therefore, each cluster is represented by a 40-dimensional vector, called *centroid*).
3. The average response value per statement is calculated also with regards to the total sample (once again a 40-dimensional vector).
4. The average of the total sample is subtracted from the centroid of each cluster, thus obtaining four new 40-dimensional vectors, which are ultimately represented in the graph.
5. The vectors obtained represent, for each cluster, the distance of the centroid of that cluster from the average of the total sample.

By analyzing the graph, it is possible to spot some quite evident trends:

- Class 3 and Class 4 seem to have very different opinions on several statements, such as statement 7, 11, 14, 15, 17, 23, 28, 29, 32, 34; while similar views for statements 16, 18, 19.
- The same happens for Class 1 and Class 2, which show very contrasting perspectives on statements: 1,3,9,14,23, 29, 38, 40; while they agree for instance for statement 31.

This suggest the presence of a diversity of mindsets among the different clusters. Further insights can be gained by investigating the content of the statements, as well as the value of their respective correlation (r).

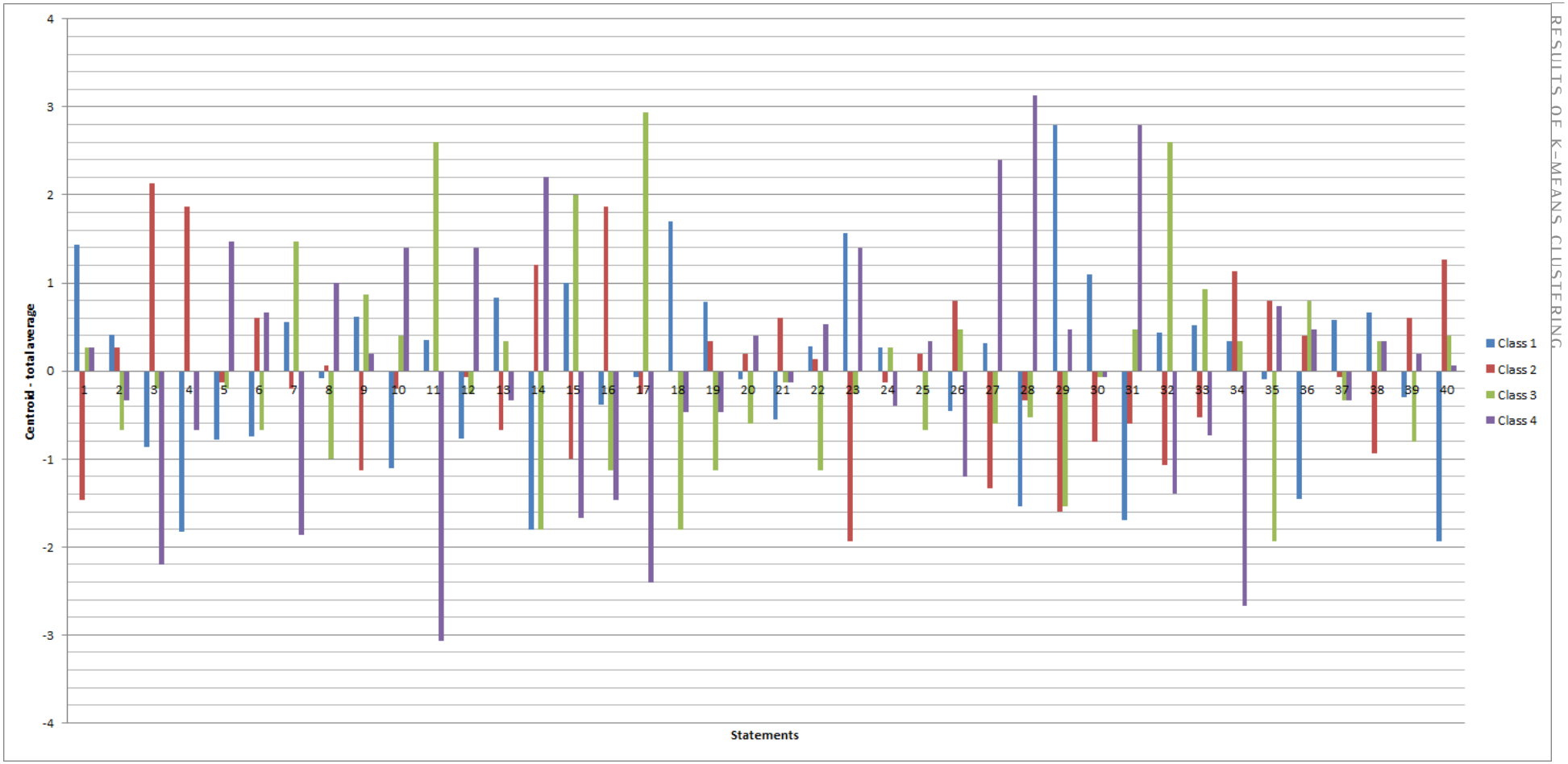


Figure G.1: Difference between centroids per cluster and average of the total sample

Statements	Class 1	Class 2	Class 3	Class 4
1. Insights from game players or participants should be incorporated at an early stage in the game design process.	AGREE	DISAGREE	SLIGHLTY AGREE	SLIGHTLY AGREE
2. It is important to have a structured debriefing in order to have valuable and useful results.	AGREE	SLIGHLTY AGREE	DISAGREE	SLIGHTLY DIS-AGREE
3. I would like to have a way to consult results or access documentation from previously played games.	DISAGREE	STRONGLY AGREE	SLIGHTLY DIS-AGREE	STRONGLY DIS-AGREE
4. The needs of each stakeholder involved in the game should be analyzed before the beginning of the game design process.	DISAGREE	AGREE	NEUTRAL	DISAGREE
5. Game designers are mainly concerned in designing a game which can obtain measurable quantitative results.	DISAGREE	SLIGHTLY DIS-AGREE	SLIGHTLY DIS-AGREE	AGREE
6. Games represent a positive environment for participants to show concerns and insights about their everyday operational activities.	DISAGREE	AGREE	DISAGREE	AGREE
7. Games represent a unique occasion for operators (e.g. train drivers, train traffic controllers) to come in contact with the designers of the infrastructures.	AGREE	SLIGHLTY DIS-AGREE	AGREE	DISAGREE
8. I believe that, in games, strict rules and high validity of results are more useful than loose rules and more space for personal interaction (open discussion, face-to-face interaction).	SLIGHLTY DIS-AGREE	SLIGHLTY AGREE	DISAGREE	AGREEE
9. In order to be helpful and have valuable results games should be characterized by a balance between number of possible scenarios and accuracy of data.	AGREE	DISAGREE	AGREE	SLIGHLTY AGREE
10. Participating in the game improves participants' ability to cope with unexpected changes in their day-to-day working activities.	DISAGREEE	SLIGHLTY DIS-AGREE	AGREEE	AGREE
11. Games allow to test situations which would not be possible to test in real life.	AGREE	NEUTRAL	STRONGLY AGREEE	STRONGLY DIS-AGREE
12. Games allow for a better understanding among participants of each other roles and tasks.	DISAGREE	SLIGHLTY DIS-AGREE	SLIGHTLY DIS-AGREE	AGREE
13. Games allow to better understand the reasons of certain actions performed by participants in real life	AGREE	DISAGREE	SLIGHTLY AGREE	SLIGHLTY DIS-AGREE
14. Games serve as an occasion for participants to evaluate each others' work.	DISAGREE	AGREE	DISAGREE	STRONGLY AGREE
15. The organization as a whole gains through games a better understanding of operations and their functioning.	AGREE	DISAGREE	AGREE	DISAGREE

Statements	Class 1	Class 2	Class 3	Class 4
16. Games bring together actors that would not interact so closely in real life (e.g. representatives of municipalities or ministries, members of project team, train traffic controllers, game designer, etc.)	DISAGREE	AGREE	DISAGREE	DISAGREE
17. Games help organizations implementing new infrastructure designs.	SLIGHLTY DIS-AGREE	SLIGHLTY DIS-AGREE	STRONGLY AGREE	STRONGLY DIS-AGREE
18. Games are useful for the organization for understanding operators' needs.	AGREE	NEUTRAL	DISAGREE	DISAGREE
19. Games allow the identification of procedures which are not standard, but are the result of experience and contextual factors.	AGREE	SLIGHLTY AGREE	DISAGREE	DISAGREE
23. The complexity of a game is directly correlated to the value and utility of its results.	AGREE	DISAGRE	SLIGHLTY DIS-AGREE	AGREE
27. Digital games (e.g. computer simulations) are more beneficial that analog games (e.g. board games).	SLIGHLTY AGREE	DISAGREE	DISAGREE	STRONGLY AGREE
28. I believe the accuracy of the inputs (e.g. data such as infrastructures, timetables) is fundamental in any type of game.	DISAGREE	SLIGHLTY DIS-AGREE	DISAGREE	STRONGLY AGREE
29. The results of a game are valuable as long as the game takes into consideration as many aspects related to the problem as possible (e.g. in the design of a new infrastructure such aspects would be: logistics, maintenance, reliability, etc.).	STRONGLY AGREE	DISAGREE	DISAGREE	AGREE
31. I think a game is more effective if there is a variety in participants' roles and expertise.	DISAGREE	DISAGREE	AGREE	STRONGLY AGREE
32. I believe the more times a game session is repeated, the accuracy and validity of the results increase.	AGREE	DISAGREE	STRONGLY AGREE	DISAGREE
33. I think that games' results (both qualitative and quantitative) would be more useful if organized in a structured database (e.g. combination of repositories of data, videos, forum for questions, etc.)	AGREE	DISAGREE	AGREE	DISAGREE
34. In the case I was interested in a particular game, I would appreciate to have the possibility of consulting video or audio recordings from game sessions or debriefing of that game.	SLIGHLTY AGREE	AGREE	SLIGHLTY AGREE	STRONGLY DIS-AGREE

Statements	Class 1	Class 2	Class 3	Class 4
35. I think it would be useful for both game designers, project teams and operators, to have a session after the end of the game to discuss the "lesson learned" (in addition to the debriefing)	SLIGHLTY DISAGREE	AGREE	DISAGREE	AGREE
36. Analog games are better used for learning purposes than testing.	DISAGREE	AGREE	AGREE	AGREE
40. Games are drivers for technical advancements (e.g. developing a software for the game play)	DISAGREE	AGREE	AGREE	SLIGHTLY AGREE

Table G.1: Differences in opinions per clusters (classes)

G.2 DESCRIPTIVE STATISTICS

This section displays important information with regards to the results of the application of the k-means algorithm.

Class	1	2	3	4
Objects	4	5	3	3
Sum of weights	4	5	3	3
Within-class variance	136.333	156.900	151.000	193.000
Minimum distance to centroid	9.341	8.926	9.165	10.708
Average distance to centroid	10.069	11.021	10.009	11.314
Maximum distance to centroid	11.651	14.494	10.863	12.463
	1Om_PR	2Kd_NS	4Ot_PR	6Kp_PR
	7Om_PR	3Kd_NS	9Od_TU	10O'p_NS
	11Kp_NS	5Kd_NS	13Et_PR	14Kp_NS
	15Et_PR	8Kd_PR		
		12Et_PR		

Table G.2: Results by class

Class Central Object	1 (11Kp_NS)	2 (8Kd_PR)	3 (13Et_PR)	4 (6Kp_PR)
1 (11Kp_NS)	0	16.553	17.205	18.974
2 (8Kd_PR)	16.553	0	15.492	20.000
3 (13Et_PR)	17.205	15.492	0	20.347
4 (6Kp_PR)	18.974	20.000	20.347	0

Table G.3: Distances between the Central Objects

	Absolute	Percent
Within-class	156.782	88.74%
Between-classes	19.894	11.26%
Total	176.676	100.00%

Table G.4: Within-Class and Between-Classes Variance

Class	1	2	3	4

1	2.5	-0.4	1.333333333	1.333333333
2	2.75	2.6	1.666666667	2
3	-1	2	-0.333333333	-2.333333333
4	-0.5	3.2	1.333333333	0.666666667
5	-3.25	-2.6	-2.666666667	-1
6	1.25	2.6	1.333333333	2.666666667
7	0.75	0	1.666666667	-1.666666667
8	-2.75	-2.6	-3.666666667	-1.666666667
9	0.75	-1	1	0.333333333
10	-0.5	0.4	1	2
11	2.75	2.4	5	-0.666666667
12	2.5	3.2	3	4.666666667
13	3.5	2	3	2.333333333
14	-3	0	-3	1
15	3	1	4	0.333333333
16	0.75	3	0	-0.333333333
17	0	-0.2	3	-2.333333333
18	3.5	1.8	0	1.333333333
19	2.25	1.8	0.333333333	1
20	-1.5	-1.2	-2	-1
21	-3.75	-2.6	-3.333333333	-3.333333333
22	0.75	0.6	-0.666666667	1
23	-0.5	-4	-2.333333333	-0.666666667
24	2	1.6	2	1.333333333
25	-2	-1.8	-2.666666667	-1.666666667
26	-3.25	-2	-2.333333333	-4
27	-2.75	-4.4	-3.666666667	-0.666666667
28	-1	0.2	0	3.666666667
29	2	-2.4	-2.333333333	-0.333333333
30	0.5	-1.4	-0.666666667	-0.666666667
31	-1.5	-0.4	0.666666667	3
32	0.5	-1	2.666666667	-1.333333333
33	0.25	-0.8	0.666666667	-1
34	0	0.8	0	-3
35	2.5	3.4	0.666666667	3.333333333
36	-4.25	-2.4	-2	-2.333333333
37	-1.75	-2.4	-2.666666667	-2.666666667
38	2	0.4	1.666666667	1.666666667
39	-0.5	0.4	-1	0
40	-3	0.2	-0.666666667	-1
Sum of weights	4	5	3	3
Within-class variance	136.3333333	156.9	151	193

Table G.5: Class Centroids

Class Centroid	**1**	**2**	**3**	**4**
1	0	11.311	9.819	12.553
2	11.311	0	10.498	12.037
3	9.819	10.498	0	14.142
4	12.553	12.037	14.142	0

Table G.6: Distances between the Class Centroids

Observation	Class	Distance to centroid
1Om_PR	1	9.811
2Kd_NS	2	10.774
3Kd_NS	2	11.700
4Ot_PR	3	10.000
5Kd_NS	2	9.213
6Kp_PR	4	10.708
7Om_PR	1	9.474
8Kd_PR	2	8.926
9Od_TU	3	10.863
10O'p_NS	4	10.770
11Kp_NS	1	9.341
12Et_PR	2	14.494
13Et_PR	3	9.165
14Kp_NS	4	12.463
15Et_PR	1	11.651

Table G.7: Results by object

	Eigenvalue	Variability (%)	Cumulative (%)
F1	6.256139184	15.64034796	15.64034796
F2	5.39996633	13.49991583	29.14026379
F3	4.692309944	11.73077486	40.87103865
F4	4.471709829	11.17927457	52.05031322
F5	3.346684886	8.366712214	60.41702543
F6	3.207089178	8.017722946	68.43474838
F7	2.623343149	6.558357873	74.99310625
F8	2.403810785	6.009526963	81.00263321
F9	1.995988888	4.98997222	85.99260543
F10	1.743984037	4.359960092	90.35256553
F11	1.42049505	3.551237626	93.90380315
F12	0.997847599	2.494618997	96.39842215
F13	0.796058545	1.990146363	98.38856851
F14	0.644572595	1.611431489	100

Table G.8: PCA: Eigenvalues