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A research agenda

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DOI
10.1109/WSC.2018.8632377

Publication date
2019

Document Version
Final published version

Published in
2018 Winter Simulation Conference (WSC)

Proceedings of the 2018 Winter Simulation Conference
M. Rabe, A. A. Juan, N. Mustafee, A. Skoogh, S. Jain, and B. Johansson, eds.

THE FUTURE OF CONTEXTUAL KNOWLEDGE IN GAMING SIMULATIONS: A RESEARCH AGENDA

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ABSTRACT

Gaming simulations (games) are increasingly becoming the tool of choice for modeling and understanding the complexity of today's systems. This increased popularity has consequently revealed the weaknesses of games in several areas. These limitations range from inconsistencies on the game design to the unexploited explicit and tacit knowledge that games invoke. This paper focuses on games that do not aim at generalizing the produced knowledge but, instead, at understanding how a system works within a specific context. The first step of the analysis is identifying these limitations based on an extensive literature review. Based on this, different directions that could mitigate or even fully address these limitations are proposed. The paper concludes with a focused research agenda.

1 INTRODUCTION

Gaming simulations (hereinafter referred to as games) are a powerful tool for organizations, which need to identify solutions in uncharted areas (Duke and Geurts 2004). Games are one of the simulation techniques with the highest stakeholder engagement rates (Jahangirian et al. 2010). Despite being a mature professional discipline, the primary area of focus in games has been education and training (Jahangirian et al. 2010), while the study of areas like decision making, policy testing, and design of Complex Adaptive Systems (CAS) through games has received less attention.

Nevertheless, recent developments have shown that games can be, and have been, used in areas other than education as a way to understand how CAS work and how impactful decisions and insights can be deduced within those systems. Several examples are shown later in this paper of how games have been used, in order for companies and researchers to gain understanding of fields like healthcare, transportation, and supply chain management.

The limited adaptation of games in areas other than education has yielded numerous unaddressed problems with regards to their application and the applicability of the results derived from them. Several of these problems are associated with the design of games and the primary reason for that is that gaming as a discipline lies between the design and the analytical sciences. Moreover, the nature of these simulations, which involve human participation, significantly increases the associated cost. Subsequently, many game sessions are conducted with small sample sizes in terms of the number of participants, which has implications on the validity and the generalizability of the results. Finally, perhaps the least researched aspect of games is the overall management of the knowledge acquired through games. While this knowledge can create valuable insights, and at the same time is quite expensive to obtain, there is almost a complete lack of methodologies on how to manage it. Solving this can not only maximize the insights obtained from a game but also use the acquired knowledge in the future for a small fraction of the cost.

978-1-5386-6572-5/18/$31.00 ©2018 IEEE

In Section 2, the state of the art in gaming simulations is examined, which results in the identification of the current limitations. In Section 3, based on the limitations identified in Section 2, potential directions for improvements are explored. In Section 4, a research agenda is presented. Finally, in Section 5, final remarks are made.

2 STATE OF THE ART

In this section, the state of the art in games is examined. In Section 2.1, several examples of studies that used games for understanding how CAS and Socio Technical Systems (STS) function are presented. In Section 2.2, the characteristics of games are examined. Section 2.3 poses the conclusion of the literature in which the limitations of the state of the art are identified, which in turn are the starting point for potential directions for improvements and a research agenda that is further examined throughout this paper.

2.1 Game Studies

Games have been used in a variety of fields for understanding CAS and STS, and particularly the design and decision making processes within those systems.

In healthcare, Kotiadis et al. (2014) started by proposing a conceptual modeling framework, which then evolved in a multi-methodology framework (Tako and Kotiadis 2015) that supports stakeholder participation in simulation studies. The framework incorporates several stages that take place during the lifecycle of a participatory simulation study. In a later study, the authors (Kotiadis and Tako 2018) reported positive results, yet they also acknowledge a few drawbacks, of which perhaps the most important is the observer's effect, which can severely invalidate a simulation study (Campbell and Stanley 1963). Similarly, Raghothama et al. (2017) defined a hybrid, composable approach to healthcare simulations based on requirements drawn from a participatory simulation. The results of the application of their approach to a case study in the New Karolinska Solna hospital in Sweden pinpointed the need for variability in the workflow processes and the ability of such solutions to be able to integrate in hospitals' current IT infrastructure. Indicative on both of these approaches is the need to explicitly or implicitly involve stakeholders in all stages of modeling, in order to elicit not only their explicit but also their tacit knowledge.

Another major area of study of CAS and STS with games is transportation. Games in transportation span in various areas. (Middelkoop et al. 2012) introduced a flexible and scalable backbone to support games in railways. The approach is based on the High Level Architecture (HLA) (Kuhl et al. 1999), which allows coupling new and existing simulations. The associated project has led to the development of several microscopic (Middelkoop and Loeve 2006) and macroscopic simulations (Middelkoop and Bouwman 2001), which in turn were used to built games for various purposes (Meijer 2012a), like testing market mechanisms for capacity allocation, testing and validating a control concept for high frequency train transport, testing different scenarios for train traffic optimization, to name a few. These games have provided insights on how CAS and STS function. In particular, these insights are the following:

- The market mechanisms, in which case flexible prices for optimizing the rail capacity were found to be less optimal than open information and communication between the railway infrastructure manager and its clients, as revealed by three game sessions on train cargo operations (Meijer et al. 2012).
- The selection of the abstraction level for the different components of games (Meijer 2012b), in which case it was determined that the operational aspects of games (e.g., train traffic controllers) required a familiar, almost the same as in real-life, interface. On the other hand, non-operational aspects of games could accommodate for high levels of abstraction (e.g., managers were able to be fully immersed in highly abstracted games even if these games where low-tech on pen and paper).
- The particularities of validating games, in which case the game session runs only once and usually the number of participants is not large due to the associated cost of having a large number of professionals taken away from their regular activities almost for a whole day (Meijer 2012b). In

this case, the authors broke down the validation in two stages: 1. the formal validation of the underline model, submodels, and software components, and 2. the utilization of self-validation, in which the participants' behavior and comments were monitored at all times and participants were encouraged to state their opinion for every process during the game.

Kurapati et al. (2018) built a game, which introduces the concept of synchromodality to the infrastructure managers in the railways. Finally, with regards to transportation in the context of smart cities, Zomer et al. (2015) proposed a framework for incorporating the human behavior and knowledge in urban transportation modeling. In this case, the game is not the end product but a concrete method for hybridization of simulation models, similar to the approach of Raghothama et al. (2017), but for the transportation field.

Games have also been heavily used in logistics and supply chain management. One of the first and most famous games in this area was the Beer Game (Sterman 1989). The Beer Game demonstrates the bullwhip effect (Forrester 1961) that occurs in distribution channels through a beer company. Since its introduction the game has been heavily used in a variety of studies. Kurapati et al. (2015) proposed a gaming approach for improving resilience in intermodal transport operations in seaports. The authors observed not just the training capabilities of games but also the ability to steer decision making towards choices that lead to resilient transport operations in container terminals. (Lukosch et al. 2016) introduced the concept of microgames to support situated learning in order to foster situational awareness of planners in seaport container terminals. They used a microgame with 142 participants, concluding that the microgame allowed for an enjoyable game activity, while providing a meaningful situated learning experience towards situational awareness. Tobail et al. (2011) developed a web-based automobile supply chain management game as a learning tool that promotes collaboration. Apart from the applicability of the proposed game, the paper stretches the lack of methodologies and applications of web-enabled technologies in studying and understanding supply chain management. Fumarola et al. (2012) argued for the need of rigorous design methods for game design and as a result, they proposed a design method comprised of 10 steps. They used two case studies from the logistics field for the development and assessment of the method. Despite the specific domain of the case studies, they concluded that the method can also be applied in other information intensive domains.

In other areas, Fumarola and Verbraeck (2008) proposed an architecture to design a game to support the training process for spatial decision making. The authors used a "what-if"-analysis, which enabled the trainees to achieve more robust results. Cleophas (2012) designed a framework for the design of games in the area of revenue management. The proposed framework is intended to evaluate future alternative designs of games aiming to improve revenue management understanding and strategy evaluation. Katsaliaki and Mustafee (2012) presented a survey of games for sustainable development. Their findings suggest that the most popular games are single player, available online, free of charge, targeted at youngsters who undertake the role of a decision maker, and are sandbox games with 3D graphics.

2.2 Game Characteristics

Games represent dynamic models of real situations (Kriz 2003). Unlike pure simulations, games have a distinct characteristic, which is the human participation, or in other words games have a *Game Layer* on top of the simulation or the *Simulation Layer*. As a result, games are in the intersection of analytical and design sciences (Grogan and Meijer 2017).

Games span in various different domains; the generated knowledge from games can be used for different purposes; and they can be addressed in a diversified audience. Hence, any analysis on game methodologies should first be based on a comprehensive characterization of games. Characterization of games can occur in different levels depending the criteria. This paper starts by adopting the characterization proposed by Grogan and Meijer (2017), as shown in Table 1.

The characterization proposed by Grogan and Meijer (2017) is based on two criteria, the type of knowledge generated by the game and the stakeholder or stakeholders who are the beneficiaries of this knowledge. With regards to the type of knowledge generated, the authors distinguish between two categories: i. Generalizable, meaning that the knowledge acquired during the game provides for broad insights beyond the scope of a particular game scenario, and ii. Contextual, meaning that the knowledge acquired during the game provides for deep insights closely related to a particular game scenario.

With regards to the beneficiary of the generated knowledge, the authors again distinguish between two categories: i. Participant, meaning that the beneficiary of the knowledge acquired during the game is the person or persons who play the game, and ii. Principal, meaning that the beneficiary of the knowledge acquired during the game is any stakeholder or stakeholders other than the participants, like decision makers, researchers etc.

Table 1: Canonical Applications of Gaming Methods.

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

Another major game characteristic is the level of abstraction, which is the degree to which the game has simplified the complexity of the real system, in order to be easier to model and reason about (Iwasaki and Simon 1994). Games can have i. high level of abstraction, meaning that they are a very simplified version of reality, perhaps in the form of a board game, ii. low level of abstraction, meaning that they are a very realistic representation of the real system, usually this is in the form of a computerized game, and iii. anything in-between the two aforementioned levels, since the abstraction level is a continuum.

With regards to validation of games, there are different kind of validities that a game should adhere to. As it has been described above, a game consists of the *Game Layer* and the *Simulation Layer*. Validation of the *Simulation Layer* has been vastly researched through the course of the last three decades (Sargent 1996; Balci 1998; Balci 2004), where numerous formal methods and statistical techniques have been proposed. The *Game Layer*, on the other hand, due to its nature of including humans, should and usually does depend more on experts' opinion, i.e. face validation, than formal methods.

In literature, several kinds of validity pertaining to games are identified. The most important ones are i. construct validity, ii. internal validity, iii. external validity, and iv. reliability for research and usage of the game insights and results (e.g. for policy making or decision making) (hereinafter referred to as game utilization). Construct validity is the degree to which a test measures what it is supposed to measure (Cronbach and Meehl 1955). Consequently, for games, construct validity is the degree to which an artefact, i.e. a game, represents the construct from reality it is suppose to represent. Internal validity refers to the degree to which the behavior of the dependent variable is explained by the behavior of the independent variable (Reis and Judd 2014). For games, internal validity examines the degree to which the game is an adequate representative of the system it imitates. External validity examines the degree to which results from a study can be valid and generalized for the population in general or even for different populations (Aronson et al. 2018). For games, external validity is closely related with the sample size of the game session (Grogan and Meijer 2017) and debriefing (Seymour 2012). The latter is responsible for transferring the acquired knowledge from the game session to reality, making it applicable in a real context, and thus generalizable. Game utilization refers to the minimization of errors and bias of a study, by ensuring that results are replicable (Yin 2009), as well as the utilization of the results and insights from a game in reality. In games, where the uncertainty introduced by humans eliminates the possibility for absolutely reproducible results (Hofmann 2015), game utilization is related with the way the knowledge created within the game is captured, documented, managed, and reused.

2.3 Limitations in the Gaming Simulation Field

The state of the art in games and their characteristics, as it was illustrated in Section 2.1 and Section 2.2, reveals several limitations of games. These limitations are perhaps a consequence of the small body of knowledge for games focused on applications other than learning and training (Duke and Geurts 2004).

With regards to the construct validity, as it was identified in Section 2.2, games are in the intersection of design and analytical sciences, which generates confusion, misunderstanding, and frustration between the two communities (design and analytical), due to the fact that they are working separately and that they have different success criteria. Another major limitation is the rare application of rigorous design methods in game design (Fumarola et al. 2012), which has two significant drawbacks. First, problematic areas in the real system that would benefit from gaming are not identified in a systematic way. Second, games in various occasions are not consistent with the real-world system they are suppose to imitate. Finally, an important game design decision that is often not in line with the purpose of the game is the abstraction level. Games span in various applications ranging from low-tech board games to high-tech simulation games (Meijer 2015). Selecting the type of game, and consequently the abstraction level, depends on the objective of the game. Too much abstraction could lead to vague and unclear goals within the game. On the other hand, too little abstraction could result in strict rules that do not adhere to the real-world system under study and also it could not provide the flexibility to use games for future systems for which the rules are not known.

With regards to the internal validity of games, the greatest impediment is the informal way with which games are validated, e.g. face validation. Consequently, validation relies heavily upon experts' opinion thus to their subjectivity. This limitation is related to the lack of design methods for games (mentioned in the previous paragraph) as well as to the usually low number of participants (mentioned in the next paragraph). These interconnections of the game characteristics not only reveal the complexity of games but also the need for methodologies that would first acknowledge and then model these interconnections.

With regards to the external validity of games, the most important aspects are the sample size (number of participants) and debriefing. A small sample size is easy to obtain but has limited possibilities for analytical conclusions thus limited possibilities for generalizing the observations from the game. A large sample size, while it solves the analytical problem and the generalizability of the results, it is usually expensive to obtain and difficult to coordinate. While debriefing has been identified to be the most important feature of games (Crookall 2010), very few research articles report results on the effectiveness of debriefing (Dufrene and Young 2014), and even less for games focused in areas other than education.

Finally, with regards to the game utilization, it has been strongly suggested that, even thought it may be complex, the collection of empirical data from game sessions can create a body of knowledge that can facilitate the researchers' understanding of systems' behavior (Hofstede and Meijer 2007). Despite that, the research on methodologies on management and reuse of knowledge derived from games is severely limited (Roungas et al. 2017b). The only exception has been the military, where large scale strategic games have been widely used (Herz and Macedonia 2002), and methodologies for managing and reusing knowledge have been proposed and tested through the years. Nevertheless, the majority of those methodologies are domain specific and consequently the state of the art is specialized to the military; thus, most of the associated outcomes cannot be generalized and used in other domains.

Based on the literature reviewed and the definitions of the different kinds of validity, four main areas in game research can be distinguished:

1. Game design, which is related to the construct validity of games.
2. Game validation, as defined in simulations (Balci 1998), which is related to the internal validity of games.

3. Game session, which is related to the external validity of games.
4. Knowledge management, which is related to the game utilization.

3 POTENTIAL DIRECTIONS FOR IMPROVEMENTS

In this section, potential directions for improvements, based on the limitations presented in Section 2.3, are explored. Methodologies and work in-progress that can help mitigate or even fully address the limitations are identified. These methodologies concern only approaches focused in applications other than education and training. The four subsection are based on the four main areas of games, identified in Section 2.3.

3.1 Game Design

Game design as a discipline lies in the intersection of the design and analytical sciences with all the limitations that that entails, which were identified in Section 2.3. Therefore, bridging the gap between those two communities will result in more robust, generalizable, and context rich theories.

One of the first attempts towards bridging the design and analytical aspects of games was made by Duke (1980), in which he identified 9 steps for game design: 1. Developing written specifications for game design, 2. Developing a comprehensive schematic representation of the real-world problem, 3. Selecting components of the real-world problem to be gamed, 4. Identifying the game components, 5. Providing content for the game components, 6. Providing the game mechanics, 7. Implementing and testing the game, 8. Evaluating the game, and 9. Field testing the game.

Point 1 refers to what is widely known as *Requirements*. In layman's terms, requirements are a list of needs communicated by the client that define the objective of the game (Bethke 2003). Potential directions for improvements in this area could be to:

- Develop theories that would unify all aspects of games by incorporating notions from the traditional requirement engineering field (Goguen 1994) as well as the social sciences, in the form of human factors and mental models (Lo et al. 2014).
- Enable seamless and effective communication between the stakeholders like game designers, decision makers etc. (Harteveld 2011). A way would be to use gaming as it was proposed by Raghothama et al. (2017) in a participatory manner.
- Develop domain specific languages by using well-established methods, like the Unified Model Language (UML), that would allow to more effectively elicit the game requirements (Bethke 2003).
- Develop tools for more effectively documenting the requirements and the game design choices throughout the whole design lifecycle (Roungas and Dalpiaz 2016).

Point 2 refers to the identification of the problem in the real-world that needs to be gamified. This point relates to the limitation that problematic areas in the real system are not identified in a systematic way. Potential directions for improvements in this area could be to:

- Develop methodologies for more effectively understanding and analyzing STS and CAS. Particularly, formal methods, like game theory, can be used to pinpoint the problematic areas of multi-actor systems (Vorobeychik and Wellman 2009).
- Acknowledge and research the behavior of actors within the scope of bounded rationality that seems to characterize many STS and CAS (Simon 1972).

Point 3 refers to those parts of the real system that will be chosen to be part of the game; hence it heavily relies on point 2. Reality cannot be gamified in its full complexity, thus abstractions should be made. Hence, this point concerns the abstraction level of the game. A potential direction for improvement in this area could be understanding the advantages and disadvantages of the different levels of abstractions (Meijer 2012b). In turn, given the different characteristics of games and the real system under study (game objective, intended audience, etc.), designers will be able to choose the level of abstraction that would both maximize the outcome of the game and keep the development cost in manageable levels.

Points 4, 5, and 6 are each the natural next step of the previous point. In point 4 the particular game components are chosen; in point 5, subject matter experts (SMEs) cooperate with game designers to provide the appropriate content; in point 6, game designers choose the most effective game techniques given the problem at hand. A potential direction for improvement for point 6 could be to build a lexicon of game techniques (game mechanics) and use case studies to understand under which circumstances certain techniques should be preferred than others (Sweeney and Meadows 2010).

Points 7, 8, and 9 concern the validation of the game and are discussed in Section 3.2.

3.2 Validation

Similar to game design, game validation has to combine methods from the design and the analytical sciences. A validation study should balance the attention between the *Simulation* and the *Game Layers*. First and foremost, validation should not be performed just once after the implementation of the game; instead, it should be carried out in an iterative manner not just during the implementation (Point 7) but throughout the whole lifecycle of the game (Balci 1998). While Duke (1980) defines game evaluation (point 8) as the client's in-house validation once the final product has been delivered to them, the authors of this paper refer to game evaluation as the complete validation and verification (V&V) study of a game (Balci 2004). Similarly, the authors consider point 9, i.e. field testing, to be also part of the V&V study. Potential directions for improvements in this area could be to:

- Incorporate, given the numerous V&V methods (Balci 1998), the appropriate ones for the *Simulation Layer* (Roungas et al. 2017a), and whenever possible automate them (Roungas et al. 2018b).
- Develop methodologies that would allow the formalization of the validation of the *Game Layer*, similar to what it was proposed in Section 3.1 for the game design.

It should be noted that while the game's sample size, i.e. the number of participants, and debriefing heavily influence the validity of a game, they are part of the game session, thus they are analyzed separately in Section 3.3.

3.3 Game Session

Even the most realistic games are still an abstracted version of reality and as such the knowledge from the game session should effectively be transfered to, and generalized for, reality. Hence, the sample size and debriefing are of utmost importance for the analysis of the game outcome. Potential directions for improvements with regards to the sample size could be to:

- Verify, before characterizing the sample size as small, that it is indeed small (Lenth 2001) and that it actually compromises validity.
- Incorporate, if the sample is small, the appropriate V&V methods and statistical techniques (Roungas et al. 2018a).
- For games in which participants do not need to physically be present, use technology to reach a greater audience (Katsaliaki and Mustafee 2012).

Whereas, potential directions for improvements with regards to debriefing could be to:

- Develop methodologies for formalizing debriefing, which in turn can enable the facilitators to choose the most beneficial methods for debriefing given the game and the real system at hand.
- Build a standard for best practices in debriefing (Roungas et al. 2018).

3.4 Knowledge Management

A knowledge management system (KMS) can been used for one or more purposes, like own-project improvement, cross-project improvement, organizational culture improvement, and network improvement. Currently, there are two types of KMS widely used in organizations: i. Personalization and ii. Codification (Markus 2001). The former is more suitable for those professionals who inquire on experts' opinion but do not want to acquire their knowledge, in which case they will most likely prefer to consult an expert in a one-to-one conversation. The latter is more suitable for those professionals who want to learn from past projects and apply this knowledge in the future, in which case they will most probably prefer a documented and detailed record of these past projects. Potential directions for improvements in this area could be to:

- Establish strict and precise protocols for root cause analysis, in case problems or accidents occur throughout the lifecycle of a game or due to decisions made based on a game (Latino et al. 2016).
- Develop methodologies for acquiring, indexing, and reusing knowledge from games, that can potentially benefit an organization in the future (Roungas et al. 2018).
- Build a repository of game artifacts, from game-related materials (e.g. game engines, boards, cards etc.) to any analysis pertaining to a game (e.g. reports, data etc.) (Roungas et al. 2017b).
- Build a network that would allow professionals within an organization to easily identify the most appropriate experts based on the problem at hand (Ahuja et al. 2012).

4 RESEARCH AGENDA FOR GAMING SIMULATION

In this section, based on the potential directions for improvements explored in Section 3, the authors propose a research agenda. Again, the research agenda is based on the four main areas of gaming simulation, identified in Section 2.3.

In game design, the authors identify two directions that could significantly enhance the understanding of complex systems and consequently improve their modeling. First, stakeholders should be more involved not only in the post-game analysis but also during the game design. This participatory approach can enable communication between the different hierarchical layers within an organization, thus allowing information to flow between SMEs, decision makers, and the upper management. This flow of information is more likely to create trust and awareness between the different professional, which in turn can evolve in building the "know-how" of the organization around systems' and people's behavior and facilitate the dissemination of tacit knowledge. Second, while Game Theory (GT) has been scarcely used in game design, it is a well-established tool for understanding and modeling the relationships of different actors in an analytical way. There have been supportive studies towards using GT in game design (Salen and Zimmerman 2003; Ritterfeld et al. 2009). GT is a tool that can be coupled with existing methodologies and help bridging the gap between the design and analytical communities. Moreover, GT can systematically analyze real-world systems and pinpoint those areas within these systems that are problematic and could benefit from the use of games (Roungas et al. 2018). Finally, GT can be directly used in the game design by formalizing the game design choices and using the optimal strategies wherever is required (Vorobeychik and Wellman 2009).

In validation, the small sample size is perhaps the greatest cumber for generalizing insights from games. While there have been statistical techniques developed to address this problem, these are mainly applicable on the *Simulation Layer*. The *Game Layer* would be benefited only through gradually extending the body of knowledge by building upon previous work. This aspect is directly linked with knowledge management, analyzed below, in the sense that the more experiments/sessions are conducted the more evidences of a system's behavior are discovered and the cumulative sample size gradually becomes large enough to generalize the outcome of the game.

In game sessions, debriefing is the key for transferring the knowledge from the game environment to reality. Hence, it is essential to develop methodologies that would steer debriefing from its current almost fully synthetic nature towards a process that would balance experience and robust analytical thinking. In order to accomplish that, extensive qualitative research is required that would enable to properly categorize games and then identify the most effective debriefing methods for each category. Moreover, building analytical tools on top of a structured debriefing methodology would further strengthen the generalizability of the game outcome.

In knowledge management, information can be used for future projects or it can also be used to trace what happened in the past. The former can be improved by augmenting the body of knowledge in order to understand how games can be used by researchers and practitioners to build evidences of systems' behavior, as part of a larger scheme. This body of knowledge is vast but a large part of it is in the form of tacit knowledge. Therefore, new methodologies are needed that would elicit and disseminate this knowledge (Roungas et al. 2018).

5 CONCLUSION

As a discipline, gaming simulation lies in the intersection of the design and the analytical sciences, which seems to be the core impediment for its methodological evolution. The conflict between the design and analytical communities has in turn resulted in a limited adaptation of games in areas other than education and training. The obvious aim of this paper was to identify the limitations pertaining to games, and consequently propose a research agenda, by first identifying a wide range of potential improvements. Nonetheless, the ulterior motive behind this paper has been the need to bridge the gap between the design and analytical communities by first acknowledging the struggle between them and then providing a fertile ground for discussion and future research.

ACKNOWLEDGMENTS

This research is funded through the Railway Gaming Suite 2 program, a joint project by ProRail and Delft University of Technology.

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